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DESERT MULE DEER USE OF A CORRIDOR
AND SURROUNDING HABITATS

by

John Christopher Tull

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In Partial Fulfillment of the Requirements
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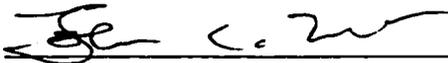
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For the white man to live in harmony with the [land] seems to require either a degree of public regulation he will not tolerate, or a degree of private enlightenment he does not possess.

—Aldo Leopold, 1927

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ABSTRACT

I examined the efficacy of a mitigation project in Avra Valley, Arizona that was established to provide wildlife access across the barrier created by the Central Arizona Project aqueduct. I monitored movements of 17 radiocollared desert mule deer (*Odocoileus hemionus crooki*) to determine if deer were using the corridor for access across the aqueduct and the 26 km wide valley. I also examined deer use of vegetation associations and proximity to landscape features. Four deer crossed the canal but stayed within 500 m of the crossing site. One deer traversed the valley via the corridor. Overall, 22.4% of deer locations were in the corridor land system. Female mule deer generally used the mesquite (*Prosopis velutina*)-burroweed (*Isocoma tenuisecta*) vegetation association more than it was available and the palo verde (*Cercidium* spp.)-mixed cacti association less than it was available. Female deer were generally closer to the CAP, housing developments, roads, and permanent water than random points.

INTRODUCTION

This thesis is compiled from 3 articles intended for submission to various peer-review journals. Each article constitutes a chapter within the thesis that is intended to partially fulfill the requirements for a Master of Science in Wildlife and Fisheries Science in the Graduate College at The University of Arizona. Chapter I is formatted for submission to Conservation Biology, Chapter II is formatted for The Journal of Wildlife Management, and Chapter III is formatted for The Southwestern Naturalist. The writings represent my ideas, analyses, and technical composition abilities. I designed and performed the research and analyses for each of the manuscripts and composed the writings contained herein. I did consult my graduate advisor on design ideas and relied on his input in manuscript reviews. I also consulted Dr. Robert J. Steidl on statistical matters for Chapter III. These contributions are reflected in junior authorship on the manuscripts. I used the authorship guidelines of Dickson and Conner (Guidelines for authorship of scientific articles. 1978. Wildlife Society Bulletin. 6:260-261).

DESERT MULE DEER USE OF A WILDLIFE CORRIDOR SYSTEM IN SOUTHERN
ARIZONA

RH: DEER USE OF A MOVEMENT CORRIDOR

2,990 words

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Abstract: Agencies and landscape managers have planned and developed corridors for wildlife movement with little empirical information. We examined the efficacy of a mitigation project in Avra Valley, Arizona that was established to provide wildlife access across the barrier created by the Central Arizona Project aqueduct to county, federal, and Native American lands. We monitored movements of 17 radiocollared desert mule deer (*Odocoileus hemionus crooki*) to determine if deer were using the corridor for access across the aqueduct and the 26 km wide valley. We also determined the frequency of corridor use by desert mule deer relative to surrounding lands. Four deer crossed the canal but stayed within 500 m of the crossing site. One deer traversed the valley via the corridor. Two of the five deer used crossing areas not in the planned corridor. Overall, 22.4% of deer locations were in the corridor land system. The Tucson Mitigation Corridor currently serves as a link with other undeveloped lands to provide a movement corridor for animals seeking to cross Avra Valley, but some lands within this corridor system are scheduled for development for agriculture. With increasing pressures from a burgeoning urban population, the Tucson Mitigation Corridor may prove to be of greater value in the future as a small refuge for wildlife rather than a link to other lands.

Introduction

There has been much debate regarding the wisdom of wildlife movement corridors (Noss 1987; Simberloff & Cox 1987; Hobbs 1992; Simberloff et al. 1992; Hess 1994). Noss (1987) stated that corridors are possibly a “fad” and are being developed with little or no understanding of the biological consequences, yet he and others (Wilson & Willis 1975; Harris & Scheck 1991; Harris et al. 1996) have argued for the creation of wildlife corridors to provide interconnectivity between large habitat reserves to maintain biodiversity. Two substantive arguments against movement corridors are: (1) the benefit-cost ratio of a corridor may prove other wildlife management activities to be of greater value, and (2) there is a potential for spread of pests and disease via corridor routes

(Simberloff & Cox 1987; Simberloff et al. 1992; Hess 1994). Both sides of the issue have legitimate concerns, but without sufficient empirical data the debate will continue.

Simberloff et al. (1992) reviewed the research and found that often cited studies were lacking proper experimental control to support the effectiveness of wildlife movement corridors. MacClintock et al. (1977), Suckling (1984), and Bennett (1990) each failed to distinguish use of corridors from use of surrounding habitats due to a deficiency of information on animal movements outside of corridors. More recently, Machtans et al. (1996) were unable to differentiate forest bird use of movement corridors as available habitats or actual movement zones between connected reserves; also, survey methods inside forested habitats versus clearings were different leading to suspect comparisons. Beier (1995) tracked radiocollared juvenile pumas (*Puma concolor*) during dispersal and found that they used corridors and avoided urban landscapes; his work allowed for identification of crossings outside of corridors, but it is unclear if and how many pumas crossed urban areas during dispersal. Wildlife movement corridors need to be examined by observing animal use of habitats inside corridors, connected reserves, and surrounding areas.

We explored desert mule deer use of the Tucson Mitigation Corridor (TMC) in southern Arizona. We studied deer because they are the most abundant, wide-ranging mammal available. Our objective was to collect information on deer movements inside and outside of the corridor system, thus allowing us to compare deer use of the corridor system to surrounding lands and obtain large-scale movement patterns in the study area. With large-scale patterns defined, we were able to determine use of the corridor system relative to other lands in the study area.

Study Area and Methods

The study area was in Avra Valley, Pima County, Arizona and was bounded by the Tucson Mountains to the east and the Roskrige Mountains to the west (Fig. 1.1). Tucson

was approximately 30 km east of Avra Valley. The Central Arizona Project (CAP) followed the eastern edge of Avra Valley and was proximate to Saguaro National Park and Tucson Mountain Park to the east. Elevations within the area ranged from 1,429 m at Wasson Peak in the Tucson Mountains to about 610 m in north Brawley Wash. Vegetation associations in the area were common to the Sonoran Desert and included: palo verde (Cercidium spp.)–mixed cacti on bajadas, creosote (Larrea tridentata)–bursage (Ambrosia spp.) in undisturbed flats, mesquite (Prosopis velutina)–burroweed (Isocoma tenuisecta) in disturbed flats (i.e., former agricultural lands), ironwood (Olneya tesota)–canyon ragweed (Ambrosia ambrosioides) in washes, and desert grassland (Fig. 1.2).

Precipitation is typically bimodal with most occurring during the July-September monsoon and the remaining in winter storms (Reitan & Green 1968). Mean precipitation was 28.3 cm for Tucson, Arizona, 1996 (National Climatic Data Center, unpublished data). Normal (1961-1990) precipitation was 30.6 cm; average normal seasonal temperatures were 24.3, 30.2, 16.6, and 13.6 C for spring (Apr-Jun), summer (Jul-Sep), autumn (Oct-Dec), and winter (Jan-Mar), respectively (National Climatic Data Center 1993). Seasons were defined based on weather patterns and biology of desert mule deer (Krausman 1985).

The TMC was an 11 km² corridor established to mitigate for lost habitats from CAP construction and to provide wildlife access to habitats on either side of the fenced CAP, which was a large-scale linear obstruction to wildlife movements. Lands for the TMC were purchased for \$6,200,000 (U.S.). The placement of the TMC was based on research by deVos et al. (1983).

Lands west of the TMC were developed for housing or were in the Tohono O'odham Nation (i.e., Garcia Strip). The east was bounded by Tucson Mountain Park, a permanent reserve. To the north, the boundary was adjacent to private land zoned for housing or state and federal lands. The land beyond the southern boundary was fallow

ranch land. Extensive housing development had occurred south and east of the TMC. Saguaro National Park was about 800 m beyond the northernmost extension of the TMC.

The canal was oriented northwest to southeast through the TMC with seven wildlife crossing areas from 40 to 230 m wide spaced nearly evenly along the canal route. The aqueduct was underground and at least one wash was present at each crossing area. Vegetation in crossings was different than surrounding vegetation because of disturbances from canal construction, although grasses and shrubs were reclaiming the crossing sites and were structurally similar to the native plant community. Two water catchments (one fed from the Tucson Aqueduct and one from a well) provided water to wildlife within the TMC. One was located east of the aqueduct near the northern boundary and the other was west of the canal near the center of the TMC.

Four flumes (engineered structures designed to allow water moving downslope across the landscape to pass over the canal) were present along the CAP. They were approximately one km apart beginning about five km north of the TMC. Saguaro National Park was within 1.2 km of all four flumes. Private, developed lands blocked direct access for each of the flumes, but Bureau of Land Management lands provided indirect access to Saguaro National Park. Fallow fields and rangeland were west of the flumes with little or no development westward to the Roskrige Mountains. In addition, the CAP was underground for approximately one km from a pumping plant about 1.5 km north of the TMC to 500 m north of the TMC. We defined these a priori as alternate crossing areas for deer.

Saguaro National Park and Tucson Mountain Park abutted each other forming an extensive wildlife reserve (approx. 101 km²). The Roskrige Mountain lands were owned by the Tohono O'odham Nation, the Bureau of Land Management, and Arizona (i.e., Roskrige Complex). The combined lands of the TMC and the Garcia Strip served as a movement corridor system (i.e., lands serving as a movement corridor but managed by

different agencies) linking the Roskruge Complex and the Tucson Mountain/Saguaro National Park reserve. The corridor system was 16.1 km long and 1.6-3.2 km wide. A two-lane highway bisected the 1.6 km shared boundary of the TMC and Garcia Strip.

We captured desert mule deer with net-guns (Krausman et al. 1985) in November 1995 and February 1996 to obtain a representative sample of the population. Each collar was color-coded to permit visual identification of individuals. We relocated each radiotagged deer by direct observation, triangulation, helicopter, or infrared camera ≥ 16 times/season to obtain seasonal home range estimates following Mares et al. (1980). Locations on individually marked deer were taken ≥ 24 hours apart during daylight. Triangulated locations were determined from two single-observer directional locations taken within five minutes. We used a handheld geographic positioning system (Magellan Systems Corp., San Dimas, Calif.) to obtain universal transverse mercator coordinates for each location and estimated the seasonal home ranges for each deer with the minimum convex polygon method (Southwood 1966). We estimated error of triangulation (White & Garrott 1990) under the assumption that deer were stationary during locations.

We placed location data into a geographic information system (GIS) for spatial analyses. We were able to identify movement patterns of radiocollared deer with the GIS and determine when and where deer moved across the CAP. We obtained counts of deer locations within the overall corridor system (i.e., Saguaro National Park/Tucson Mountain Park, TMC, Garcia Strip, or Roskruge Complex) and outside the corridor system. We then created 1,000 random points within a composite minimum convex polygon of all deer locations and obtained the same count information. The random point counts served as available proportions. We used Z -tests of proportions to determine if deer were using the corridor system and lands outside the corridor in proportion to their availability.

Results

We captured 17 desert mule deer. Three males and 14 females provided a ratio similar to all deer observed in the study area from July 1996 to March 1997 (i.e., 39 males and 154 females). One animal was killed by a puma in summer 1996; one collar failed after summer 1996; two animals died from unknown causes in winter 1997; and one deer was poached in winter 1997. We obtained 177 radiocollared deer-months of data. Over half (54.5%; $n = 954$) of animal locations were visual observations. Deer were observed moving 35.3% of all visual locations. Error of triangulation for the remaining locations was estimated at 215.2 ± 28.9 (SE) m.

Of the 17 radiotagged desert mule deer, five crossed the CAP (Table 1.1). All crossings were short duration (≤ 15 days) exploratory movements with the exception of one animal. Male number 18 crossed the CAP at the onset of the winter season and moved east to the bajada and foothills of the western slope of the Tucson Mountains. He wandered Tucson Mountain Park for approximately 40 days during the rut (mid- to late-Jan), and returned east of the canal and toward his traditional home range before being poached 15 February 1997. We located him in the foothills of the Roskrige Mountains in all other seasons, thus he moved across Avra Valley and used the TMC for his passage of the CAP.

The other four animals that crossed the CAP never ventured >500 m beyond the canal. Deer number four had all her seasonal home ranges abutting the CAP and utilized the TMC for habitats extensively. In early autumn she was photographed at a water source centrally located in the TMC and about 100 m west of the aqueduct. In winter she crossed the CAP near the northernmost crossing area and briefly moved onto private land. Male number three and female number seven ventured across the CAP from Saguaro National Park to the north and crossed the one km underground aqueduct to move to habitats on the opposite side of the canal route.

We found deer use of the TMC to be 4.3% of all radiolocations and use of the Garcia strip was 4.1% (Table 1.2). Overall use of the Tucson Mountain/Saguaro National Park reserve was 11.7%, and use of the Roskrige Complex was 2.3%. Lands not within the corridor system or adjoined reserves were used 77.6% of the time. Deer use of the east and west land reserves was less than expected ($Z \leq -5.3$, $P < 0.0001$), and use of lands outside of the corridor system was greater than expected ($Z = 13.36$, $P < 0.0001$) (Fig. 1.3).

