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Habitat Determinants of the Threatened Sahel Tortoise *Centrochelys sulcata* at Two Spatial Scales

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***Abstract.*—The African Spurred Tortoise (*Centrochelys sulcata*), the second largest tortoise species in the world, is threatened with extinction because of a variety of threats, including habitat loss. Because details of habitat use for this species have not been published for wild populations of this species, we conducted this study to qualify and quantify habitat selection at two spatial scales in Burkina Faso and Niger (West Africa). Tortoises were active above-ground almost exclusively in August, during the peak of the wet season. We surveyed seven potential habitat types but the majority of adult and juvenile tortoises were observed in only two, dry river beds (locally named *kori*) and stabilized dunes. We used GIS (Geographical Information System) to map the known distribution of the African Spurred Tortoise in both countries in relation to the availability of kori. The habitat preference of African Spurred Tortoises widely overlaps with the occurrence of kori (and not permanent rivers or other water bodies) in the landscape. We discuss the biological and ecological reasons explaining the results, as well as the conservation consequences.**

Key Words.—conservation; ecology; habitat selection; Sahel; tortoise; West Africa

Introduction

Habitat loss is considered one of the main drivers of the extinction reptiles worldwide, with approximately 74% of threatened species being impacted by agricultural practices, 64% by logging and harvesting and 22% by climate change (Böhm et al. 2013, 2016). Despite the negative effect of habitat loss for many threatened terrestrial reptiles (Böhm et al. 2013), there are virtually no field studies devoted to understanding patterns of habitat use and/or selection, either at the local or at the regional scale for several species of high conservation concern. One species of conservation concern is the African Spurred Tortoise (*Centrochelys sulcata*; Fig. 1), described as the second largest tortoise species in the world, with a wide distribution across the African Sahel (Branch 2008). Despite its wide range in this region, this species has a patchy distribution, likely due to declines and extirpation of local populations (Branch 2008; Petrozzi et al. 2017) caused by extensive hunting for domestic consumption and the international pet trade (Luiselli et al. 2016). Nonetheless, because of the scarcity of historical (distributional and ecological) data on this species and the shortage of field studies on habitat use/selection, it is difficult to evaluate whether the wide gaps in the distribution of this species are due to the extirpation of many populations or to the lack of understanding of habitat preferences at the local scale. Petrozzi et al. (2017) observed that the overall distribution of the African Spurred Tortoise is

negatively correlated to that of both domestic livestock (mostly cattle) and bush-fires, supporting the notion that both cattle and fires can profoundly affect the tortoise conservation status (Branch 2008; Petrozzi et al. 2017). African Spurred Tortoises are not only negatively influenced by a high density of domestic livestock, but this is compounded in areas where both high livestock density and high wildfire frequency occurs (Petrozzi et al. 2017). In addition, Petrozzi et al. (in press) surveyed populations using line-distance transects and found that the mean density of African Spurred Tortoises was 0.002 individuals/ha in Burkina Faso and 0.167 individuals/ha in Niger, with a considerable variability in density estimates by transect in both countries, especially in Teneré-Termit (Niger) where the density of tortoises was much higher (over 2.00 individuals/ha). This paper explores the determinants of distribution patterns of the African Spurred Tortoise by analyzing habitat use of local populations of African Spurred Tortoises in two West African countries (Niger and Burkina Faso) at a landscape scale, and extrapolating the observed patterns to the country scale using GIS-based and other statistical modeling analyses. The paper further asks the questions: Is the African Spurred Tortoise a habitat generalist in the Sahel region or does it select specific habitat types within the region, and if it selects specific habitat types, do known distributional patterns and gaps correlate with the spatial distribution of preferred habitat features detected at the local scale?

