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Activity patterns of aoudad (*Ammotragus lervia*) in a Mediterranean habitat

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Abstract. There is increasing recognition of the occurrence of non-native species that are invasive and potentially contribute to biodiversity loss. A two-year camera trap survey was undertaken on Mountain Mosor, Croatia to determine the daily and seasonal activity patterns of recently introduced non-native aoudad (*Ammotragus lervia*). Aoudad were most active in open rocky habitats and least active in forest habitats. The effect of habitat on the recorded number of aoudad was significant, while the effects of month and the interaction month × habitat were not. The results showed a typical bimodal activity pattern of aoudad, with a modest peak in activity between 5:00 and 9:00 a.m., and a second, more pronounced activity peak between 5:00 and 7:00 p.m. Since the native habitat of aoudad is similar to that in the Mediterranean region, the inferred range of daily and seasonal activities show that the species is well adapted to the new habitat.

Key words: Barbary sheep, camera trap, habitat use, locomotor activity, non-native species, ungulate

Introduction

Camera traps have become a popular and commonly-used tool in wildlife research during the past decade. An advantage of this technique is its low cost compared to other techniques, such as GPS or WHF radio tags (Lashley et al. 2018). Camera trapping offers reliable visual data on wildlife without disturbing them, providing insight into the ecology and individual interactions between and within species for a large number of taxa in different habitats (Burton et al. 2015, Wearn & Glover-Kapfer 2019). Since camera traps provide temporal data, it is possible to acquire information on activity patterns, including seasonal variations, which is important for understanding the ecology and behaviour of focal species (Ridout & Linkie 2009, Frey et al. 2017). Therefore, camera traps in ecological and wildlife studies represent a key non-invasive tool in the management of native and non-native species (Davis et al. 2018).

While introduced ungulate species can generate or enhance hunting opportunities, especially when

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native ungulate species have become scarce, they can also have a significant impact on indigenous species and ecosystems through competition, transmission of pathogens, hybridisation or habitat alteration (Carpio et al. 2017). To estimate potential negative impacts, and define guidelines for sustainable management of such species, it is vital to study their adaptation to the new, non-native environment. Activity pattern analysis can be used to describe patterns of co-occurrence with other species (Centore et al. 2018) and to help in management planning of the species. Animal activity patterns are shaped by multiple factors (Pipia et al. 2008). Biological processes, such as sexual activity (von Hardenberg et al. 2000), antler growth (Kavčić et al. 2019), foraging (Rosenbaum et al. 2019), and rumination (Parker et al. 2009) are known to determine activity patterns, and environmental factors such as the presence of humans (Sibbald et al. 2011), hunting pressure (Ikeda et al. 2019), predator-prey activity (Šprem et al. 2015), and weather conditions (Brivio et al. 2016) can further shape them. Wild ruminant ungulates mostly exhibit a bimodal activity pattern, with activity peaks during the day, at dawn and dusk (Pipia et al. 2008, Darmon et al. 2014, Ikeda et al. 2015), and a similar pattern is predicted for aoudad (*Ammotragus lervia*). The importance of understanding daily activity is accentuated in habitats where several species coexist, especially where non-native species are present, as these species are among the major causes of biodiversity loss worldwide (Spear & Chown 2009).

The aoudad or Barbary sheep is a caprid (goat-antelope) originating from the mountainous regions of North Africa, but has been introduced to different continents and several European countries, including Croatia (Šprem et al. 2020) for the purposes of hunting (Carpio et al. 2017, Mori et al. 2017). The aoudad is a generalist herbivore and is extremely plastic in its utilization of available food resources (Lazarus et al. 2019). It is a polygynous species with high fitness and reproductive success (Mori et al. 2017), and great potential to spread to different localities whenever conditions are appropriate (Šprem et al. 2020).

Several authors have explored the distribution, habitat preferences, home range, and behaviour types of the aoudad (Habibi 1987, Cassinello 1998, Anadón et al. 2018, Pascual-Rico et al. 2018), though data on activity patterns are lacking. Since there is scarce information about aoudad activity, the aim of this paper was to determine the daily and seasonal activity pattern of this species using camera traps.