Discussion

The confusion caused by the overuse of the word corridor has been discussed (Hobbs 1992; Simberloff et al. 1992). Corridor can denote a right-of-way along a road or railway; it can denote a riparian system (e.g., the Lower Colorado River Corridor); corridor can be used to describe a greenbelt or buffer zone; it can be used to describe a geologic landbridge; it can denote a culvert crossing or underpass that provides wildlife access across linear barriers; and finally corridor can be used to characterize a strip of land that allows wildlife access between habitat reserves. Clarification or separation of these terms is necessary.

Unfortunately, the name Tucson Mitigation Corridor lends itself to these confusions. The TMC did provide access across a linear barrier, the CAP, but it did not meet the definition of a movement corridor (Hobbs 1992; Simberloff et al. 1992) when considered alone because it does not provide connectivity to two reserves. However, the TMC does serve as a possible link to reserved habitats in concert with the Garcia Strip, thus acting as an overall movement corridor system.

Previous research designated the TMC lands as being important in maintaining wildlife movements across Avra Valley (deVos et al. 1983; deVos et al. 1985). Our data show only one desert mule deer made a large-scale movement across the valley via the

TMC. Is this enough evidence to proclaim the TMC an useful wildlife movement corridor? The benefits to the deer population have to be recognized.

If the CAP construction along with other habitat fragmentation has created a barrier separating deer on either side of Avra Valley, then mixing of eastern and western Avra Valley wildlife populations could be important to the maintenance of genetic variation (Lande & Barrowclough 1987). According to Lande and Barrowclough (1987), only one breeding individual per generation would need to successfully traverse the valley and mate to maintain a panmictic population, and we observed a mature buck at least make the journey.

There may also be a population benefit to animal movements across the valley if animals are emigrating (Brown & Kodric-Brown 1977), but dispersal was not observed during the study. A rescue effect could be addressed by following fawns through to dispersal, but we only collared adult desert mule deer. We expect that dispersal occurs primarily in male offspring, as described for desert mule deer in Arizona (Scarborough & Krausman 1988) and for whitetail deer (*Odocoileus virginianus*) in the Adirondacks (Tierson et al. 1985; Mathews 1989; Aycrigg & Porter 1997). This is based on observations of female grouping (3-5 animals/group) across all seasons that suggests female desert mule deer move in social groups similar to the matrilinear association found in whitetail deer (Hawkins & Klimstra 1970; Hirth 1977; Nelson & Mech 1981; Mathews & Porter 1993; Aycrigg & Porter 1997) and suggested to be in another desert mule deer population (Ragotzkie 1988). The benefits of matrilinear association include group tending for fawns (this was observed on one occasion when we heard two fawns bleating and all known females of the group converged and cooperatively safeguarded the fawns) and group protection against predators. These benefits are independent of large-scale movements, therefore would only aid females and fawns in groups and would not require a movement corridor to be realized.

Although we observed one deer traverse Avra Valley via the TMC and two additional deer cross the canal in the TMC, we also observed two deer cross the CAP outside of the TMC. We do not know that the valley crossing would have been impeded had the TMC not been present. We do know that alternate crossing areas currently exist and are used.

Our finding of deer use of the corridor system less than expected suggests that deer prefer habitats outside the wildlife movement corridor system over those within the system. This indicates that the corridor does not provide the best available habitats for desert mule deer in Avra Valley.

The future of a wildlife corridor system in Avra Valley is uncertain. The land ownership of the Roskrige Mountains are predominantly Tohono O'odham Nation and Bureau of Land Management, but they are not a recognized reserve as are Tucson Mountain Park and Saguaro National Park on the east. Agricultural development is planned for the Garcia Strip and an aqueduct from the CAP is currently being created (United States Bureau of Reclamation 1988). The corridor width would shrink from 2,440 m to approximately 800 m at its narrowest under the proposed development plan. A proposed development alternative would maintain a corridor strip of 240 m. These changes would clearly affect the usefulness of the Garcia Strip within the corridor system and would probably eliminate its effectiveness for preserving a wildlife movement route.

Immediately south of the Garcia Strip are lands owned by the City of Tucson's water department, several working ranches, and Arizona. Tucson Water has been developing a recharge program for CAP waters, but it is unknown if these lands will be converted to that purpose. Drought and low prices for beef, in addition to development pressures, do not assure the stability of current private land practices. Finally, state lands are held in trust to provide future funding needs for public programs in Arizona, therefore they can be sold for development purposes. If any one of these variously owned lands

were developed in addition to the Garcia Strip, continuity of the Avra Valley corridor system would be lost.

If the Avra Valley corridor system is severed, then the TMC will simply serve as an extension to the reserved habitats of the parks in the east. As more people move into Avra Valley due to human population pressures from Tucson, the TMC may prove increasingly valuable as space for plants, wildlife, and recreation, but the TMC may not survive as part of a large-scale wildlife movement corridor. Considering the cost of the TMC, there is uncertainty that the money was most appropriately spent or if it may have better served other wildlife management uses. Greater benefits may have been realized through the purchase of numerous small reserves across many vegetation associations (Shafer 1995); this strategy has its merits for floral and faunal populations that suffered habitat losses from CAP construction.

With the protected habitats within Saguaro National Park and Tucson Mountain Park and with the overall lack of permanence of the current corridor system, we argue that the TMC may not serve as a corridor. The TMC reserved habitats benefit wildlife, but do not clearly provide a lasting solution for wildlife access across Avra Valley, Arizona. We are not arguing against movement corridors, but present our data on the Tucson Mitigation Corridor as an example of planning that lacked the necessary foresight to guarantee that the objectives of its establishment would be met and maintained. We urge conservation biologists and planners to fully consider the long-term feasibility of large-scale mitigation projects and to weigh alternative mitigations based on biology and sound science.

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Table 1.1. Desert mule deer crossings of the Central Arizona Project (CAP) in Avra Valley, Arizona, 1996-1997.

Animal no.	Sex	Approx. date(s) of crossing	Duration across CAP	Crossing location in Tucson Mitigation Corridor (TMC)
3	M	5 Feb 1997	1-11 days	No ^a
4	F	4 Oct 1996	<1 day	Yes
		29 Jan 1997	1-6 days	Yes
		17 Feb 1997	1-8 days	Yes
7	F	6 Apr 1996	<7 days	Yes ^b
17	F	24 Jul 1996	3-15 days	No
		1 Aug 1996	<1 day	No
18	M	1 Jan 1997	35-45 days	Yes

^a All crossings outside of the TMC occurred across a 1 km stretch of underground aqueduct that begins approximately 500 m north of the canal.

^b The location point that places deer 7 across the canal is suspect because it is a triangulated location and was not noted as being across the canal in the field records.

^c Deer 18 was across the mitigation corridor until his last location on 15 Feb 1997.

Table 1.2. Desert mule deer frequency of locations in various components of a corridor system and tests of proportions for observed and expected values in Avra Valley, Arizona, 1996-1997. Expected values were from 1,000 random point locations within the composite home range of all desert mule deer locations.

Component	Observed		Expected		Z	P
	n	%	n	%		
Corridor system						
Tucson Mitigation Corridor	41	4.3	53	5.3	-1.03	0.3007
Garcia Strip	39	4.1	57	5.7	-1.65	0.0994
Connected lands						
Tucson Mountain/Saguaro National Park	112	11.7	206	20.6	-5.30	<0.0001
Roskrige Complex	22	2.3	201	20.1	-12.37	<0.0001
Other lands	740	77.6	483	48.3	13.36	<0.0001
Total	954	100.0	1,000	100.0		

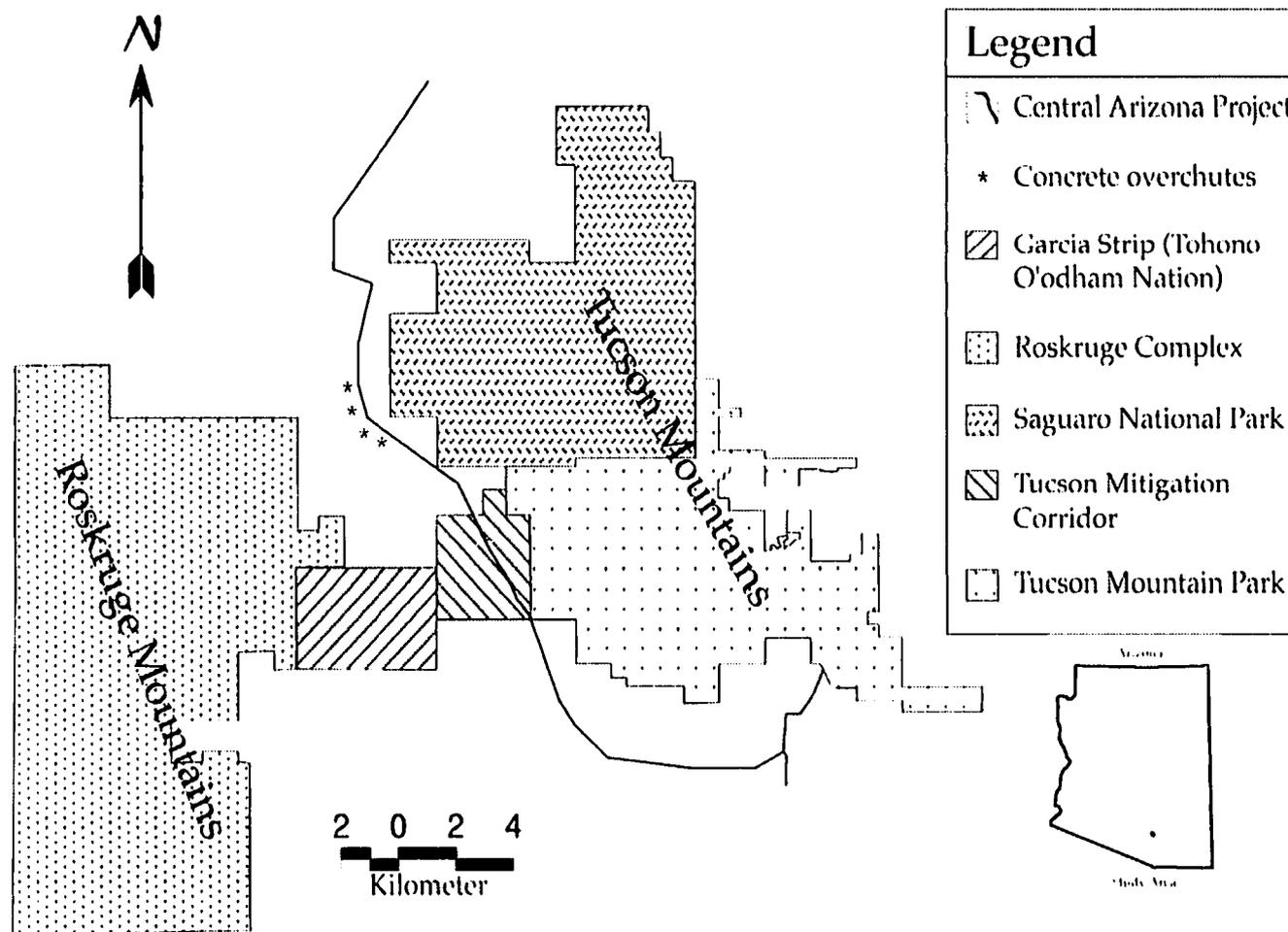


Fig. 1.1. The desert mule deer study area in Avra Valley, Arizona, 1996-97. The Roskrige Complex (Tohono O'odham Nation, federal, and state lands) formed a reserve on the west, and Saguaro National Park and Tucson Mountain Park created a reserve on the east. The Garcia Strip and the Tucson Mitigation Corridor served as a wildlife movement corridor system.

