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Statistical analysis of Asiatic cheetah movement and its spatio-temporal drivers

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ABSTRACT

We analyzed the movement behavior of a male Asiatic cheetah (*Acinonyx jubatus venaticus*), a critically endangered species, to understand its habitat preferences and relationship to its ambient environment. Using a hidden Markov chain approach, we identified distinct behavioral phases within the cheetah's movement track. We explored the conditions under which the cheetah switched between these behavioral phases. We computed summary statistics of the displacement and duration for the portion of time that the animal had constant behavior and found a linear pattern between its displacement and duration per behavioral phases. We then employed resource-selection and step-selection approaches to understand the cheetah's habitat preferences in general. The cheetah preferred intermediate elevations, low to intermediate slopes, intermediate distances from villages and shorter distances to the water resources. The cheetah moved over a range of 1137 km^2, mainly staying in the more montane northern part of the range. With further validation, the environmental variables and their relationship with the cheetah's behavior could be employed to aid in the conservation of this rare cat.

1. Introduction

Habitat loss, persecution and poaching by humans, and loss of prey has led to dramatic drops in large carnivore abundance from the tropics to the Arctic, with consequences for the functioning of landscapes and ecosystems (Ripple et al., 2014). Several of Iran's native big cats, including Asiatic lion (*Panthera leo persicus*) and Caspian tiger (*Panthera tigris virgata*) have been extirpated, and others, including the Asiatic cheetah (*Acinonyx jubatus venaticus*), Persian leopard (*Panthera pardus saxicolor*) and Caucasian lynx (*Lynx lynx dinniki*) have experienced substantial pop-ulation declines, geographic range contractions, and fragmentation of their habitat. This is problematic because large carnivores are crucial for the maintenance of biodiversity, and human actions cannot fully replace the role of large carnivores.

The Asiatic cheetah is the most critically endangered member of the family Feli-dae (IUCN red list category) and based on recent reports, only 50–70 Asiatic cheetahs live in Iran (Durant et al., 2016). Given the extreme rarity of the species, very little is known about its movement behavior and ecology. Low prey density, and the presence of large competitors prompts individual Asiatic cheetahs to range over hundreds of kilometers connecting fragmented reserves through corridors, as was recently discovered using camera traps and spot-matching techniques (Farhadinia et al., 2016).

Remote sensing images at a wide range of spatial, temporal, spectral and radiometric resolutions, can inform analyses of animal movement. Free remote sensing products with a global coverage are suitable for the extraction of certain variables such as temperature, land-cover, and elevation at a large scale; yet, they lack the spatial resolution needed to extract small scale man-made infrastructures. Here, we used ground truthing of human land features supplemented with remote sensing imagery to understand habitat preferences and behavioral switching of an Asiatic cheetah.

Specifically, we address the following questions: **1)** How does the cheetah allocate time for encamped and moving behavior during the day? **2)** How far does the cheetah travel and how long does it stay in a moving or encamped state? **3)** What habitat variables influence the cheetah to transition between behavioral phases? **4)** What are the cheetah's general and moving habitat preferences?

