Journal of Arid Environments 141 (2017) 76–85

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Sonoran Desert rodent abundance response to surface temperature derived from remote sensing

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ARTICLE INFO

Article history:
Received 5 September 2016
Received in revised form
28 January 2017
Accepted 15 February 2017
Available online 3 March 2017

Keywords:
Sonoran Desert
Rodent
Abundance
Habitat modeling
Response curves
Surface temperature
Thermal infrared
Landsat

ABSTRACT

Nocturnal rodents play a key role in the Sonoran Desert ecosystem as consumers, prey and reservoirs of disease-yet rodent distribution remains poorly mapped. We use surface temperature extracted from the Landsat Thematic Mapper thermal infrared band to model rodent abundance obtained from trapping data at the Organ Pipe Cactus National Monument in southwest Arizona. We produce response curves that describe the effects of surface temperature on species abundance. Daytime surface temperature derived from images collected in June across thirty rodent trapping grids ranged from 318 K (45.0 °C) to 332 K (59.2 °C). Results show peak seasonal surface temperature splits high species abundances into two groups: Merriam's kangaroo rat, Arizona pocket mouse, desert pocket mouse and southern grasshopper mouse species prefer habitat characterized by higher surface temperatures; and white-throated wood rat, cactus mouse, rock pocket mouse and Bailey's pocket mouse species prefer habitat characterized by lower temperatures. Abundances for the high and low temperature habitat groupings correlate linearly with surface temperature ($r = +0.66$ and -0.75, respectively, $p < 0.001$). Surface temperature integrates multiple landscape characteristics (e.g. topography, vegetation cover and soil properties) that define the dominant habitats of ORPI rodents. These results prove that simple models can inform complex ecological processes.

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1. Introduction

Desert rodents are active only a few centimeters above the ground, where the air is usually much warmer than ambient temperatures due to solar heating of the soil surface (Cloudsley-Thompson, 1991). Rodents have evolved physiological, morphological and behavioral adaptations to survive extreme desert conditions characterized by little or no free water, minimal shade, low humidity and high daytime temperatures. Subspecies of heteromyids from xeric locations show significantly lower evaporative water loss than those from mesic locations (Tracy and Walsberg, 2000). The kangaroo rat has an exceptional capacity to withstand elevated body temperatures as a means to tolerate high air temperatures (Dawson, 1955). Other species, such as the woodrat (murids), lack the physiology to conserve water (Dial, 1988), thus they are more susceptible to dehydration. Water balance dictates their primary food choices (Vorhies and Taylor, 1940; Hoffmeister, 1986), and they are found therefore in association with cactus in desert regions (Olsen, 1973). Most rodents are nocturnal, staying underground during the heat of the day. Burrows and nests provide lower, stable temperatures, but depths are typically 40–60 cm below the surface at the deepest portion where soil temperatures remain high (Walsberg, 2000). The effects of solar heating occur also at night when heat stored in desert soils substantially elevates air temperatures.

Surface temperature, a source of conductive, convective and radiant energy transfer, is a direct measure of the thermal environment at the surface. The thermal niche for rodents is defined by lethal limits, physiological or metabolic optima, behavioral performance optima, or by behavioral preferences (Magnuson et al., 1979). Extreme temperatures in the summer stress thermal adaptations of warm-adapted desert mammals and vegetation that they depend upon for food, moisture and cover (Alagaili et al., 2017). The true response of a species to one variable, however, is usually detectable only when all others occur at non-limiting levels (Liebig's law of minimum; Huston 2002; Austin 2007)- the thermal properties and relatively uniformity of arid land surfaces presents an opportunity to explore surface temperature as a measurable factor for rodent habitat modeling (Fisher et al., 2007).

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http://dx.doi.org/10.1016/j.jaridenv.2017.02.006
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We hypothesize that maximum seasonal (summer) surface temperature explains rodent abundance in the Organ Pipe Cactus National Monument of southwestern Arizona. We aim to characterize the response of rodent abundance to surface temperature, and to use the response to determine the spatial distribution of nocturnal desert rodent abundance in the monument.

2. Study area and methods

2.1. Sonoran Desert and the Organ Pipe Cactus National Monument (ORPI)

The Sonoran Desert stretches approximately 260 000 km^2 across southwestern Arizona and southeastern California in the United States, and western Sonora and Baja California in Mexico. ORPI (133 882 ha), at the center of the desert, is located in southwestern Arizona with a southern border along the Mexican state of Sonora. It is one of the most biologically diverse protected areas within the Sonoran Desert biome (ORPI, 2006), and 95% is designated as wilderness. The region is distinguished by its semi-arid climate, mild winters and a bimodal rainfall pattern (summer monsoonal and winter low-pressure systems). Mountain ranges, volcanic hills, bajadas (coalesced alluvial fans), valley floors, and drainage systems are typical of Sonoran geomorphology (Hoffmeister, 1986). Alluvial plains, approximately 12 km in width and 300–450 m in elevation, are divided by mountain ranges up to 1465 m in the east and in the center of the monument (Warren et al., 1981). Aridisol ORPI soils are characterized by their volcanic rock origins, low organic content, and poor development of horizons (Chamberlain, 1972). Caliche and desert pavement are common, resulting in lower water infiltration rates and sparse vegetation (Musick, 1975). Creosote bush-bursage desert scrub and palo verde-mixed cacti desert scrub account for approximately 95% of the ORPI vegetation cover (Fig. 1; Warren et al., 1981; REGAP, 2004). Creosotebush-bursage associations are found primarily on nearly level, fine textured, silty, permeable, and alkaline soils of valley bottoms. Paloverde-mixed cacti associations, in contrast, occupy rolling upper bajadas and the lower mountain slopes where coarser soil texture and increased gravel and rock content provides greater available soil moisture (Warren et al., 1981).