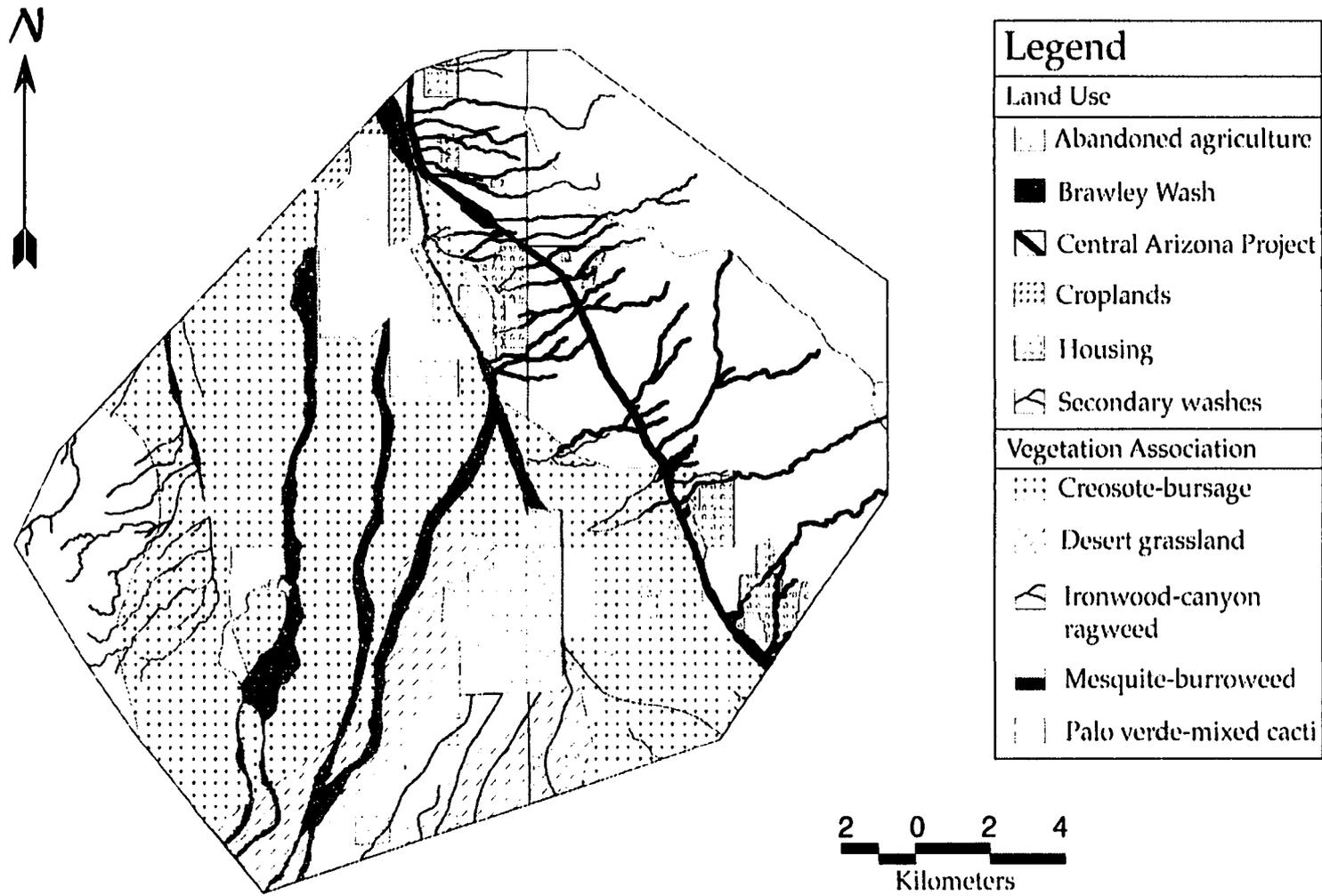


Fig. 1.2. Land use and vegetation associations for the desert mule deer composite home range in Avra Valley, Arizona, 1996-97.

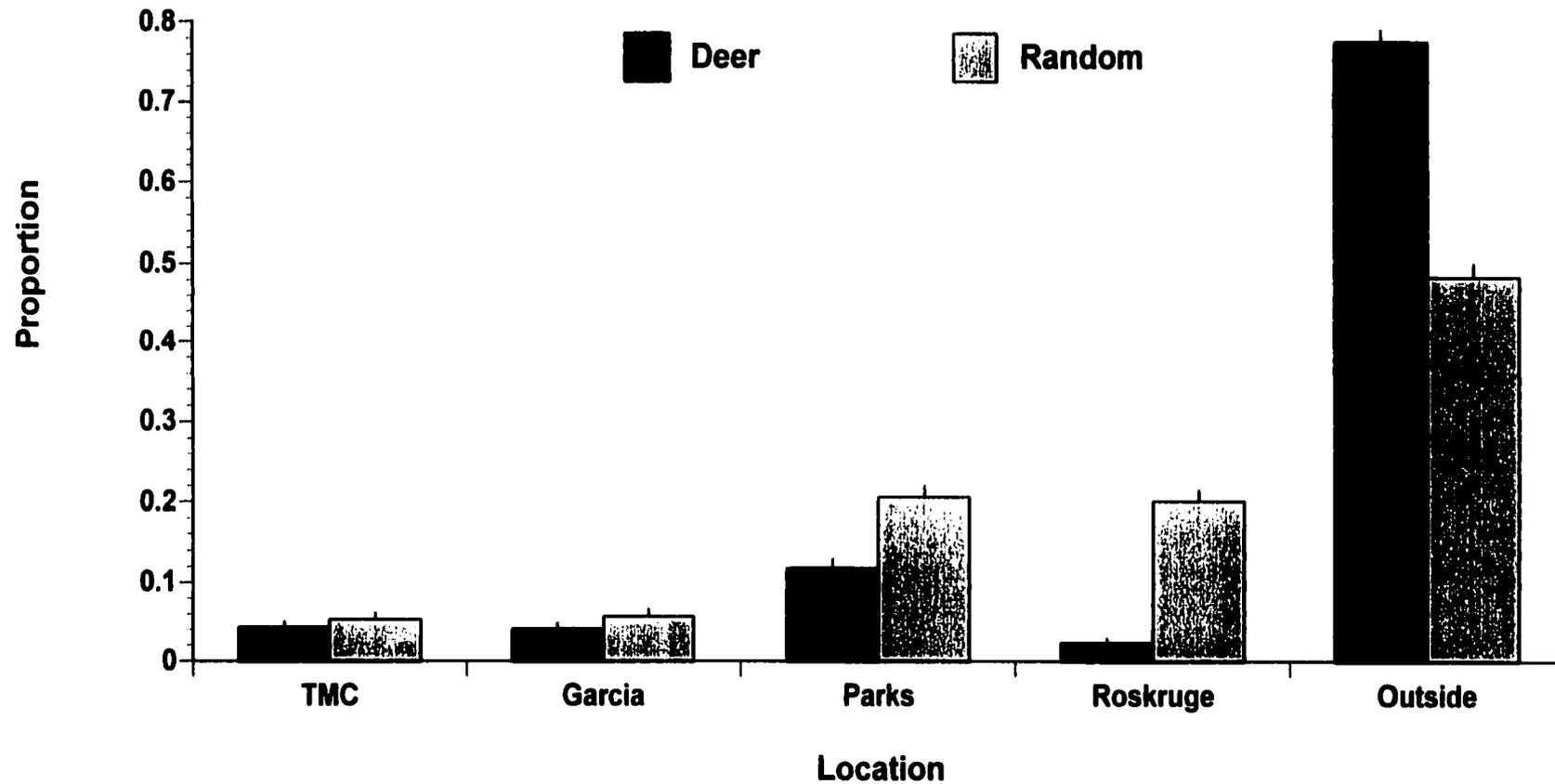


Fig. 1.3. Desert mule deer proportional use of corridor system lands and lands outside of the corridor system in Avra Valley, Arizona, 1996-97. Corridor system lands included the Tucson Mitigation Corridor, the Garcia Strip, Saguaro National Park/Tucson Mountain Park, and the Roskruge Complex. All other lands lie outside of the recognized wildlife movement corridor system. Vertical bars indicate 1 standard error.

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RH: Desert Mule Deer in Arizona • Tull and Krausman

DESERT MULE DEER HABITAT USE IN A FRAGMENTED LANDSCAPE

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Abstract: Wildlife populations are threatened by human developments and activities that contribute to habitat fragmentation. The Tucson Aqueduct of the Central Arizona Project (CAP) is a large-scale linear barrier to wildlife movements in southern Arizona. Avra Valley is 20 km west of Tucson, Arizona and is bisected by the CAP. The valley is a patchwork of federal, county, municipal, ranch, and residential lands. We examined desert mule deer (Odocoileus hemionus crooki) use of vegetation associations and proximity to landscape features to determine how human activity and developments influenced habitat use. We believed that use of habitats would be altered based on the amount of human activity (i.e., deer would generally avoid areas impacted by humans). We radiocollared 17 deer and relocated them from March 1996 to March 1997. We spatially analyzed home range and location data in a geographic information system. Female desert mule deer generally used the mesquite (Prosopis velutina)_burroweed (Isocoma tenuisecta) vegetation association more than it was available and the palo verde (Cercidium spp.)_mixed cacti association less than it was available. Female deer were

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generally closer to the CAP, housing developments, roads, and permanent water than random points. Male deer were typically farther from the CAP, housing developments, and roads, but closer to water sources than were random points. Our prediction that deer would avoid human activity was not demonstrated with female deer.

Key words: Arizona, Central Arizona Project, radiocollar, triangulation, Tucson Mitigation Corridor.

Human developments often create barriers to wildlife movements. Furthermore, habitat fragmentation by human encroachment can isolate wildlife populations and create small reserves with accelerated rates of extinction (MacArthur and Wilson 1967). Understanding how wildlife interact with and use landscape features around human developments is important to minimize the effects of isolation.

The CAP is an aqueduct system designed to provide water for irrigation and municipal and industrial uses in central and southern portions of Arizona (United States Bureau of Reclamation 1981). The CAP traverses desert mule deer habitat through Avra Valley, Arizona, and it lies ≥ 3 km from county and federal parks, housing developments, Bureau of Land Management lands, the Tohono O'odham Nation, municipal, and private lands along its route. Impacts on desert mule deer from the CAP, its construction, and the effectiveness of mitigation features have been evaluated (Krausman 1985, Hervert and Krausman 1986, Carmichael et al. 1991, Krausman et al. 1992, Krausman et al. 1993), but an examination of the areas influenced by human activities in addition to the CAP has not been conducted.

Our objective was to identify deer interactions with vegetation associations and natural and human-created landscape features (i.e., washes, the CAP, permanent water sources, roads, and housing developments). We predicted that deer would avoid housing

developments, paved roads, and altered vegetation associations (e.g., abandoned agricultural lands), would be attracted to water sources, and would not be affected by the CAP.

STUDY AREA

The study area was in Avra Valley, Pima County, Arizona and was bounded by the Tucson Mountains to the east and the Roskrige Mountains to the west (Fig. 2.1). Tucson was approximately 20 km east of Avra Valley. The Central Arizona Project (CAP) followed the eastern edge of Avra Valley and was proximate to Saguaro National Park and Tucson Mountain Park to the east. Elevations within the area ranged from 1,429 m at Wasson Peak in the Tucson Mountains to about 610 m in north Brawley Wash. Lands immediately west of the Tucson Mitigation Corridor (TMC) were developed for housing or were in the Tohono O'odham Nation. The east was bounded by Tucson Mountain Park. To the north, the boundary was adjacent to private land zoned for housing or state and federal lands. The land beyond the southern boundary was fallow ranch land. Extensive housing development had occurred south and east of the TMC. Saguaro National Park was about 800 m beyond the northernmost extension of the TMC. The central portion of the valley, drained to the north by Brawley Wash, was predominantly range land in ownership by the Tohono O'odham Nation and private interests. Approximately 2.6 km² were abandoned agricultural lands owned by Tucson's water department; wells exist on these lands providing drinking water for the city. Saguaro National Park and Tucson Mountain Park formed an extensive wildlife reserve (101 km²) on the east. The Roskrige Mountain lands were owned by the Tohono O'odham Nation, the Bureau of Land Management, and the state of Arizona and provided a reserve (>260 km²) on the west.

Vegetation associations in the area were common to the Sonoran Desert and included: palo verde (Cercidium spp.)–mixed cacti on bajadas, creosote (Larrea tridentata)–bursage (Ambrosia spp.) in undisturbed flats, mesquite (Prosopis velutina)–burroweed (Isocoma tenuisecta) in disturbed flats (i.e., former agricultural lands), ironwood (Olneya tesota)–canyon ragweed (Ambrosia ambrosioides) in washes, and desert grassland (Fig. 2.2).

Precipitation is typically bimodal with most occurring during the July–September monsoon and the remaining in winter storms (Reitan and Green 1968). Mean precipitation was 28.3 cm for Tucson, Arizona, 1996 (National Climatic Data Center, unpubl. data). Normal (1961-1990) precipitation was 30.6 cm; average normal seasonal temperatures were 24.3, 30.2, 16.6, and 13.6 C for spring (Apr–Jun), summer (Jul–Sep), autumn (Oct–Dec), and winter (Jan–Mar), respectively (National Climatic Data Center 1993). Seasons were defined based on weather patterns and biology of desert mule deer (Krausman 1985).

The TMC was an 11 km² parcel of land established to mitigate for lost habitats from CAP construction and to provide wildlife access to habitats on either side of the fenced CAP via wildlife crossing areas. The TMC placement was based on research performed prior to construction of the CAP to identify wildlife movement routes and, thus, reduce CAP impacts to movements of wildlife (deVos et al. 1983, 1985).

Two water sources (1 fed from the Tucson Aqueduct and 1 from a well) provided water to wildlife within the TMC, 7 existed in Tucson Mountain Park, 2 in Saguaro National Park, and 6 on ranch and other lands. Only developments known to provide water year-round were included as water sources.

METHODS

We used net-guns to capture and collar desert mule deer (Krausman et al. 1985) in November 1995 and February 1996 to obtain a representative sample of the Avra Valley population. Each collar was color-coded to assist visual identification of individuals. We relocated each radiotagged deer by direct observation, triangulation, helicopter, or infrared camera to obtain adequate seasonal home range estimates following Mares et al. (1980).

Locations on individually marked deer were obtained ≥ 24 hours apart during daylight hours. Triangulated locations were determined from 2 single-observer directional locations within 5 minutes of each other. After triangulating a location, we hiked to the animal and attempted a visual location. We used a handheld geographic positioning system (Magellan Systems Corp., San Dimas, Calif.) to obtain Universal Transverse Mercator coordinates for each location. We estimated error of triangulation (White and Garrott 1990) under the assumption that deer were stationary during locations.