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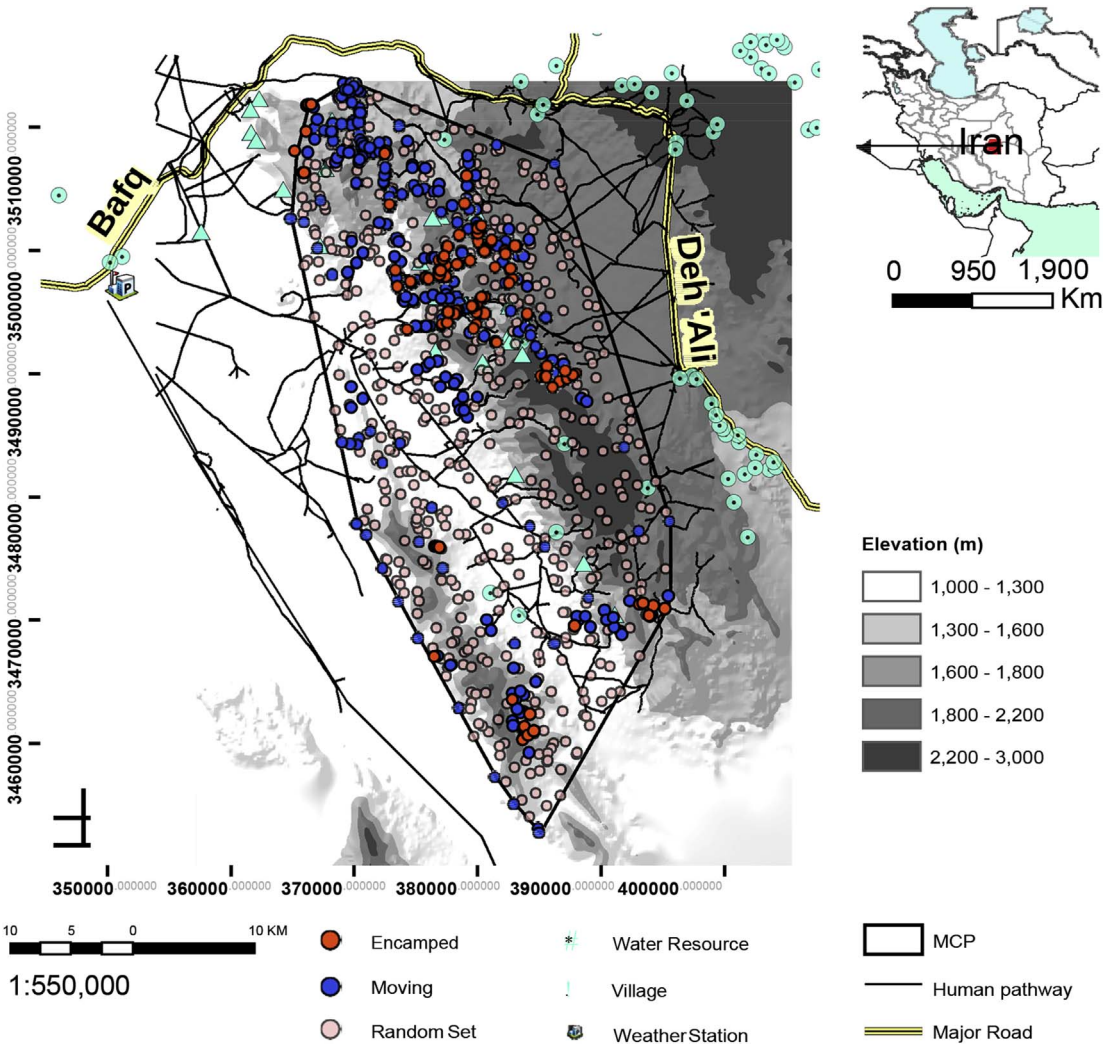

Fig. 1. The study area and the movement locations of the cheetah. The elevations are classified using Jenks classification algorithm. The encamped and moving locations are estimated from HMM. Random set is created using spatial uniform sampling in the minimum convex polygon of the track. Coordinate system information: EPGS: 32640, datum (ellipsoid): WGS 84, projection system: universal transverse Mercator, zone: 40 north.

2. Materials and methods

2.1. Data

2.1.1. Study area

The cheetah study was conducted in the Bafq protected area in Yazd Province in central Iran (Fig. 1), one of the five protected areas identified by the Conservation of Cheetah Project (CACP) as the most important areas for cheetahs. Bafq is a barren area of land characterized by desert and xeric shrubland biomes, with scarce rainfall, high temperature and degraded landscapes. The Bafq desert is surrounded by human infrastructure such as cities and highways that exacerbate the situation for cheetah dispersal. The transportation networks adjacent to protected areas contribute to a higher risk of mortality through roadkill where 7 out of 50–70 Asiatic cheetahs have been lost due to vehicle collisions in the region over the last decade (Mohammadi and Kaboli, 2016).

2.1.2. Movement track

Two male cheetahs (age 3–5) were captured using foot snares, under permits from the Iran Department of Environment. The animals were instrumented with GPS collars (Vectronics, Germany) and the collars were set to transmit locations every 8 h (at 00:00, 08:00 and 16:00). The first collar transmitted for 137 days from 27. February 2007 to 13 July 2007 (384 observation), when the corresponding cheetah was found dead, likely killed by a Persian leopard; then, the other cheetah was immediately recaptured and the data were collected. These cheetahs were members of a sibling coalition; cheetahs are mainly solitary except when in a coalition, usually comprised of brothers born in the same litter who stay together after weaning (Kingdon, 2015). Due to the sparse vegetation in the study area, there were relatively few missing points (4.5% and 7% for cheetahs 1 and 2 respectively) and the gaps were mainly one-step (16 h) with very few two-step gaps (24 h). The two cheetahs moved side by side, thus we included only the first cheetah in all analyses as it had the fewest missing datapoints. We interpolated the consecutive points using averaging to maximize the data available for analysis.

2.1.3. Environmental data

As an indirect proxy for the cheetah's prey, we examined three ecologically relevant vegetation covariates: normalized difference vegetation index (NDVI), soil-adjusted vegetation index (SAVI) and tasseled cap greenness were computed from Landsat 7 imagery. Due to very sparse vegetation mainly in the form of shrubs, NDVI and tasseled cap were not able to detect vegetation and were discarded in favor of SAVI (Amiraslani and Dragovich, 2013). We received climatic data including temperature, humidity, pressure, and wind (speed and direction) from Iranian meteorological organization, and infrastructure