Supplemental materials

A tale of an African ungulate in north-western Italy: population history, abundance, and ecology

Table S1: Model averaging of the 3 best models, out of 16 compared by AICc. All models had working days as an offset and camera trap site as random intercept.

Model	df	logLik	AICc	delta	weight
slope+daytime+elevation^2+streams+path+conifer	10	-122.61	266.58	0	0.42
slope+daytime+elevation^2	7	-125.96	266.60	0.02	0.42
slope+daytime+elevation^2+streams+path	9	-124.67	268.46	1.88	0.16

Figure S2

Figure S2: Examples of morphological features that allowed individual identification of adult males.

Links to media showing video recordings of the species in the Park, awarded within the IV National Camera-trapping Contest in 2021 [in Italian: IV Concorso Nazionale Fototrappolaggio], Canislupus Italia ONLUS, author Fabio Leoncini:

Bathing male aoudad: https://www.youtube.com/watch?v=JRbwNpwvQM4

Mix of videos: https://www.youtube.com/watch?v=zu5Pbik1prI

Table S4. Camera traps models used

Year	Camera traps
2017-2018	1 IR PLUS BF 110° (Ziboni technology), 1 Trap Car, 1 Bolyguard, 8 Bolyguard SG520 (Boly Inc.), 2 Bushnell Trophy Cam HD (Bushnell outdoor products).
2018-2019	8 Bolyguard SG520, 1 Bolyguard BG962-X30W, 3 Scoutguard 2060-X (Boly Inc.), 1 Victure HC200 (Go Victure), 1 IR PLUS BF 110°, 2 Bushnell Trophy Cam HD, 1 IR PLUS BF.
2019-2020	1 Bolyguard BG962-X30W, 2 Scoutguard 2060-X.

Detailed results on minimum population size and distribution

The first record of aoudad in the protected area is a picture of a probable sub-adult male posted in June 2009 in a nature forum, but only discovered in 2017 (Natura Mediterraneo 2009, available from https://www.naturamediterraneo.com/forum/topic.asp?TOPIC_ID=82795). In autumn 2011, three aoudads were spotted close to a farm just outside the northern boundary of the Beigua Natural Park (Arzarello A., *pers. com.*) (Fig. 3). Between November 2011 and December 2012, just 2 camera traps out of the 100 used for a wolf monitoring project (Fasano et al., 2013) registered the presence of at least 8 aoudads, but with a low frequency (22 times over 238 camera days for one trap, and 2 times over 365 camera days for the other). Moreover, from 2011 to 2013 an amateur wildlife photographer took several pictures of aoudads using two camera traps placed in the southern part of the Park (Lazzarini A., *pers. obs.*, available from https://www.flickr.com/photos/medde67/ [1 February 2023]). The most interesting data regarded two adult males in April 2012, two fighting adult males in January 2013, and a group of 4 individuals (2 adult females, 1 yearling, and 1 subadult) in March 2013.

Therefore, in 2012-13 at least 9 individuals were present: 3 adult males, 2 adult females both with 1 kid, 1 yearling, and 1 subadult (Table 1). One kid was born in late March since a picture of a new-born was recorded with no horn tips emerging (Cassinello, 1997), while another was observed at the end of August.

In the following years, observations of aoudads were rare (only 3 in 2015, and 1 in 2017), also because there were no camera traps in the core area of the species. The most interesting one was the

discovery of the remains of an adult male (skull and bones) in March 2015, further west from previous observations (Calcagno M., *pers. obs.*) (Fig. 3).

First census and camera traps: 2017

In 2017 the Park organised a census of the aoudad by simultaneous vantage point counts (Meriggi et al., 2008), involving volunteers and hunters (Pastorino et al., 2017). Observations have been carried out four times between April and May 2017 from 10 sites from sunrise to 9:00 am. Binoculars 8x42, 10x42, and 10x50 and spotting scopes 20-70x were used due to long-distance observations; number of individuals, observation period, age, and sex, when possible, were noted.   Vantage point counts confirmed the presence of the species just in the same area where aoudads have been camera-trapped in previous years, while no observation occurred in other areas (Pastorino et al. 2017). The total numbers of aoudads observed in the first session were 11 (spotted from 3 out of 9 observation sites), 4 in the second session (2/8 sites), 0 in the third one (0/2 sites) and 0 in the fourth one (0/8 sites). During the first session, two groups were observed: 6 individuals (1 adult male, 2 adults females, 3 subadults) and 5 (3 adult females, 1 adult/subadult, and 1 kid). During the second session, a group of 4 aoudads (3 adult males and 1 adult female) was spotted. Combining the results of all sampling occasions and considering age classes and sex, a minimum of 13 aoudads have been observed, i.e. 3 adult males, 5 adult females, 1 adult female or subadult, 3 sub-adults, and 1 kid (Table 1).

Similarly to vantage point results, aoudads had just been camera-trapped in the same site of 2012 (1 out of 5 camera trap sites), where 44 animals were recorded in 19 events, over 83 days. Through identification of age and sex classes, a minimum of 7 individuals was recorded in 19 events, i.e. 1 adult male, 3 adult females, 2 subadults (1 yearling), and 1 kid. The other 4 camera traps did not record any aoudad (3 over 86 days each and 1 over 28 days).