We estimated the seasonal home ranges for each deer with the minimum convex polygon method (Southwood 1966); we used 95% utilization distributions to calculate home ranges with program CALHOME. We determined if deer home ranges differed across seasons with the Kruskal-Wallis test, a nonparametric Chi-square equivalent to the one-way analysis of variance (ANOVA), because sample sizes were small and distributions non-normal (Zar 1984). We separated sexes in analyses due to differences in home range sizes, movements, and habitat use across seasons for male and female desert mule deer (Krausman 1985).

We placed location data into a geographic information system (GIS) for spatial analyses using ARC/INFO (Environmental Systems Research Institute 1992). We calculated a composite minimum polygon from all deer locations that served as the effective study area for spatial analyses. From this GIS we were able to calculate area of

vegetation associations within the study area; these calculated areas served as habitat proportions available for deer use. Used values were calculated as the proportion of all female and male deer locations in each vegetation association for each season. When use of an association was less or more than expected by the proportion of availability, we refer to use of associations as avoided or selected, respectively. We compared actual use of vegetation associations with their availabilities for females and males with log-likelihood ratio tests (Zar 1984).

We generated 1,000 random location points within the study area; these locations were randomly assigned to 1 of 4 seasons providing 250 random locations/season. For each season, we calculated the shortest distance to Brawley Wash, the CAP, housing developments, roads, secondary washes, and permanent water sources for deer locations and random locations using ARC/INFO. We determined if mean minimum distances varied by location type (i.e., deer and random location points) and season using a full factorial two-way ANOVA. If deer location distances were closer to or farther from a feature than were random point distances, we assumed they selected or avoided that feature, respectively.

RESULTS

We captured 17 deer (14 F, 3 M) providing a ratio similar to all deer observed in the study area from July 1996 to March 1997 (i.e., 39 males and 154 females). One female was killed by a puma (Puma concolor) in summer 1996, 1 collar malfunctioned (F) after summer 1996, 2 females died from unknown causes in winter 1997, and 1 male was poached in winter 1997. We obtained 177 radiocollared deer-months of data. Over half (54.5%; $n = 954$) of animal locations were visual observations. 299 (31.3%) were obtained by triangulation, 131 (13.7%) were located from helicopter, and 5 (0.5%) were captured by infrared cameras. Deer were observed moving 35.3% of all visual locations. Error of triangulation for the remaining locations was estimated at 215.2 ± 28.9 (SE) m.

We located individual deer ≥ 15 times/season with the exception of 1 female ($n = 12$; summer) and 1 male ($n = 9$; winter) that died prior to season end. Female home range sizes among seasons averaged from 735.4 ha to 1,602.5 ha; male home range sizes averaged from 836.8 ha to 2,178.2 ha (Table 2.1). Female home range sizes differed ($\chi^2 = 14.47$, 3 df, $P = 0.0023$) between seasons whereas male home range sizes did not ($\chi^2 = 1.77$, 3 df, $P = 0.6217$), although small sample size ($n = 3$) for males precluded the detection of seasonal variation that was apparent under visual inspection (Fig. 2.3).

Females did not use vegetation associations equally in relation to availability for all seasons ($G \geq 56.65$, 4 df, $P < 0.001$). They selected the mesquite-burroweed association in all seasons and desert grasslands in autumn and winter. Palo verde-mixed cacti was avoided in all seasons and desert grasslands were avoided in spring and summer. Creosote-bursage use was in proportion to availability for summer, autumn, and winter, but was avoided in spring (Fig. 2.4). We detected weak differences in use versus availability for summer ($G = 8.39$, 4 df, $P = 0.0782$) and spring ($G = 6.99$, 4 df, $P = 0.1367$), but no differences were detected in autumn ($G = 2.70$, 4 df, $P = 0.6093$) and winter ($G = 5.52$, 4 df, $P = 0.2380$). During spring and summer seasons male deer selected creosote-bursage and ironwood-ragweed; creosote-bursage was avoided in winter. Desert grassland was avoided during all seasons, and palo verde-mixed cacti was avoided in spring, summer and autumn, but selected in winter. The mesquite-burroweed association was used in proportion to availability for all seasons (Fig. 2.5).

Female desert mule deer selected Brawley Wash with a weak interaction of the location and season factors ($F = 2.01$; 3, 1,757 df; $P = 0.1101$) (Fig. 2.6). Female deer avoided secondary washes in autumn and winter, but neither avoided nor selected washes in spring and summer ($F = 6.98$; 3, 1,757 df; $P < 0.0001$). Female deer selected roads ($F = 18.83$; 3, 1,757 df; $P < 0.0001$) seasonally ($F = 6.09$; 3, 1,757 df; $P = 0.0004$); they did

not select for roads during spring. Females also selected permanent water sources ($F = 193.79$; 3, 1,757 df; $P < 0.0001$) with shorter distances to water in winter ($F = 2.04$; 3, 1,757 df; $P = 0.1059$) Female deer selected the CAP ($F = 5.79$; 3, 1,757 df; $P = 0.0162$) and housing ($F = 126.20$; 3, 1,757 df; $P < 0.0001$), but no seasonal variation was detected for these features..

Male desert mule deer selected Brawley Wash in all seasons except winter ($F = 6.00$; 3, 1,181 df; $P = 0.0005$) (Fig. 2.7). The CAP ($F = 5.65$; 3, 1,181 df; $P = 0.0008$) and roads ($F = 5.38$; 3, 1,181 df; $P = 0.0011$) were avoided by males during all seasons except winter when both features were selected. Secondary washes were avoided during spring, summer, and autumn ($F = 2.37$; 3, 1,181 df; $P = 0.0688$). Male deer avoided housing developments ($F = 19.14$; 3, 1,181 df; $P < 0.0001$) and selected permanent water sources ($F = 8.36$; 3, 1,181 df; $P = 0.0039$) without detectable seasonal variation.

DISCUSSION

Although we were unable to detect a difference in male desert mule deer home range sizes between seasons because of low sample size (i.e., 3 radiocollared male deer each season), male home ranges appeared to be largest in autumn and winter. Increased movement activity coincided with pre-rut and rut activity that occurred in late January. Female home ranges were largest in winter, also possibly due to movements related to breeding activity. Home range sizes for females among seasons were only 33.7% (spring), 48.4 % (summer), and 42.5% (autumn) as large as home ranges of female desert mule deer in the Belmont and Big Horn mountains of Arizona (Krausman and Etchberger 1995) but were similar in winter; male seasonal home ranges were smaller for all seasons (19.6% [spring], 16.2% [summer], 24.4% [autumn], and 41.4% [winter]) compared to data from Krausman and Etchberger (1995). In the Belmont and Big Horn mountain ranges, vegetation was more sparse and annual precipitation was approximately 75% of that for our study area, thus we would expect home range sizes in Avra Valley to be

smaller than home ranges of desert mule deer in the more arid Belmont and Big Horn mountains following McNab's (1963) hypothesis.

Our movement data supports early work in the Tucson Mountain area conducted by Clark (1953) where he identified increased movements in male desert mule deer occurring in early December. Our observations indicate that reproductive activity in males is initiated in December with rut continuing into January, following similar findings on desert mule deer (Hanson and McCulloch 1955, Desai 1962, Rodgers 1977, Truett 1979, Ragotzkie 1988). We observed no migration (i.e., non-overlap of winter and summer dry seasons) by any radiocollared deer during the study. Desert mule deer in drier regions are reportedly migratory and move to areas with greater supplies of water (Rautenstrauch and Krausman 1989), but permanent water sources were sufficiently distributed throughout our study area and may have precluded the need for deer to seek water beyond established home ranges for any given season.

Overall use of the mesquite-burroweed vegetation association was greater than available for females but not males, therefore sexual segregation was occurring with females using this association more frequently than males. Female deer were observed feeding on mesquite beans on several occasions, and mesquite may meet higher nutritional needs required for lactating females (Smith and LeCount 1979, Urness 1981). Additionally, sexual segregation limits competition between sexes and improves reproductive efficiency (Bowyer 1984). The mesquite-burroweed association is found in flats, and female deer located approximately 25-55% of the time in these areas during each season. The proportion of female locations in the mesquite-burroweed association during summer, when fawning occurred and nutritional requirements would be high, was 41.8%. Whereas others (Ordway and Krausman 1986, Bellantoni et al. 1993, Fox and Krausman 1994) have found desert mule deer fawning and use of habitats during fawn rearing in mountainous terrain to minimize predatory losses of fawns, we found <1% of

locations of does in steeply sloped areas. We suggest that females make greater use of the mesquite-burroweed association due to the increased cover that it provides; this association replaces traditional escape terrain (Geist 1981) and allows protection of fawns from predators. We found approaching deer without being discovered in dense mesquite to be difficult and assume that it would also be difficult for predators to do the same. Our data imply that female deer can use areas of dense cover for escape and protection of fawns during critical fawn rearing periods. Because much of the mesquite-burroweed association is found on abandoned agricultural lands, the use of this association greater than it was available was counter to our prediction that abandoned agriculture lands would be avoided.

We observed female deer use of the palo verde-mixed cacti association less than available for all seasons, and male use appeared greater than available for winter only. Use less than availability may be due to the sparseness of flora in the palo verde-mixed cacti association that provides limited security for animal movements, especially females caring for fawns. One female that used this association extensively dropped a fawn on 8 August 1996, but was not seen with her fawn again after 4 September 1996 (we assumed mortality of the fawn). Also, our only known puma mortality (pregnant F) during the study occurred in this association on 17 August, 1997 further suggesting vulnerability to predators in the palo verde-mixed cacti association.

Male use of vegetation associations was nearly equal to availability for all associations and seasons. Strong patterns may not have been detected because of sample size inadequacies for male deer.

Female desert mule deer selected Brawley Wash, the CAP, housing, roads, and permanent water sources; they avoided secondary washes. Males only selected for Brawley Wash and permanent water while avoiding the CAP, housing, roads, and washes. Females and males may have selected habitats along Brawley Wash because of

the previously discussed escape cover and nutritional benefits found in the mesquite-burrowweed association. Only females used the mesquite-burrowweed association more than it was available, though.

Secondary washes were avoided by males and females, perhaps because the narrow corridors created by these washes may serve as movement corridors for predators. Also, the ironwood-canyon ragweed association that occurs in secondary washes may have little nutritional value for desert mule deer. The avoidance of washes is consistent with our vegetation association use data because deer, especially females, used habitats that washes moved through (predominantly palo verde-mixed cacti association) less frequently than they were available.

Female deer selection of housing and roads and male avoidance of these features could have resulted from female use of habitats generally closer and male use of habitats generally farther from these landscape features. Our prediction that desert mule deer would avoid both roads and housing was not supported.

Our finding of female and male selection of permanent water sources is in accordance with Krausman and Etchberger (1995). From research on observations of female and male desert mule deer activity around water tanks in southern Arizona, Ragotzkie (1988) believed that an abundance of water sources will tend to minimize the influence of water on desert mule deer distributions. Our study area had abundant water (1 permanent water source per 14 km²) relatively evenly spaced across the landscape, but female and male desert mule deer selected water sources. Information on the effect of various densities of water sources within similar desert mule deer habitats would need to be studied to appropriately address the issue of the effect, if any, of water abundance on desert mule deer distributions.

Female deer selected the CAP, and 1 female's home range abutted the CAP in all seasons. One male was typically near the CAP, but the other 2 males had location points

farthest from the CAP out of all collared animals. It is evident that females selected and males avoided the CAP due to habitats used. The CAP did not preclude animal movements across the valley because 3 females and 2 males crossed the CAP. Four animals crossed and travelled <500m from their CAP crossing sites. One male crossed the CAP and traversed the valley. Deer used crossing sites inside and outside of the TMC. The CAP had no apparent effect on desert mule deer activities in Avra Valley.

MANAGEMENT IMPLICATIONS

Human development is increasing in Avra Valley with Tucson's westward expansion. Desert mule deer habitats in Avra Valley will likely become more fragmented over time as human population pressures from Tucson result in increased development. Of all 5 vegetation associations, we observed deer use of the mesquite-burroweed association most strongly. This association was located almost entirely on municipal, state, Bureau of Land Management, private, and Tohono O'odham Nation lands, and much of the land use was abandoned agriculture. The Tohono O'odham are planning conversion of much of their lands in the study area to agricultural production (United States Bureau of Reclamation 1988) and future conditions are uncertain for private lands, although we have seen increased housing development during the study (e.g., 4 new homes were constructed along the northern boundary of the TMC from 1996-97, and a multihome development was being surveyed along approximately 15% of the southern boundary of the study area).

With changes in land use producing fragmented habitats unfavorable to or incompatible with desert mule deer, we conclude that federal lands will become increasingly important for the maintenance of a viable deer herd in Avra Valley. Although western Avra Valley developments may lead to the loss of deer in much of the currently used areas, lands in Saguaro National Park, Tucson Mountain Park, and the TMC should continue to support a deer population in eastern Avra Valley, although these

lands may become increasingly isolated over time. With continued management objectives favoring the maintenance of natural desert habitats in Tucson Mountain Park, Saguaro National Park, and the Tucson Mitigation Corridor, desert mule deer habitat should be secure in Avra Valley.

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Table 2.1. Seasonal home ranges (ha) of desert mule deer in Avra Valley, Arizona, 1996-97.