Material and Methods

Study area

The study was conducted in the southern Dinaric region of Croatia on Mount Mosor (surface area 11.3 km²; N 43°31′54.2573″, E 16°38′29.1241″) with its highest peak Veliki Kabal (1,339 m). The climate is mostly Mediterranean, with hot-dry summers and wet autumns/winters. The mean annual temperature is 18.01 °C and mean annual precipitation is 1,665 mm. Elevations above 1,200 m feature a boreal climate with Mediterranean influence (Anonymous 2020). The area is interlaced with rough terrain with numerous meadows, ditches and rocks. Coupled with Sub-Mediterranean and Euro-Mediterranean vegetation, the region harbours typical habitat types, e.g. macchia, scrubland and forest (see Lazarus et al. 2019). As a result, a variety of vegetation and topographic types contribute to area suitability as habitat.

The aoudad population has been present in the Mount Mosor area since 2002 following the illegal release of three female and two male specimens originating from the Czech Republic, Germany and Slovakia (Šprem et al. 2020). The population has since adapted well to the Mediterranean habitat (Kavčić et al. 2020) and the estimated population size is approximately 140 individuals (Šprem et al. 2020).

Two other ungulate species are permanently present in the study area: European mouflon (*Ovis aries musimon*) and wild boar (*Sus scrofa*) though at low densities (Anonymous 2016). The sporadic occurrence of the threatened Balkan chamois (*Rupicapra rupicapra balcanica*) from neighbouring Mount Biokovo has also been recorded (M. Olujić, pers. comm.). The study area is also occupied by two large carnivores, brown bear (*Ursus arctos*) and grey wolf (*Canis lupus*).

Camera trapping and analysis

Ten camera traps were used to collect data over a period of 25 months, from May 2015 to June 2017 (758 trap-days), 24 h/day. Dorr Snapshot Limited 5.0 MP cameras were set at different altitudes (from 357 to 1,025 m) in different habitat types (four cameras in forest, two in macchia, two in mixed, and two in rocky areas) (cf. Rowcliff et al. 2008).