The mean group size of independent events recorded by camera trap was 2.29±0.40 individuals, n=14 (Table 1). Considering both vantage point counts and camera trap data, the mean group size was 2.82±0.44 individuals, n=17.

Core area monitoring: 2017-2018

Camera traps set from June 2017 to May 2018 recorded 107 videos over 1235 days of activity (mean days per camera trap= 112±9.15), even though the actual field effort was higher due to missing data on working days (Fig. 1; Table 1).

In September 2017, a herd of 9 aoudads was recorded, composed of 2 adult females, 5 subadults, and 2 kids. One of them was roughly one month old, again proving birth occurrence in late summer, as occurred in 2012. A pregnant adult female was recorded in January 2018, and a new-born was

observed in March 2018 with the mother and a yearling. In April, a different new-born was registered with 2 females and 1 kid (<5 months). In June, 3 kids (<5 months) were registered together with their mothers. Subsequent recordings showed that two of them were twins. Since no twins were recorded before, it is likely that at least 4 or more probably 5 kids were born before summer 2018 (Table 1).

Analysis of the time elapsed between new births and simultaneous observations in videos allowed us to estimate a minimum of six adult females. At least six adult males were recognizable (Fig. S1). Two males had abscess-like swellings on the left thigh, one of which had a fracture on the left horn, while another one had laxity of the right thigh. At least three more male of different ages, without any distinctive sign, were recorded together, for a total of at least seven adult males (Table 1). For animals without any recognizable signs, we recorded in a single video four sub-adults. Therefore, we observed at least 22 different animals between 2017 and 2018. The mean group size was 2.13±0.16 individuals, n=107 (Table 1).

Systematic sampling: 2018-2019

The camera traps recorded 113 videos of aoudad over 3503 total days of activity (mean days per camera trap in the core area=203.4±23.3; mean days per camera trap in the external sub-areas=25.15±0.91) (Fig. 2; Table 1). During the first season, from June 2018 to September 2018, the 45 camera traps (1 was stolen at the beginning of the sampling season) worked for a total of 1767 days. During the second season, from October 2018 to February 2019, there were 41 active camera traps (as 2 more were stolen and 2 suffered malfunctioning) which worked for 1736 days.

The species was recorded in 11 out of 45 sites during the first season (naïve occupancy = 0.24) and in 11 out of 41 sites during the second one (naïve occupancy = 0.27). The difference was not significant. Overall aoudad were recorded in 12/45 sites (naïve occupancy = 0.27) (Fig. 2).

The first new-born was recorded in the first half of August 2018. A pregnant female was observed at the beginning of February 2019 and a new-born was recorded at the end of the same month. Subsequently, in April, a different new-born was registered. At least 3 kids were therefore born before summer 2019. At least 6 males were recognized by their body marks. Three animals (a male about four years old without distinctive markings, and 2 younger males) were filmed simultaneously during a fight. Two other animals, a 4-years old male and an older one with a dark brown coat, had signs on the left thigh. Moreover, one more male with visible abscesses on the left thigh and throat was observed (Fig. S2).

For animals without any recognizable signs, we recorded in single videos 4 adult females, one adult male younger than those filmed during the fight, and 4 sub-adults. Therefore, we observed at least 17 different animals between 2018 and 2019. The mean group size was 2.12±0.13 individuals, n=113 (Table 1).

Core area monitoring: 2019-2020

Although the number of camera traps on the field was much reduced, the continuous monitoring of three previously sampled sites maintained a constant data collection in the core area (Fig. 1), even though one camera was removed due to malfunctioning at the end of 2019. The camera-traps recorded 103 videos over 517 days in 2019 (mean days per camera=172±44) and 62 videos over 414 days in 2020 (mean=207±16), for a total of 933 days from March 2019 to December 2020, even though underestimated due to some missing data regarding working days (Table 1).

Two different breeding periods of 2019 and 2020 were distinguished for counting new births. Between summer and autumn 2019 at least 3 animals were born. Two groups of animals were observed in the first half of October 2019, one consisting of one adult female, one new-born, and one adult male, and the second consisting of two new-borns, two females, a young male, and an adult male. Subsequent observations confirmed that these were two different groups and that there were twins in the second one. In March 2020, one new-born with no horn tips was observed, while just another one was recorded in early August. Thus, a total of 5 new births were observed between March 2019 and December 2020 (Table 1).

At least eight adult males were observed during the last sampling period. One had an abscess on the left flank, and a second one was lame from the left leg. In February, a group of males was observed, consisting of 3 males at least three years old, and an older male with no signs of disease. In addition, two other adult males younger than the previous ones have been observed simultaneously.

The number of adult females was estimated at five. For animals without any recognizable signs, we recorded in single videos five sub-adults. Therefore, we observed at least 23 different animals between 2019 and 2020. The mean group size was 2.04±0.13 individuals, n=165 (Table 1).