Sex	Season															
	Spring (Apr-Jun)				Summer (Jul-Sep)				Autumn (Oct-Dec)				Winter (Jan-Mar)			
	\bar{x}	SE	No. animals	No. locations	\bar{x}	SE	No. animals	No. locations	\bar{x}	SE	No. animals	No. locations	\bar{x}	SE	No. animals	No. locations
F	735.4	215.2	13	211	793.5	220.5	13	209	591.4	88.8	11	178	1,602.5	200.9	10	167
M	1,175.6	725.6	3	49	836.8	169.9	3	51	2,014.9	1,063.2	3	48	2,178.2	774.8	3	41

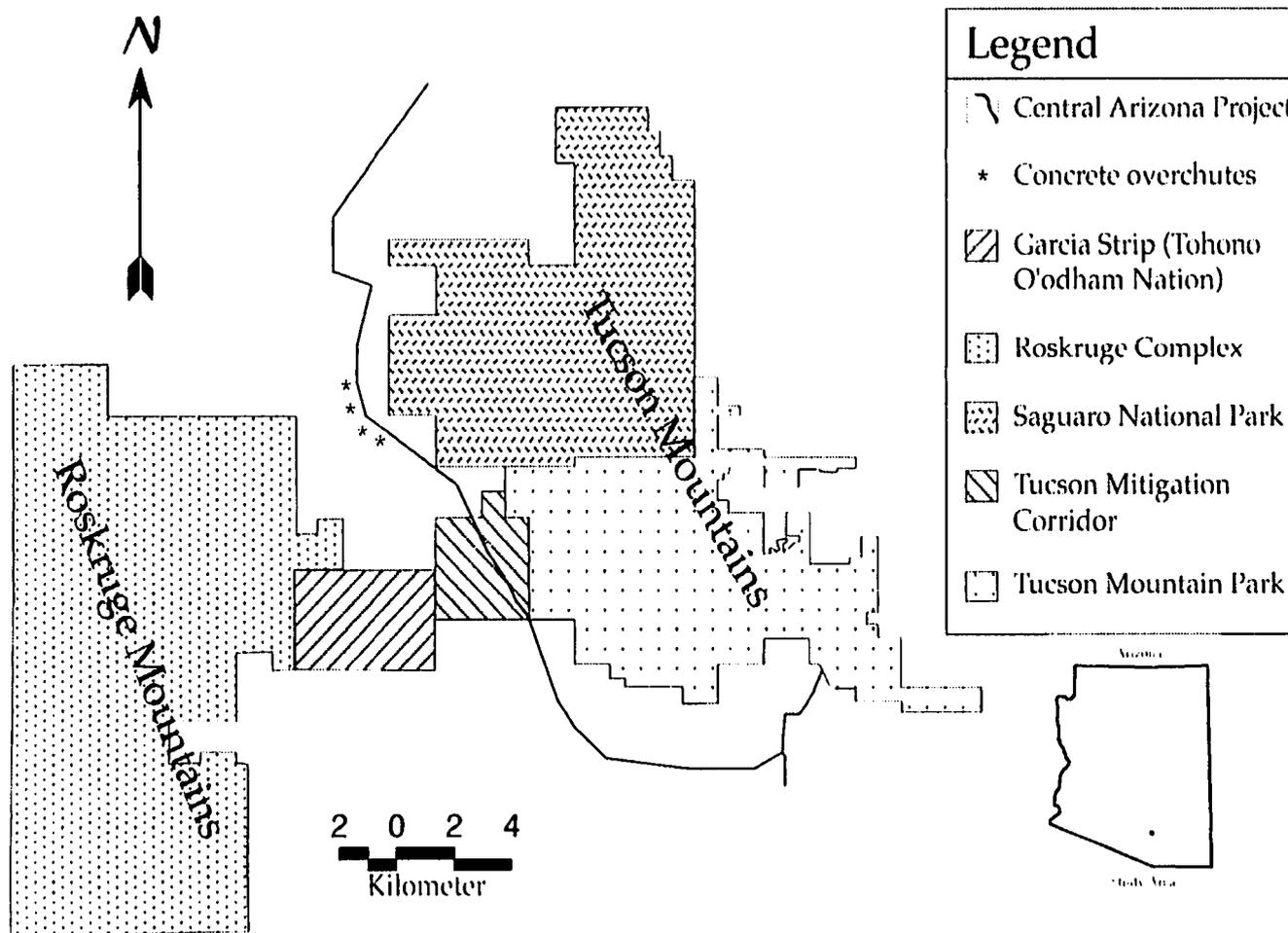


Fig. 2.1. The desert mule deer study area in Avra Valley, Arizona, 1996-97. The Roskrige Complex (Tohono O'odham Nation, federal, and state lands) formed a reserve on the west, and Saguaro National Park and Tucson Mountain Park created a reserve on the east. The Garcia Strip and the Tucson Mitigation Corridor served as a wildlife movement corridor system.

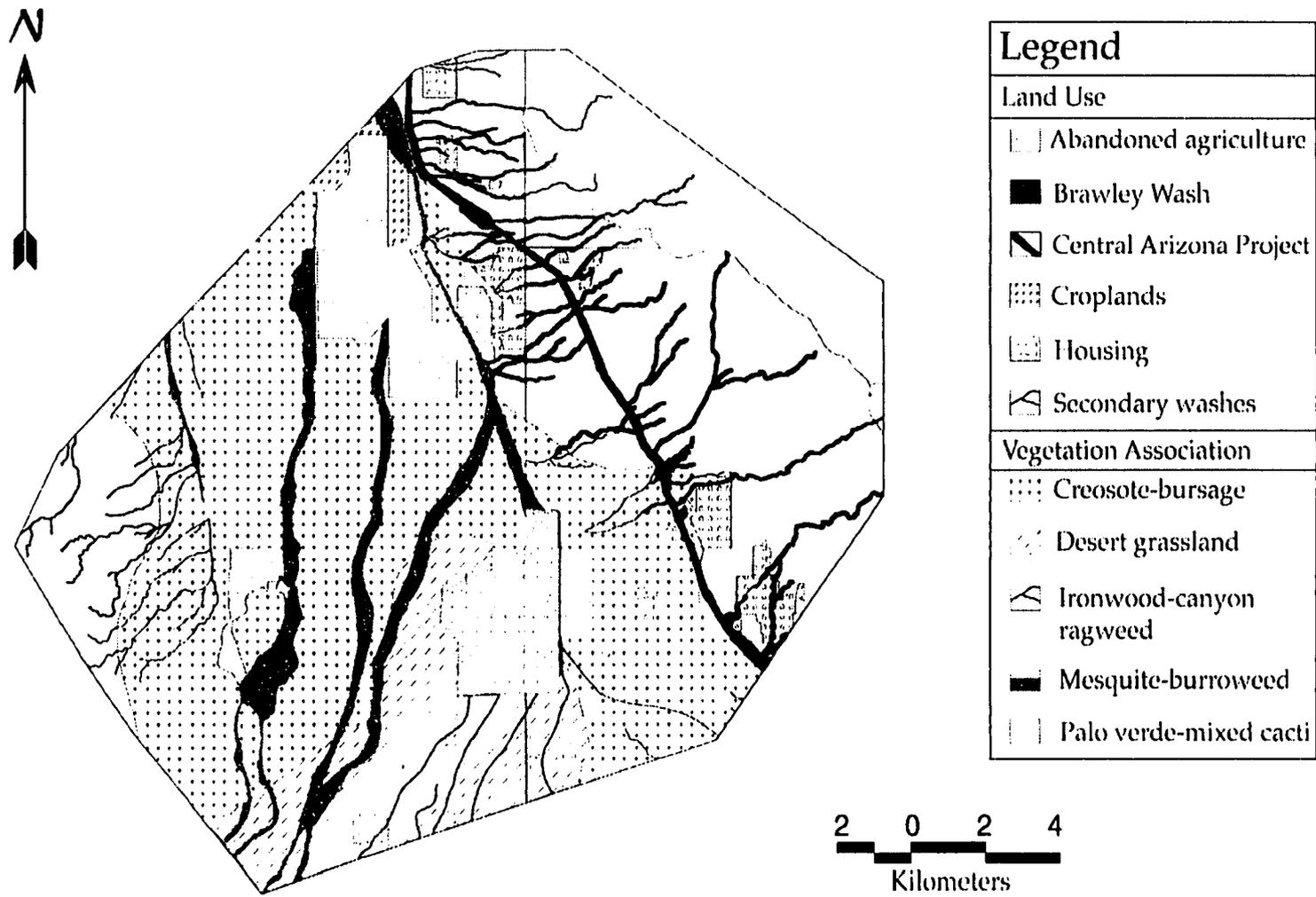


Fig. 2.2. Land use and vegetation associations for the desert mule deer composite home range in Avra Valley, Arizona, 1996-97.

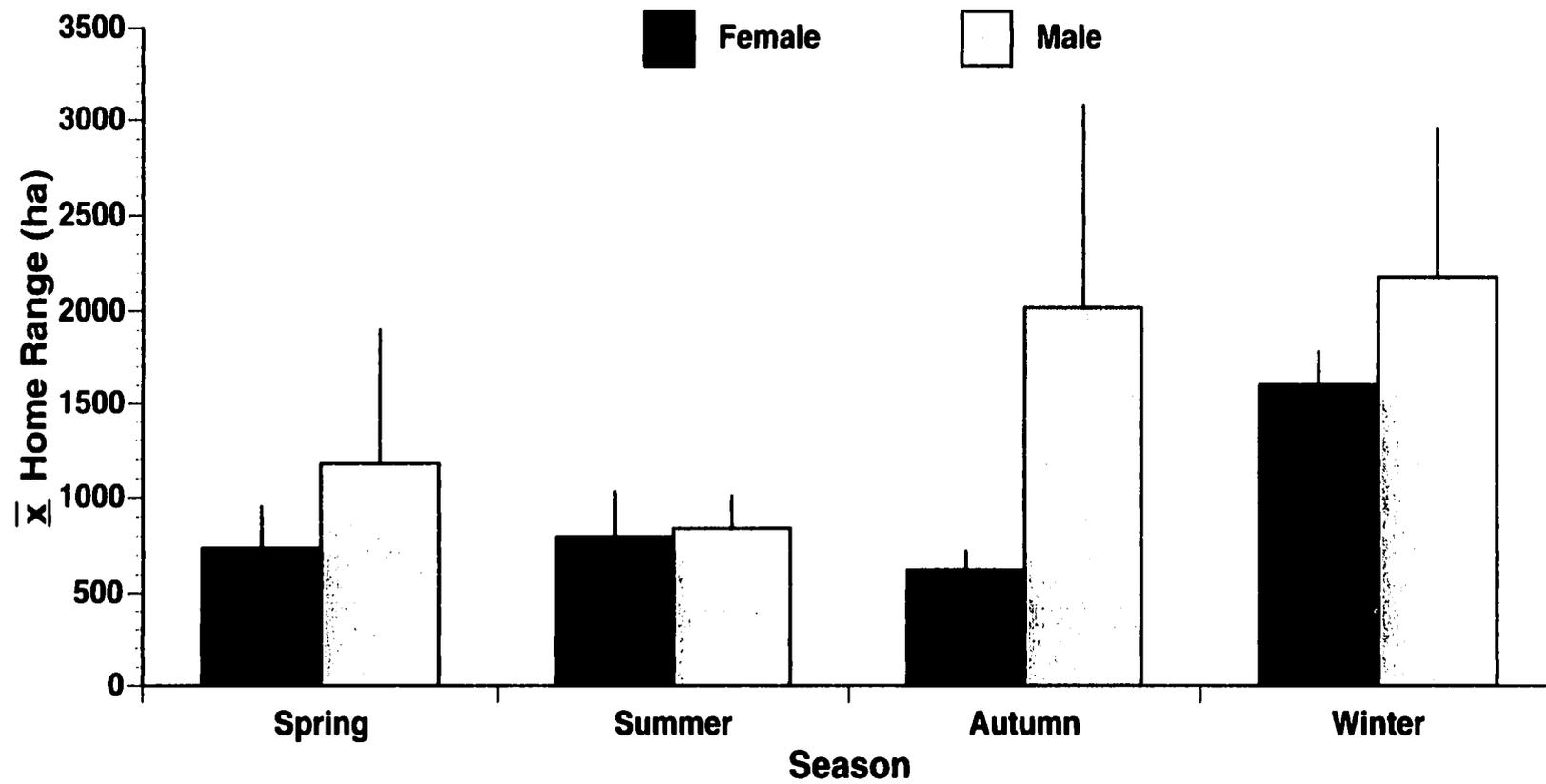


Fig. 2.3. Seasonal mean home range sizes for desert mule deer in Avra Valley, Arizona, 1996-97. Bars indicate 1 standard error.