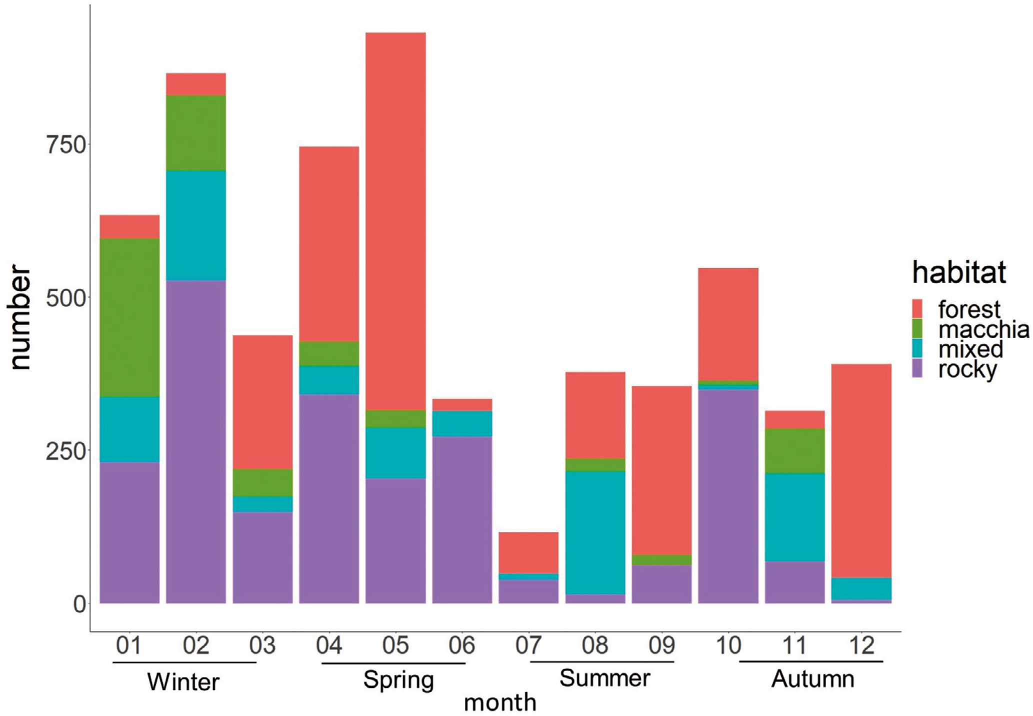

Fig. 1. Habitat type preference of aoudad (*Ammotragus lervia*) on Mount Mosor, Croatia. Each bar represents the total number of aoudad photos in each month and habitat, and each colour represents the portion of aoudad captured in each habitat. Number of recorded aoudad per season for 25 months (overall, n = 6,043): winter, n = 1,936; spring, n = 2,009; summer, n = 847; autumn, n = 1,251.

Cameras were positioned up to 1 m above ground level, with a default focus distance of 10 m, and were checked once a month to download images and check battery status. Cameras remained in the same location during the entire period of the study (25 months). The time lag between successive photo captures was set to five minutes and for every capture event, the cameras took three JPEG photos in five seconds. Only one photo was selected for further analysis, based on the number of captured aoudads and photo quality. Due to low image quality (many images were captured at night and/or at low visibility), individual animals were not identified, and each "capture" event was treated as a single observation, and the temporal distribution of captured aoudad images was used to represent daily activity budgets.

The effects of habitat and month on the total number of recorded animals per month was tested using two-way ANOVA with habitat, month and their interaction as predictors. Altitude was not included in the model due to collinearity with habitat effect, since cameras in the same habitats were also at similar altitudes. Effects were considered statistically significant at $p < 0.05$. Pairwise comparisons between the levels of factors found to be statistically significant were conducted using a Bonferroni correction.

Aoudad activity pattern was estimated from captured images, using the "overlap" package, fitting the von Mies kernel as the circular normal distribution (Meredith & Ridout 2014). We performed the analysis on the full set of recorded images, and on the sets of images divided into seasons based on the month of capture: winter (January-March); spring (April-June); summer (July-September); autumn (October-December). To account for temporal circularity, the solar time at which each photo was taken was converted to radians ranging from 0 to 2π, representing a circular random variable. Based on the simulation performed by Ridout & Linkie (2009), a number of different smoothing parameters (0.5 to 2) were plotted against the original data points. For the density estimation curve, we selected a smoothing factor value of 1.5, based on visual inspection. All statistical analyses were performed using R software 3.6.0 (R Core Team 2019).

Results and Discussion

Over a period of 758 days, a total of 8,265 JPEG photos with animal presence were collected. This number was refined, due to camera settings and multiple identical photos, to 2,755 images. Of the 2,755 JPEG images, only those with aoudad present were selected for further analyses (2,595