Materials and Methods

We conducted field surveys between 2013 and 2016 in two Sahelian countries, Niger and Burkina Faso. The climate of these two countries is predominantly arid, with a very short wet season from July to September, with heavy rains concentrated in August. We conducted field surveys by means of random walks in a suite of different habitat types available across the study region. Due to socio-political instability in the region, we were unable to carry out rigorous representative surveys across both countries. Instead, we focused our surveys on areas where the presence of the African Spurred Tortoise was already confirmed (Chirio 2009; Petrozzi et al. 2016). We therefore studied the habitat preferences of tortoises in these areas, and extrapolated the data to a larger spatial scale.

We assigned each tortoise sighting to one of the following seven habitat categories: (1) dry river beds (locally called *kori*) and their immediate surroundings (Fig. 1A). They are found in the Sahel region (north of Burkina Faso and Niger). They are characterized by lack of water during the prolonged dry season and by running water during the wet season (August). The vegetation is scarce and the riverbeds are sandy. (2) Stabilized dunes (Fig. 1B). These were dunes that have been stabilized by vegetation (*Leptadunia pirotecnica* and *Acacia* trees, sometimes planted by humans). (3) Non-stabilized dunes (Fig. 1C). These were moving dunes, with no vegetation (just sand) or with little herbaceous vegetation at the bottom. (4) Zipele (Fig. 1D). This is lateritic land, which is very stony and normally without vegetation. In general, this is a bare habitat type where wild populations of vertebrates are extremely scarce. (5) Riverine forest (Fig. 1E). This type of relatively moist forest grows along the banks of the few perennial rivers (i.e., Niger river, etc). (6) Savannah (Fig. 1F). The vegetation of savannahs comprises a tallgrass/tree-shrub savannah, dominated by *Vitellaria paradoxa*, *Terminalia* spp., *Combretum* spp., *Acacia* spp., and *Detarium microcarpum*, with main grasses being *Andropogon ascinoides* and *Schizachyrium sanguineum*. (7) Hills (Fig. 1G). These were rocky-arid hills, up to approximately 743 m above sea level, with open vegetation consisting of woody trees and shrublands. Overall these hills are very arid.

We made a concerted attempt to balance sampling effort between seasons and across habitat types. We concentrated field surveys in August (wet season; overall 30 field days) and December (dry season; overall 34 field days), especially during late night-early morning (0500–1000) and late evening-early night (1730–2300), thus avoiding the hottest daytime hours. We spent 41 survey hours in habitat 1 (19 wet season; 22 dry season), 30 in habitat 2 (14 wet season; 16 dry season), 39 in habitat 3 (17 wet season; 22 dry season), 35 in habitat 4 (17 wet season; 18 dry season), 39 in habitat 5 (17 wet season; 22 dry season), 34 in habitat 6 (16 wet season; 18 dry season), and 41 in habitat 7 (21 wet season; 20 dry season). Overall, the field effort was 121 h during the wet season (about 4 h per day) and 138 h during the dry season (about 4 h per day). We conducted searches at night using flashlights; however, because it was very difficult to find tortoises at night, we did not use the night-time data in our analysis.

Statistical analyses.—We analyzed the seasonal activity (August versus December) and frequency of use of the different habitat types, using the observed-versus-expected chi-square test. We used both original records and historical published data (Moore 1997; Kriska 1999, 2001; Trape et al. 2012; Petrozzi et al. 2016) to determine the current distribution of the African Spurred Tortoise in the two countries. Relatively unsubstantiated records available in a CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) report (undated) were not considered, nor were literature records (e.g., Nazinga Game Ranch, Burkina Faso) where our long-term (1985 to date) field surveys clearly revealed the absence of wild individuals of this species