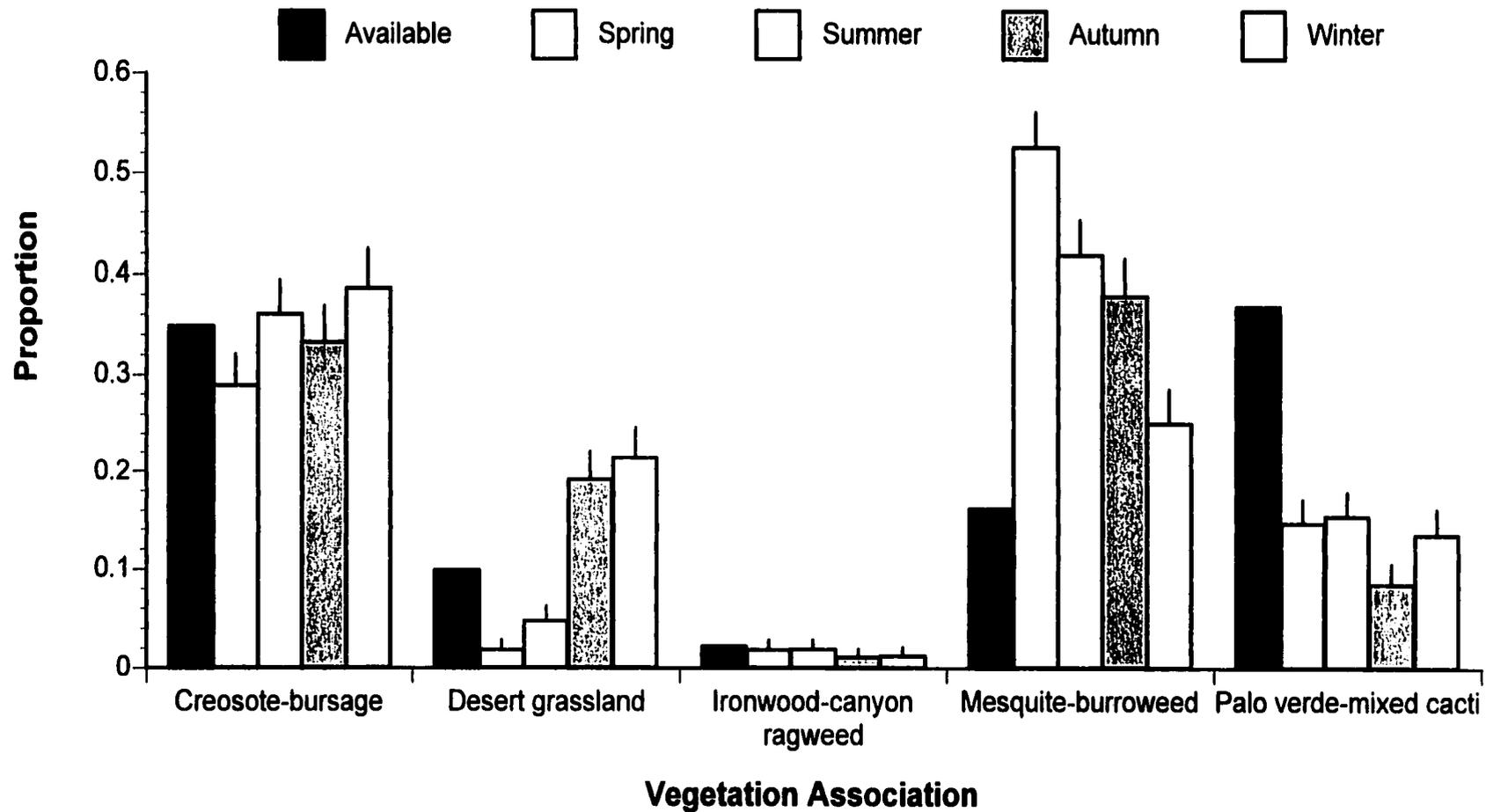


Fig. 2.4. Proportion of female desert mule deer locations in vegetation associations for spring ($n = 48$), summer ($n = 51$), autumn ($n = 47$), and winter ($n = 39$) from Avra Valley, Arizona, 1996-97. Bars indicate 1 standard error. Available proportions were calculated from spatial analyses of a composite home range for all deer locations, therefore no error is associated with these measures.

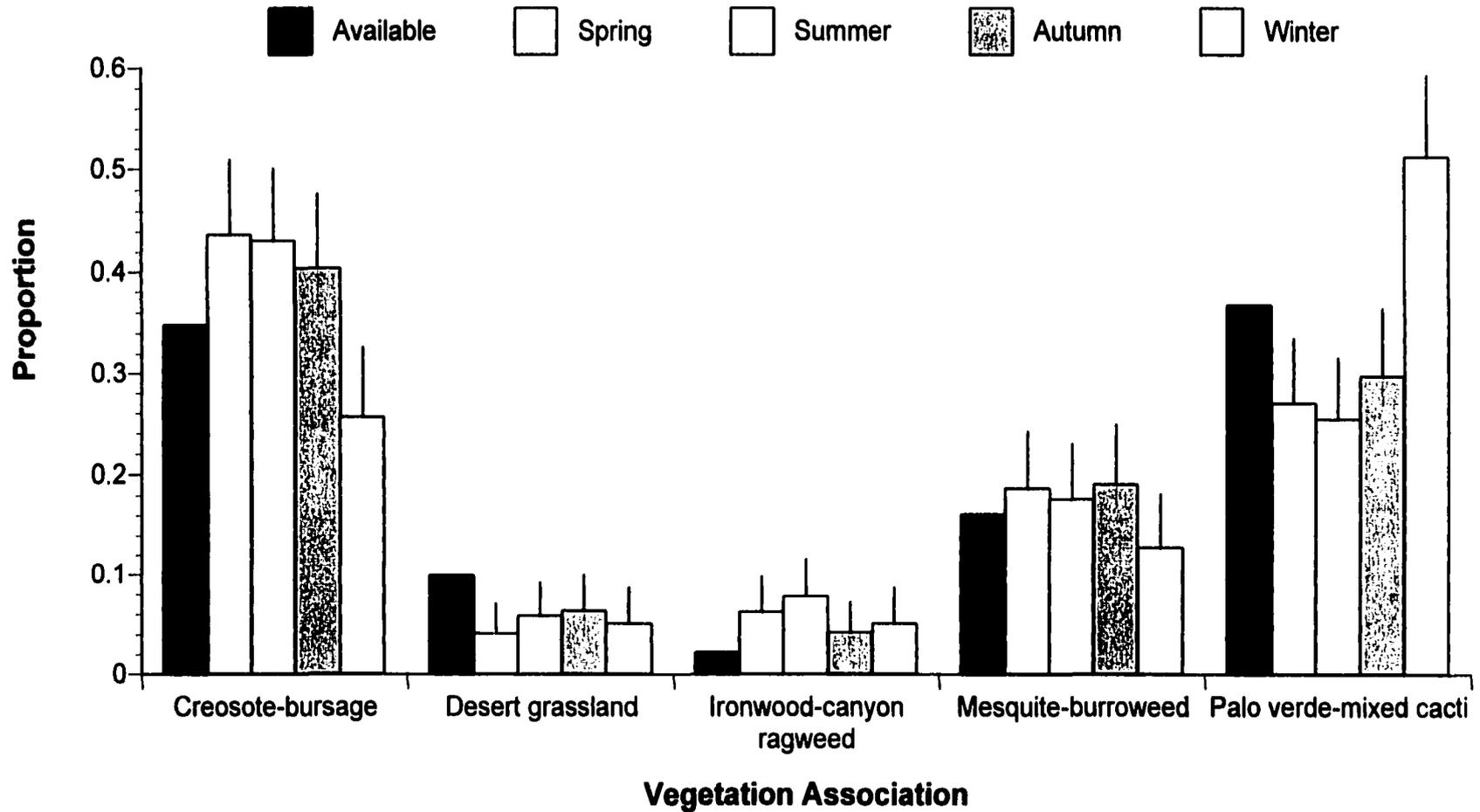


Fig. 2.5. Proportion of male desert mule deer locations in vegetation associations for spring ($n = 48$), summer ($n = 51$), autumn ($n = 47$), and winter ($n = 39$) from Avra Valley, Arizona, 1996-97. Bars indicate 1 standard error. Available proportions were calculated from spatial analyses of a composite home range for all deer locations, therefore no error is associated with these measures.

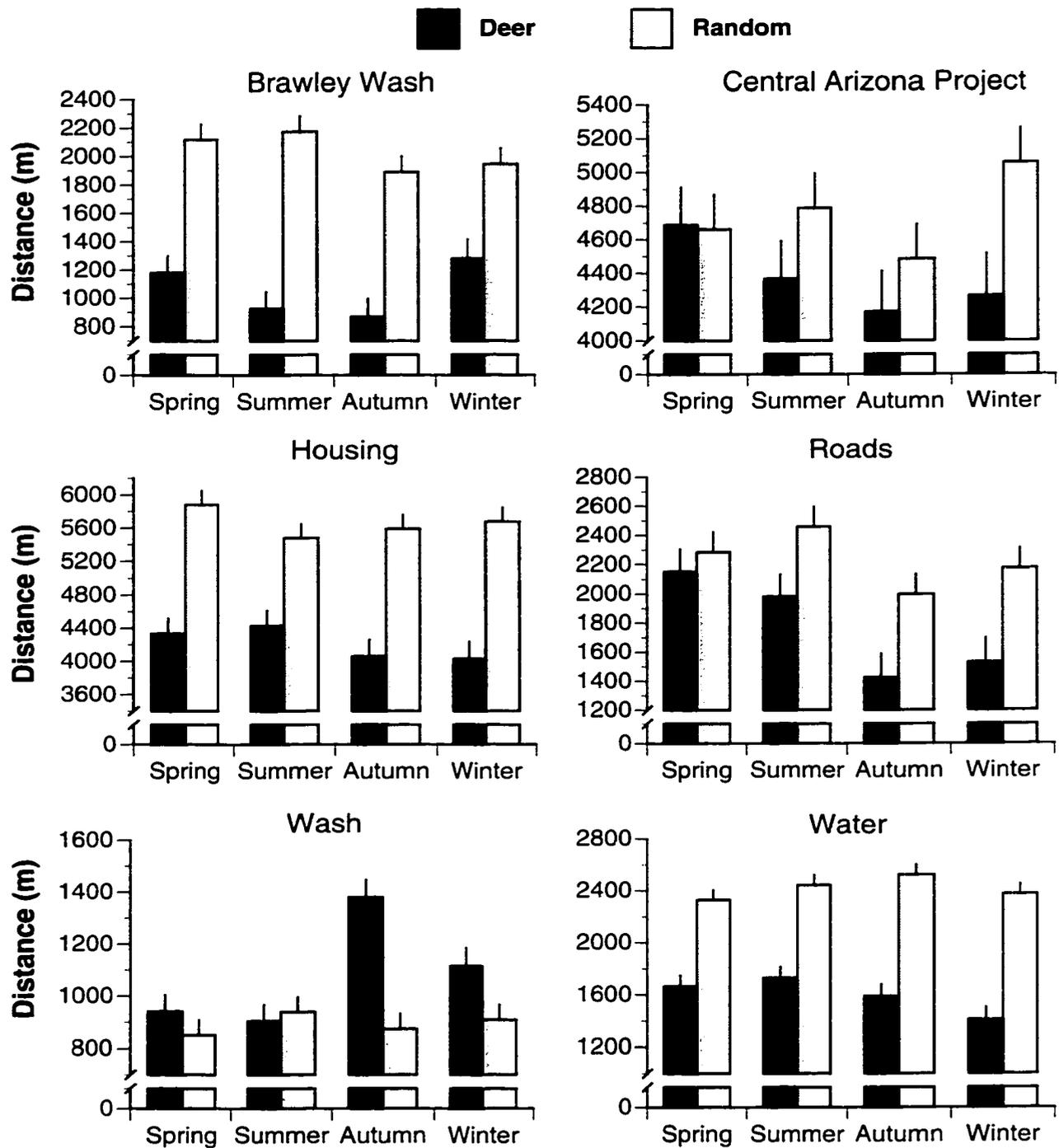


Fig. 2.6. Least square mean minimum distances of female desert mule deer and random location points (random) to landscape and habitat features for each season in Avra Valley, Arizona, 1996-97. Bars indicate 1 standard error.