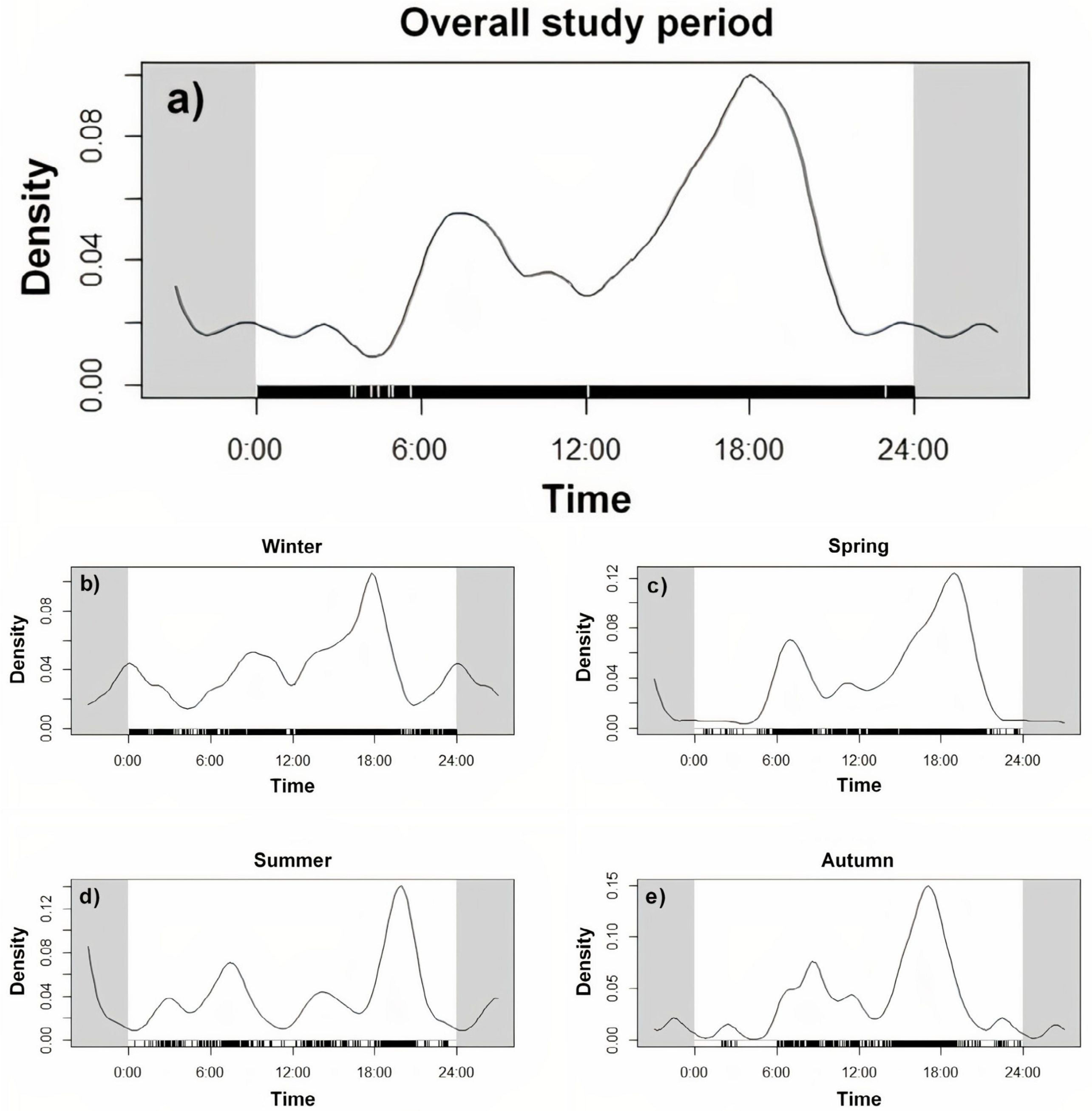

Fig. 2. Kernel density estimates (1.5 smoothing factor) of daily activity pattern and number of photos (n) for aoudad (*Ammotragus lervia*) on Mount Mosor, Croatia during: a) overall study period (25 months), b) winter, c) spring, d) summer, and e) autumn.

photos). Total number of recorded aoudad individuals over entire study period was 6,043. The remaining photos recorded the presence of six species: wild boar (n = 114), brown bear (n = 1), grey wolf (n = 8), red fox (*Vulpes vulpes*; n = 15), wildcat (*Felis silvestris*; n = 5), and European badger (*Meles meles*; n = 17). Although by-catch data can provide helpful information, due to low sample size, photos of other species were excluded from further analyses (Scotson et al. 2017).

ANOVA revealed that only habitat type had a significant effect on the monthly number of recorded aoudad (F = 4.491, $p = 0.005$). Camera trap success rate in different microhabitats indicated the highest average monthly number of recorded aoudads in open rocky habitats (75.27). In other habitat types average monthly numbers were: forested habitats (34.23), mixed habitats (32.34) and macchia (26.38) (Fig. 1).