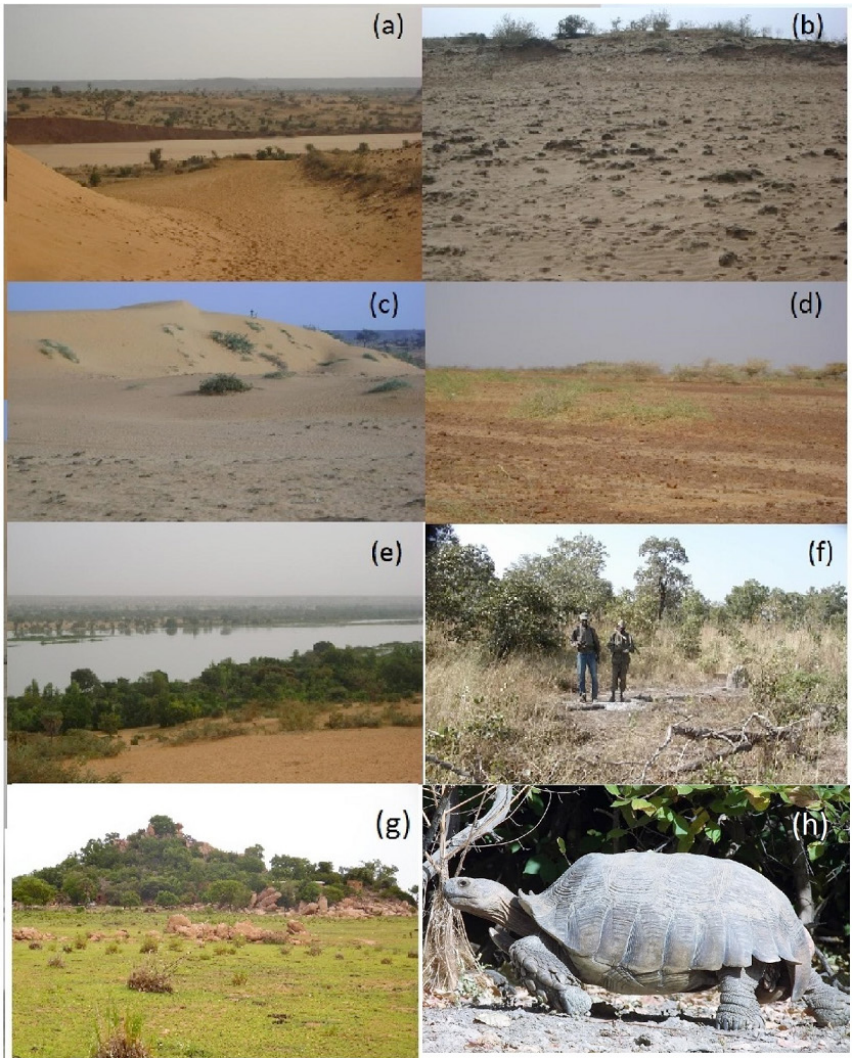

Figure 1. Habitat types available to African Spurred Tortoises (*Centrochelys sulcata*) in the Sahel of West Africa: (a) kori; (b) stabilized dune; (c) unstabilized dune; (d) zipele; (e) riverine forest; (f) savannah; (g) hills; (h) an adult individual in the wild. (Photographed by Emmanuel M. Hema).

(for more details of these unreliable localities, see Petrozzi et al. 2016). Overall, we used 37 independent records. We georeferenced all recent field records (2005–2017) by using a Garmin E-12 GPS (Garmin Limited, Olathe, Kansas, USA) or Google Earth (www.google.it/earth), and we imported records as KML files into freeware GIS (QGIS 2.16.2; http://www.qgis.org/en/site/forusers/download.html). Trape et al. (2012) records are presented as squared cells of 1° longitude and latitude. Hence, to homogenize all data, we used cells of 1° longitude and latitude for original data entries. We excluded data (cells) from Trape et al. (2012) that were intermediate between Niger or Burkina Faso and another country, and that had more than 50% of their area in the other country. We merged all distribution data (cells) with a river (either perennial or non-perennial/fluctuating: *kori*) shapefile of both countries (available at http://worldmap.harvard.edu/data/geonode:Digital_Chart_of_the_World). This enabled the summation of river data, and by using the QGIS field calculator, we were able to calculate the extent of both perennial and non-perennial rivers. We divided these data into three categories: 0 = no rivers; 1 = *kori*; 2 = perennial rivers. We used Past 3.0 software for all data analyses, with $\alpha = 0.05$.