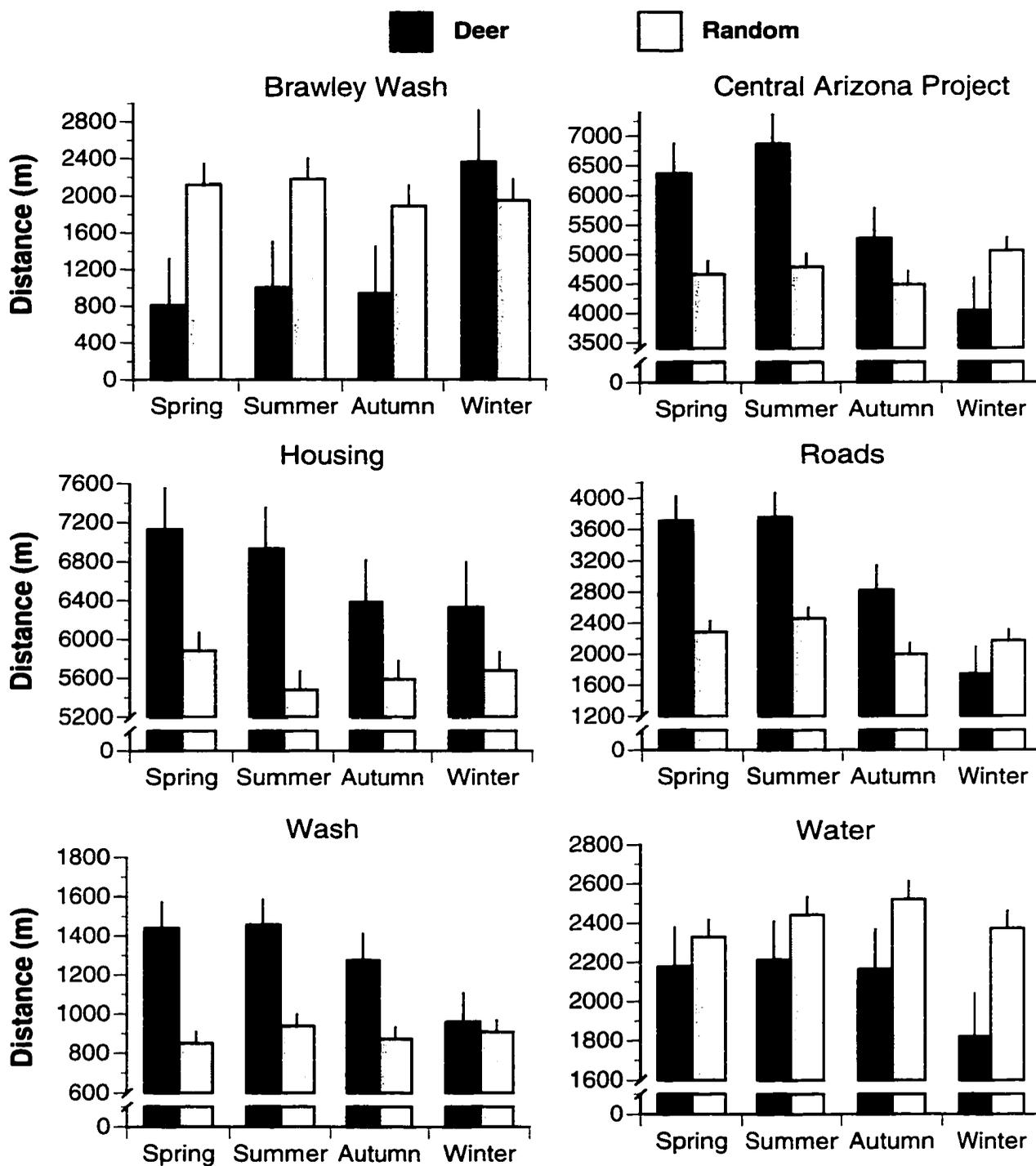


Fig. 2.7. Least square mean minimum distances of male desert mule deer and random location points (random) to landscape and habitat features for each season in Avra Valley, Arizona, 1996-97. Bars indicate 1 standard error.

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BED SITE SELECTION BY DESERT MULE DEER IN SOUTHERN ARIZONA

John C. Tull, Paul R. Krausman, and Robert J. Steidl

ABSTRACT—We investigated selection of bed sites by desert mule deer (*Odocoileus hemionus crooki*) by measuring vegetation characteristics at deer bed sites and paired random sites. We determined if deer selected bed sites based on microhabitat features or if deer were randomly using bed sites by comparing used and random vegetation measurements. Deer use of thermal cover (i.e., vegetation ≥ 75 cm high that provided shade for a deer) was strongest in spring (\bar{x} difference = $14.76\% \pm 5.18$ [SE]), intermediate in summer (\bar{x} difference = $8.32\% \pm 4.08$) and autumn (\bar{x} difference = $8.58\% \pm 3.51$), and weakest in winter (\bar{x} difference = $6.64\% \pm 3.47$).

Scale is important to understand ways that wildlife use landscapes (Kotliar and Wiens, 1990). Habitat use studies of ungulates often are performed at the home range (macrohabitat) scale with radiocollared animals. Desert mule deer (*Odocoileus hemionus crooki*) movements, forage, and cover selection have been studied at the macrohabitat scale in the southwestern United States (Dickinson and Garner, 1979; Koerth et al., 1985; Ordway and Krausman, 1986; Bellantoni and Krausman, 1990; Albert and Krausman,

1993), but there are no studies examining desert mule deer selection of bed sites (i.e., microhabitat).

Studies addressing the importance of thermal cover to deer in northern climates suggests that dense cover of conifer forest canopies benefits deer herds during winter (Cox, 1938; Verme and Ozoga, 1971; Ozoga and Gysel, 1972; Moen, 1976; DelGiudice and Riggs, 1996). Conversely, temperature extremes in southwest deserts occur during summer; therefore, thermal cover can aid in thermoregulation (Anthony, 1972; Leopold and Krausman, 1987; Hayes and Krausman, 1993). Our objectives were to determine if deer selected (Hall et al., 1997) bed sites that provided more thermal cover (i.e., vegetation ≥ 75 cm high that provided shade for a deer) than random sites and to understand vegetational characteristics of bed sites. These data may help identify habitats favorable for desert mule deer.

MATERIALS AND METHODS—This study was conducted in Avra Valley, Pima County, Arizona and was bounded by the Tucson Mountains to the east and the Roskrige Mountains to the west (Fig. 3.1). Tucson was approximately 20 km east of Avra Valley. The Central Arizona Project (CAP) followed the eastern edge of Avra Valley and was proximate to Saguaro National Park and Tucson Mountain Park to the east. Elevations within the area ranged from 1,429 m at Wasson Peak in the Tucson Mountains to about 610 m in north Brawley Wash. Land ownership in Avra Valley was patchy with municipal, state, federal, Tohono O’odham Nation, and private landholders (housing developments and ranches).

Vegetation associations in the area were common to the Sonoran Desert and included: (1) creosote (Larrea tridentata)-bursage (Ambrosia spp.) in undisturbed flats; (2) desert grassland along portions of Brawley Wash and the associated flood plain; (3) ironwood (Olneya tesota)-canyon ragweed (Ambrosia ambrosioides) in washes; (4) mesquite

(Prosopis velutina)-burroweed (Isocoma tenuisecta) in disturbed flats (i.e., abandoned agricultural lands); and (5) palo verde (Cercidium spp.)-mixed cacti on bajadas (Fig. 3.2).

Precipitation is typically bimodal with most occurring during the July-September monsoon and the remaining in winter storms (Reitan and Green, 1968). Mean precipitation was 28.3 cm for Tucson, Arizona, 1996 (National Climatic Data Center, unpublished data). Average normal seasonal temperatures were 24.3, 30.2, 16.6, and 13.6 C for spring (Apr-Jun), summer (Jul-Sep), autumn (Oct-Dec), and winter (Jan-Mar), respectively (National Climatic Data Center, 1993). Seasons were defined based on weather patterns and biology of desert mule deer (Krausman, 1985).

We used net-guns to capture and collar desert mule deer (Krausman et al., 1985) in November 1995 and February 1996 to obtain a representative sample of the Avra Valley population. Each collar was color-coded to assist visual identification of individuals.

Locations on individually marked deer were obtained ≥ 24 hours apart during daylight hours. Triangulated locations were determined from 2 single-observer directional locations within 5 minutes of each other. After triangulating a location, we hiked to the animal and attempted a visual location to determine if the deer was bedded or not. Only animals bedded were included in analyses.

When bedded deer were located, we recorded the minimum group size, presence of any other collared animals, and relative age (adult or subadult) and sex of other animals. We also recorded time and location from a hand-held global positioning system. We used the line intercept method (Canfield, 1941) to measure percent dominant vegetation to species and percent thermal cover. We randomly determined direction and measured vegetation along a 20-m line. We then randomly selected a site 50 to 100 m from the used site and repeated vegetation measurements.

We analyzed bed sites by comparing matched pairs (i.e., bed site and random site) with logistic regression. To determine if male and female observations could be

combined, we tested for equality of variances of bed site measurements between male and female deer with the Levene test (Levene, 1960). We also performed a Student's t -test with the difference in percent thermal cover as the response variable and sex as the explanatory variable for each season if variances were homogenous, otherwise we used a Welch's approximate t (Zar, 1984). We then tested the null statistical hypothesis that mean percent thermal cover at used sites was not different from random sites for all deer with a two-way analysis of variance. We modeled percent thermal cover as our response variable and sample number and site type (i.e., deer or random) as our explanatory variables.

We used logistic regression for matched case-control studies to compare vegetational characteristics of used to random bed sites (Hosmer and Lemeshow, 1989). We used stepwise selection ($P = 0.25$ to enter; $P = 0.15$ to remove) to filter extraneous variables from the data and produce a suitable model. Variables that were evaluated included sex; percent cover of all measured plant species; grouped percent cover values for trees, shrubs, forbs (i.e., annual herbaceous plants), succulents (i.e., thick, fleshy plants with water-storing leaves or stems), vines, and grasses; total percent cover for all plant species; and percent thermal cover. A change in deviance test of the final model to the null model (i.e., no parameters, thus $\beta = 0$) provided our overall measure of model adequacy. We searched for extreme outliers through plots of the change in Wald Chi-square versus the predicted probability to determine if model fit was being compromised by unusual observations.

RESULTS—We captured 17 desert mule deer. Three males and 14 females provided a ratio similar to all deer observed in the study area from July 1996 to March 1997 (i.e., 39 males and 154 females).

Percent thermal cover use was similar between female and male deer across seasons ($t < 1.82$, $P > 0.08$), therefore we combined female and male observations for further analyses. Thermal cover differed between used and random bed sites for all seasons with strongest selection in spring ($F = 8.12$, $df = 1, 45$, $P = 0.0086$), intermediate selection in summer ($F = 4.16$, $df = 1, 49$, $P = 0.0470$) and autumn ($F = 5.96$, $df = 1, 38$, $P = 0.0195$), and weakest selection in winter ($F = 3.65$, $df = 1, 45$, $P = 0.0625$) (Table 3.1).

Deer selection of bed sites was best described by different parameters each season (Table 3.2). Deer bed site selection was strongest in spring, summer, and autumn ($\chi^2 \geq 11.62$, $df = 1$, $P \leq 0.007$), but less so in winter ($\chi^2 = 3.60$, $df = 1$, $P = 0.0577$).

DISCUSSION—We would expect thermal cover to be important during spring and summer because of temperature extremes. Thermal selection was strongest in spring, and less so for autumn, summer, and winter, respectively. Selection occurred during winter, but was not as strongly detected as in other seasons, perhaps because thermoregulation is less of a factor during the mild winter months; also, deer selection of thermal cover in winter may be an artifact of deer seeking escape cover. Our research design would not distinguish between these possibilities. Summer thermal selection was less than spring and autumn; overall increases in ground vegetation cover (i.e., forbs and grasses) and the increase of foliage growth on trees and shrubs due to monsoons during summer provides increased thermal cover and homogeneity of vegetation across habitats. With greater availability of adequate forage and cover across the landscape, selection was less detected for summer.

We observed female mule deer fawning as early as 8 August 1996, which coincides with findings by Fox and Krausman (1994). Because the first 45 days of a fawn's life are most crucial to survival (Trainer, 1975), female nutritional benefits from rains may

improve lactation quality and improve fawn survival (Smith and LeCount, 1979; Urness, 1981). Additionally, we suggest that increased thermal cover, which implies increased escape cover, may improve fawn survival during summer. We observed that dense stands of mesquite made it difficult to approach deer while remaining undetected. We suspect that success for non-ambush predators is reduced in these areas of dense cover.

Models of selection were strong for spring, summer, and autumn, but weaker for winter. We expected winter bed site selection to be less detectable than in other seasons because deer are not thermally stressed, but our model identified thermal qualities of vegetation as the most important component in desert mule deer bed site selection during winter. Because thermal selection was the only component selected in the winter model, thermal selection proves to be the strongest component separating deer bed sites from random sites in winter given the components we measured. Protective and thermal cover may be indistinguishable by our measures, therefore thermal cover in the model may be a surrogate for protective cover during winter.

Observations during winter suggest that deer are not avoiding cover, but that deer are not actively seeking small habitat patches (i.e., patches of approx 100 m radius) that are more dense than the surrounding habitat. This may largely be because the desert floor has relatively little ground cover during winter outside of persistent shrub and tree cover. Areas of persistent tree and shrub cover in the study area were mostly in riparian areas and abandoned agricultural lands that constituted large patches (i.e., >100 m radius). Due to large patch sizes in areas of heavy cover, deer appeared to not actively seek cover relative to surrounding vegetation in winter within our scale of measurements (i.e., 50-100 m placement of random sites from deer bed sites). Therefore, bed site variation was weak between used and random sites during winter. By increasing the distance for measurements between paired samples, we would increase the scale of approach to possibly better address the microhabitat heterogeneity across the landscape (Wiens et al.,

1993). During other seasons, vegetation heterogeneity was measurable and detected within our scale of design.

Monsoons are likely the cause of desert mule deer habitat improvements in summer over other seasons. We suggest several explanations that account for the relief of thermal stresses for deer during summer: (1) feeding efficiency is improved due to the nutritional benefits and availability of fresh plant growth (Smith and LeCount, 1979; Urness, 1981); and (2) thermal efficiency is improved due to an increase in shade cover availability from fresh plant growth and foliage. These benefits are only realized during monsoons.

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Table 3.1. Thermal cover (%) selection from 2-way ANOVA effect tests for used versus random desert mule deer bed sites in Avra Valley, Arizona, 1996-97.

Season	Used	SE	Available	SE	Difference	F ratio (df = 1, <u>n</u>)	P
Spring (<u>n</u> = 26)	29.66	4.37	14.91	3.99	14.75	8.12	0.0086
Summer (<u>n</u> = 49)	43.66	4.11	35.34	4.35	8.32	4.16	0.0470
Autumn (<u>n</u> = 38)	39.83	4.00	31.25	4.20	8.58	5.96	0.0195
Winter (<u>n</u> = 45)	33.51	3.06	26.87	3.06	6.64	3.65	0.0625

Table 3.2. Vegetation parameters selected by stepwise procedures, their standard errors, Wald Chi-square, significance, and odds ratios for the logit of the probability of desert mule deer used versus random bed sites in Avra Valley, Arizona, 1996-97.