Rocky habitat had the highest number of recorded aoudads per month, and this was significantly higher than macchia (difference = 48.88, $p = 0.024$), mixed (difference = 42.91, $p = 0.034$) and forest (difference = 41.03, $p = 0.012$). The effects of month

(F = 0.777, p = 0.662) and the interaction of month × habitat (F = 1.313; p = 0.161) on the monthly recorded number of aoudad were not significant. These results correspond to results from southern Spain, where the frequency of aoudad sightings was much higher in open habitats than in closed or mixed habitats (Šprem et al. 2020). Another possible reason for the avoidance of forest habitat is low resource/food availability in the Mediterranean scrub-wood, especially in macchia (Minder 2012). This finding of habitat preference on Mount Mosor could also be the result of an avoidance strategy displayed by aoudad to reduce predation risk by wolves (Šprem et al. 2020), since it has been confirmed that wolves in the Mediterranean habitat often use forest habitats (Karamanlidis et al. 2017). However, since these results are based on the relatively low number of cameras per habitat type (two-four) that were fixed throughout the entire study period, they might have been influenced by camera placement. Since the selection of camera locations in different habitats was unselective, chance placement of cameras might have resulted in camera locations in some habitats being less frequented by aoudad, therefore influencing numbers of recorded animals in such habitats. To validate these results, further experimental studies are needed with more cameras per habitat.

Although there was no statistically significant effect of month, the number of aoudad records was highest during spring (April-June: 868 photos, 2009 aoudad) and decreased during summer (July-September: 329 photos, 847 aoudad). In Mediterranean habitats, the spring is relatively warm, and summer is usually the most challenging season, due to high temperatures. Therefore, a possible reason for lower aoudad activity during summer is the relatively high temperatures (24.8 °C on average) due to the influence of the Mediterranean climate. Similar findings have been reported for other mountain ungulates (see Mason et al. 2014 for Alpine chamois – *R. r. rupicapra* and Aublet et al. 2009 for Alpine ibex – *Capra ibex*). A second possible reason is the seasonal variation in resource/food availability in the study area, owing to the harsh summer conditions, as grasses that are otherwise the main food for aoudad are of low digestibility (see Lazarus et al. 2019). In such a situation, forage quality and quantity are poor, and ungulates reduce food intake and daily activity (Parker et al. 2009, Jhala & Isvaran 2016).

Over the entire study period, aoudad on Mount Mosor showed a bimodal activity pattern (Fig. 2a). Similar activity was observed by aoudad from the Sierra Espuña in southeast Spain (Pascual-Rico et al. 2018). This activity is also characteristic of other ungulate bovids, e.g. Alpine chamois (Darmon et al. 2014), and European mouflon (Centore et al. 2018). The peak of aoudad activity in the morning occurred between 5:00 a.m. and 9:00 a.m., while afternoon activity peaked between 5:00 p.m. and 7:00 p.m. Nearly 60% of photos were taken in the second half of the day, indicating the period of greatest aoudad activity. This finding was also reported by Johnston (1980). Bimodal activity was clearly expressed and generally consistent during seasons at Mount Mosor, except for winter, when nocturnal activity was also recorded. This change in activity may reflect the absence of nocturnal predators (Kusak et al. 2005), or the opportunity for additional food intake similar to e.g. male chamois (Grignolio et al. 2018). Furthermore, a photoperiod effect on postmeridian activity was recognized during different seasons, shifting activity peaks towards dusk (Fig. 2b-e). In addition to photoperiod, day and night cycles can impact ungulate activity, by regulating endogenous processes (Walton et al. 2011).

Understanding aoudad activity patterns, as a non-native species, is particularly important, since they may have a bearing on native biodiversity. Examples of the impacts of non-native species have been reviewed (Ferretti & Lovari 2014) and are primarily reflected in food competition and impacts on native and endemic flora (Šprem et al. 2020). For instance, aoudad and Iberian ibex (*Capra pyrenaica*) in Spain face resource competition and pose a threat to endemic plant species (Acevedo et al. 2007).

Information on activity patterns is important in the management of aoudad. Management strategies for non-native species are based on the assessment of their influence on native species and their commercial value. Management interventions can be more efficiently planned when the habitat preference and activity of target species are well characterised. In cases when population control measures are planned, using such knowledge can help to target the habitat type and time of day for implementation of actions and thereby streamline the allocation of resources. Since there is currently no evidence of a negative impact of aoudad on the regional flora of Spain (Cassinello 2018) or the southern Dinaric region, or competition (Lazarus et al. 2019, Šprem et al. 2020), further studies on the population dynamics, potential expansion and invasive potential of this species are needed.

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