Results

We recorded 56 wild tortoises (45 in Niger and 11 in Burkina Faso). We observed the majority (83.9%) of above-ground active tortoises in August during the peak phase of the wet season, with a significant difference between the frequency of observation across seasons ($\chi^2 = 14.57$, df = 1, $P < 0.001$). This uneven pattern

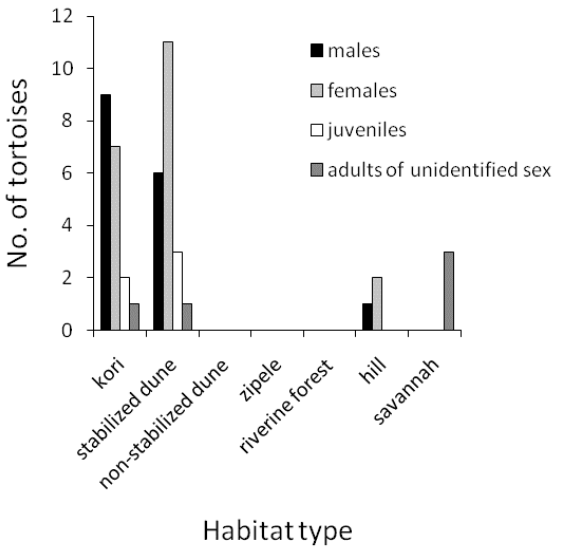

Figure 2. Distribution of African Spurred Tortoises (*Centrochelys sulcata*) observations across habitat types in the Sahel of West Africa.

of annual activity (higher by wet season) did not differ significantly between Niger (86.7% in dry season) and Burkina Faso (72.7% in dry season; χ^2= 1.271, df = 1, P = 0.358). The number of recorded tortoises differed significantly across habitat types (χ^2= 36.23, df = 6, P < 0.001), with the majority of individuals recorded in only two habitat types: *kori* and stabilized dunes. We found individuals of all population categories (i.e., adults of both sexes and juveniles) exclusively in the two above-mentioned habitat categories (Fig. 2).

Having identified *kori* and stabilized dunes as preferred habitats, we tried to explain the spatial distribution of the African Spurred Tortoise in Burkina Faso and Niger in relation to the availability of these habitat types. Unfortunately, it was not possible to find GIS layers representing the spatial distribution of stabilized dunes, whereas spatial distribution data of *kori* across the two countries were available. The literature-based presence sites of the African Spurred Tortoise widely overlapped with areas where only *kori* (and not permanent rivers or other water bodies) were found, with apparent distribution gaps largely corresponding to areas where *kori* were not present (Fig. 3). The only presence area for African Spurred Tortoises where permanent rivers dominate over *kori* was at the border between south-eastern Burkina Faso and south-western Niger (i.e., the area of West National Park, Arly, Singou Reserve, and Pama; Fig. 3). Statistically, 77.1% of the presence cells (n = 35) were dominated by *kori*, whereas perennial river accounted for 8.6% and non-river cells accounted for 14.2% of the total number of cells. These differences were significant (χ^2 = 30.31, df = 2, P < 0.001), thus confirming that the presence of African Spurred Tortoises is linked to a *kori*-dominated landscape.