Season	Parameter	Estimate	SE	Wald χ^2	P	Odds ratio
Spring	Tree	0.0707	0.0273	6.72	0.0096	1.073
Summer	Total	0.0446	0.0164	7.38	0.0066	1.046
	Grass	0.0819	0.0538	2.31	0.1282	1.085
	Vine	-0.1341	0.0708	3.59	0.0582	0.874
Autumn	Total	0.0787	0.0499	2.48	0.1152	1.082
	Mesquite	0.0845	0.0350	5.82	0.0158	1.088
Winter	Thermal	0.0252	0.0141	3.18	0.0746	1.026

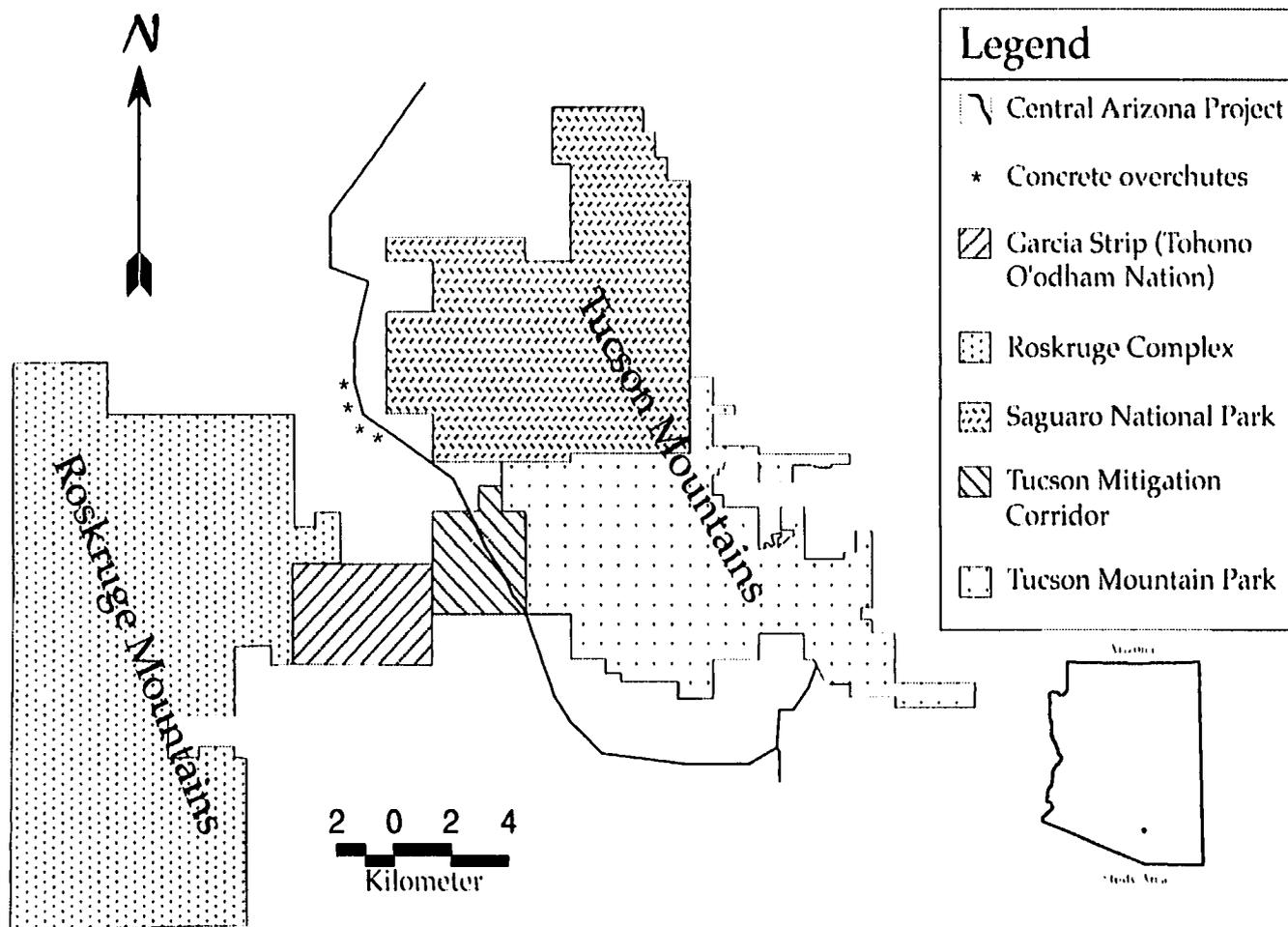


Fig. 3.1. The desert mule deer study area in Avra Valley, Arizona, 1996-97. The Roskruge Complex (Tohono O'odham Nation, federal, and state lands) formed a reserve on the west, and Saguaro National Park and Tucson Mountain Park created a reserve on the east. The Garcia Strip and the Tucson Mitigation Corridor served as a wildlife movement corridor system.

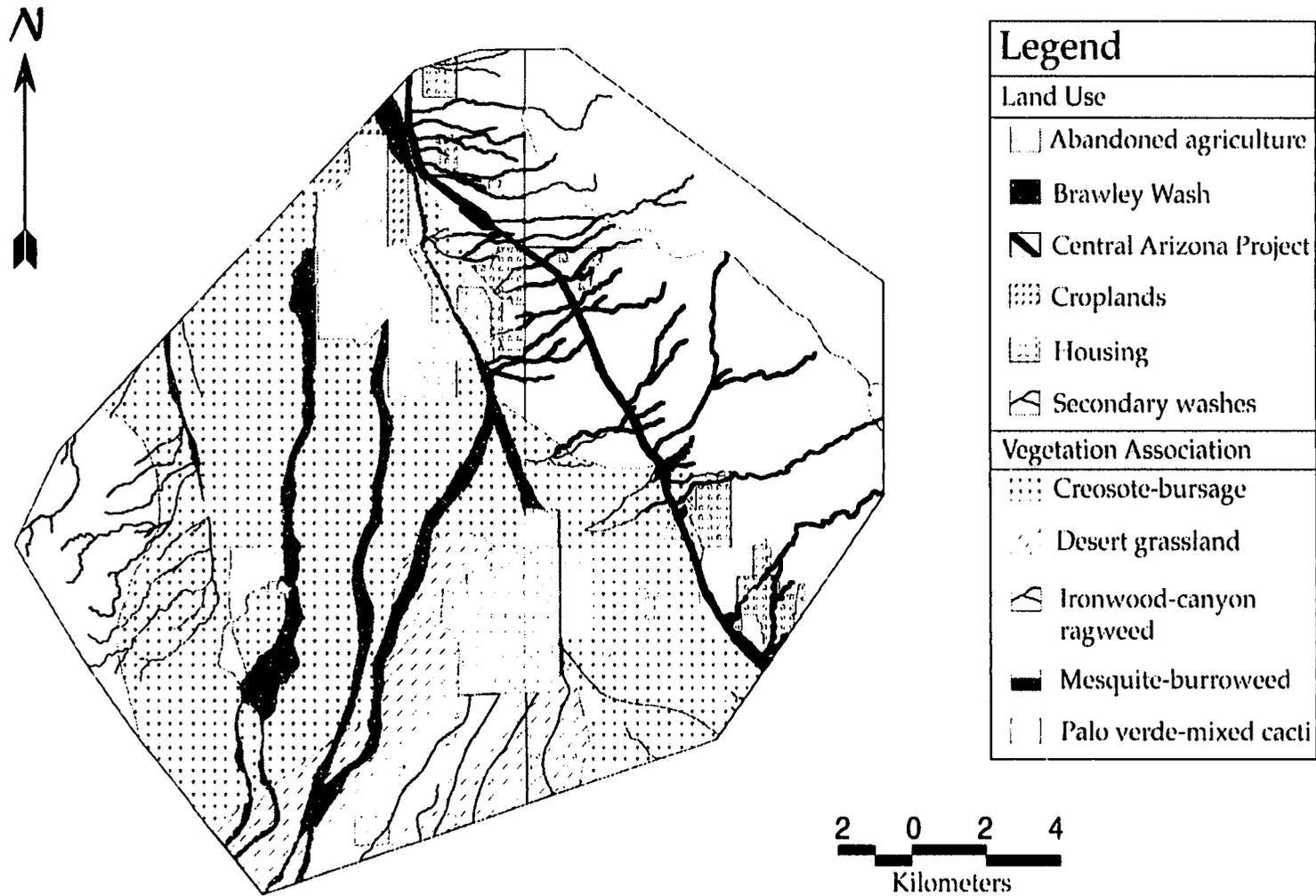


Fig. 3.2. Land use and vegetation associations for the desert mule deer composite home range in Avra Valley, Arizona, 1996-97.

CONCLUSION

My finding of deer use of the corridor system less than expected suggests that deer prefer habitats outside the wildlife movement corridor system over those within the system. This indicates that the corridor does not provide the best available habitats for desert mule deer in Avra Valley.

The future of a wildlife corridor system in Avra Valley is uncertain. The land ownership of the Roskrige Mountains are predominantly Tohono O'odham Nation and Bureau of Land Management, but they are not a recognized reserve as are Tucson Mountain Park and Saguaro National Park on the east. Agricultural development is planned for the Garcia Strip and an aqueduct from the CAP is currently being created. The corridor width would shrink from 2,440 m to approximately 800 m at its narrowest under the proposed development plan. A proposed development alternative would maintain a corridor strip of 240 m. These changes would clearly affect the usefulness of the Garcia Strip within the corridor system and would probably eliminate its effectiveness for preserving a wildlife movement route.

If the Avra Valley corridor system is severed, then the TMC will simply serve as an extension to the reserved habitats of the parks in the east. As more people move into Avra Valley due to human population pressures from Tucson, the TMC may prove increasingly valuable as space for plants, wildlife, and recreation, but the TMC may not survive as part of a large-scale wildlife movement corridor. Considering the cost of the TMC, there is uncertainty that the money was most appropriately spent or if it may have better served other wildlife management uses. Greater benefits may have been realized through the purchase of numerous small reserves across many vegetation associations; this strategy has its merits for floral and faunal populations that suffered habitat losses from CAP construction.

With the protected habitats within Saguaro National Park and Tucson Mountain Park and with the overall lack of permanence of the current corridor system, I argue that the TMC may not serve as a corridor. The TMC reserved habitats benefit wildlife, but do not clearly provide a lasting solution for wildlife access across Avra Valley, Arizona. I am not arguing against movement corridors, but present my data on the Tucson Mitigation Corridor as an example of planning that lacked the necessary foresight to guarantee that the objectives of its establishment would be met and maintained. I urge conservation biologists and planners to fully consider the long-term feasibility of large-scale mitigation projects and to weigh alternative mitigations based on biology and sound science.

With increased human development in Avra Valley from Tucson's westward expansion, desert mule deer habitats will likely become more fragmented. Of all 5 vegetation associations, I observed deer use of the mesquite-burroweed association most strongly. This association was located almost entirely on municipal, state, Bureau of Land Management, private, and Tohono O'odham Nation lands, and much of the land use was abandoned agriculture. Habitats favorable to deer during this study will likely decrease over time.

I conclude that federal lands will become increasingly important for the maintenance of a viable deer herd in Avra Valley. Although western Avra Valley developments may lead to the loss of deer in much of the currently used areas, lands in Saguaro National Park, Tucson Mountain Park, and the TMC should continue to support a deer population in eastern Avra Valley, although these lands may become increasingly isolated over time. With continued management objectives favoring the maintenance of natural desert habitats in Tucson Mountain Park, Saguaro National Park, and the Tucson Mitigation Corridor, desert mule deer should be maintainable in Avra Valley.

Thermal selection at the microhabitat level by deer was strongest in spring, and less so for autumn, summer, and winter, respectively. Selection occurred during winter, but was not as strongly detected as in other seasons, perhaps because thermoregulation is less of a factor during the mild winter months; also, deer selection of thermal cover in winter may be an artifact of deer seeking escape cover. My research design would not distinguish between these possibilities. Summer thermal selection was less than spring and autumn; overall increases in ground vegetation cover (i.e., forbs and grasses) and the increase of foliage growth on trees and shrubs due to monsoons during summer provides increased thermal cover and homogeneity of vegetation across habitats. With greater availability of adequate forage and cover across the landscape, selection was less detected for summer.

I observed female mule deer fawning as early as 8 August 1996, which coincides with other findings in the region. Because the first 45 days of a fawn's life are crucial to survival, female nutritional benefits from rains may improve lactation quality and improve fawn survival. Additionally, I suggest that increased thermal cover, which implies increased escape cover, may improve fawn survival during summer. I observed that dense stands of mesquite made it difficult to approach deer while remaining undetected. I suspect that success for non-ambush predators is reduced in these areas of dense cover.

Models of selection were strong for spring, summer, and autumn, but weaker for winter. I anticipated winter bed site selection to be less detectable than in other seasons because deer are not thermally stressed, but my model identified thermal qualities of vegetation as the most important component in desert mule deer bed site selection during winter. Because thermal selection was the only component selected in the winter model, thermal selection proves to be the strongest component separating deer bed sites from random sites in winter given the components I measured. Protective and thermal cover

may be indistinguishable by my measures, therefore thermal cover in the model may be a surrogate for protective cover during winter.