2.2. Rodent data

We obtained rodent data from ORPI. Staff monitors rodents annually since 1991 over two consecutive nights in the summer (June–August) at 35 trapping grids (plots) using capture and release field protocols based on Petryszyn (1995). Each grid consists of 49 folding Sherman traps arranged in a 7 × 7 array. The traps are placed at 15 m intervals, resulting in a 90 × 90 m grid. Effective sampling area for the rodent grid plus a 15 m buffer for average home range radius is estimated to be 1.4 ha (Holm, 2006). Heteromyids, including several pocket mice and kangaroo rat species, and murids, including a cactus mouse and a wood rat, are found typically during annual trapping events. Trapping methods and sampling plans are described in ORPI (2006). Fig. 1 exemplifies the range of biophysical habitat at two trapping sites.

We truncated the data set to 1993 through 2006 (14 years) at 30 trapping sites to minimize missing data, and 11 of the 30 grids used

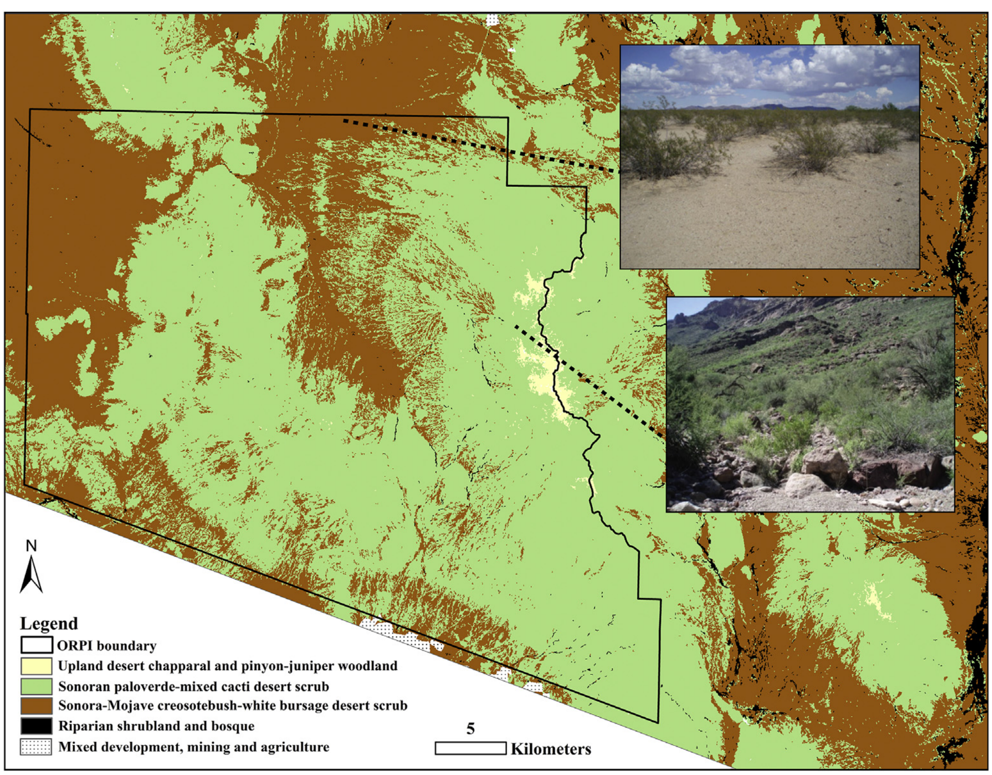

Fig. 1. Landcover classes in the Organ Pipe Cactus National Monument area derived from the Southwest Regional GAP data (REGAP, 2004). ORPI consists of broad expanses of two classes: Sonoran-Mojave creosotebush-white bursage desert scrub (brown or dark tone) and Sonoran palo verde-mixed cacti desert scrub (green or light tone). Significant agriculture use is located south of ORPI's border with Mexico, and upland chaparral and woodland are present in the higher elevations of the Ajo Mountains on the east side. Two rodent plot sites: Valley Floor (VALL, **upper insert**) and Alamo Canyon (ALAM, **lower insert**). These two sites demonstrate the range in biological and physical diversity at ORPI. The ALAM site is sloped and has significant rock coverage. Vegetation is more dense and typical of the ReGAP palo verde-cacti class. The VALL site is flat with significant soil coverage. Vegetation is sparse and typical of the ReGAP creosote-bursage class. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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