Discussion

At the local scale, our study showed that African Spurred Tortoises are generally found on slopes and hills, very rarely in flat terrain, and with a strong preference for *kori* and stabilized dunes. This specification of the preferred type of habitat for African Spurred Tortoises represents a step forward in our understanding of the habitat preferences of this species, as the current literature merely reports that the tortoise inhabits arid savannahs and scrublands in association with Sahelo-Sudanian vegetation (Branch 2008), such as *Acacia* spp., Adansonia digitata, Grewia bicolor, and several herbaceous annual plants that regenerate during the wet season (Vetter 2005). For instance, African Spurred Tortoises were reported to be associated with the Cramcram Plant, Cenchrus biflorus (CITES, unpubl. report), an abundant Sahelian plant species in ephemeral prairies existing only during the wet season (Scherman and Riveros 1989). Indeed, our observations that African Spurred Tortoises do prefer *kori* (including their immediate surroundings) and stabilized dunes make it possible to model the potential distribution of the African Spurred Tortoise at a much finer scale than previously done, when it was merely apparent that the range of this species was scattered, without a definite explanation for the many apparent gaps and discontinuities in the range. Vetter (2005) suggested that a combination of factors may be responsible for the patchiness in the range of this species, including amounts of annual precipitation, vegetation, soil type, and degree of anthropogenic habitat alteration, without providing any supporting data. Petrozzi et al. (2016) showed that, in Burkina Faso, the frequency of tortoise sightings tends to decrease with an increase in precipitation (especially when annual precipitation is higher than 600 mm). High densities of domestic livestock are negatively related to the presence of the African Spurred Tortoises (Petrozzi et al. 2017). However, our research suggests that, underlying the above-mentioned factors, the distribution of the African Spurred Tortoise may also be constrained by the absence of *kori* (and likely also stabilized dunes), thus creating wide natural gaps in its range. Unfortunately, our GIS analyses were confined to *kori* as potential predictors for the presence of the African Spurred Tortoise in Niger and Burkina Faso, whereas the same could not be demonstrated for the stabilized dunes due to the unavailability of spatial datasets. We suggest that this effect could be due to the tortoises within the livestock-inhabited areas being subjected to greater poaching effort by the cattle herders (tortoises are eaten by them in many areas) and interspecific competition for food

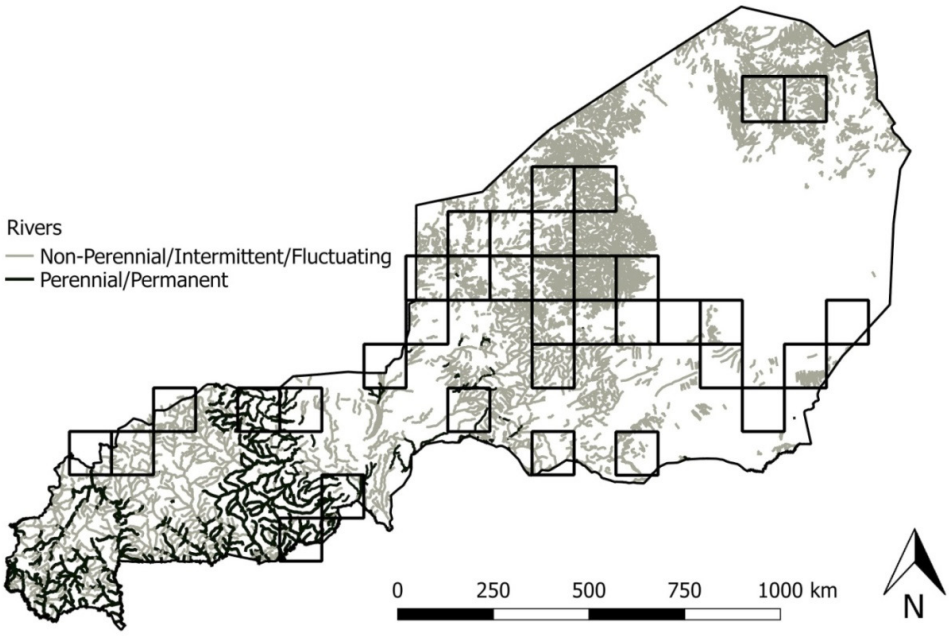

Figure 3. Map of Burkina Faso and Niger, showing the known distribution of the African Spurred Tortoises (*Centrochelys sulcata*; quadrants of 112 km side) and of *kori* (grey; indicated as Non-perennial/Intermittent/Fluctuating) and permanent rivers (black). The tortoise distribution was obtained from published literature (see text) and original data. Note that the presence quadrants for tortoises were largely associated with the widespread presence of *kori* within each quadrant.

with livestock (Petrozzi et al. 2017). Thus, it is possible that tortoises now only occur in *kori*/stabilized dune habitats as there is potentially less vegetation as these areas are seen as poor grazing range by the herders. This hypothesis could explain the dichotomy between the published literature suggesting the species is a habitat generalist (e.g. Vetter 2005) and our results, but could benefit from further verification.

An obvious shortcoming of our study concerns detectability, that is: during random walks, the surveyors ability to see many meters in any direction can be seriously compromised in more densely vegetated habitats (riverine forest and savannah) than in sparsely vegetated habitats (especially non-stabilized dunes and zipele). This could ultimately affect the detection of the tortoises by the surveyor, and it is possible that there are more tortoises in the habitats where the surveyors to able actually see more tortoises. Although this hypothesis cannot be completely ruled out, we think that detectability issues are not a large problem in our dataset. Indeed, tortoises where never encountered in less vegetated habitats (non-stabilized dunes and zipele), whereas they were encountered on multiple occasions in savannah habitat, where the visibility is much lower than in all of the other habitat types (especially in the wet season when most of the tortoise individuals were seen). Thus, while it is possible that the relative abundance of tortoises was underestimated in the savannah habitat by our survey method, it is very unlikely that this bias also occurred in the other habitat types used in the present study.

As to the question why African Spurred Tortoises clearly prefer stabilized dunes and areas with *kori*, our data suggest that they select stabilized dunes because these are richer in vegetation and more stable than mobile dunes, but still have the sandy terrain essential for these tortoises to dig their burrows (Vetter 2005). Indeed, these tortoises spend a long time inside their burrows to avoid overheating, and appear above ground predominantly during the wet season. During the wet season, the food supply provided by annual herbs is high for tortoises around the stabilized dunes, and thus it is likely that these reptiles do select this habitat type also because of the seasonal availability of highly energetic, fiber-rich food.

Concerning *kori*, we suggest the positive selection of this habitat by African Spurred Tortoises also depends upon food availability. Indeed, during the heavy wet season rains, rivers carry both carrion and considerable quantities of vegetation, which would be available as food for the tortoises when the water stops flowing. In addition, *kori* habitat may provide humidity in an otherwise exceedingly arid region. *Koris* likely provide moister soils and riverbanks for digging than surrounding soils in the dry season.

Conservation considerations.—Our study has documented for the first time that the apparently patchy distribution of African Spurred Tortoises in the West African Sahel Region may be due to intrinsic natural reasons (i.e., the presence/absence of *kori*) rather than local extirpation processes. It is therefore likely that further field surveys, focused on *kori*-dominated areas, may be instrumental in discovering additional populations of African Spurred Tortoises. In particular, additional populations of this species may exist and still be discovered in Teneré, the Air Mountains, and in the central-western regions of Niger. In central Burkina Faso, in the region of Ouagadougou, there are wide areas of *kori*-dominated landscape. However, the presence of African Spurred Tortoises can be considered as highly unlikely in these areas, due to heavy habitat alteration, high density of livestock, and extensive human development. It is likely that African Spurred Tortoises were present here, including in the immediate surroundings of Ouagadougou, until approximately 50-60 y ago, as frequently witnessed and reported by elderly people randomly interviewed by the field survey teams (see also Petrozzi et al. 2016).

In many areas inhabited by African Spurred Tortoises, bush fires considered are one of the main problems. Peaks of bush fires occur in November and December, with most of these due to poachers and cattle ranchers believing that burning improves the quality of the grassland and facilitates hunting. The high frequency of bush fires are negatively correlated with the presence of African Spurred Tortoises if fires are also accompanied with a high density of domestic livestock (Petrozzi et al. 2017). The results of this study suggest a conservation management recommendation to guard and mitigate against too many cattle and potential overgrazing of *kori* habitats and their immediate surroundings and to reduce the adverse impact of bush fires on the natural habitat (Menaut et al., 1991; Benjaminsen, 2000) to minimize potential interspecific competition between domestic grazers and the African Spurred Tortoise of the region.

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