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Abstract

Water is the lifeline for the world's drylands and the key for the distribution of water-dependent equids like khulan. We developed a simple algorithm using khulan tracks from GPS telemetry to identify waterpoints. This approach allowed us to obtain the first landscape-scale information on the use of waterpoints by khulan in Great Gobi B SPA. We discuss the merits and limitations of the algorithm and the implication for landscape level conservation.

Key words: *Equus hemionus*, behaviour, GPS satellite telemetry, Gobi Desert, Great Gobi B Strictly Protected Area, ground truthing, Mongolia, waterpoints

1. Introduction

Water is the lifeline for the world's drylands, and wildlife, livestock, and human distributions are closely linked to the availability of water. Asiatic wild asses ("khulan", *Equus hemionus*), like all equids, are hind gut fermenters, which allows them to process large quantities of low-quality food (SCHOENECKER et al. 2016) but comes at the cost of higher water requirement to sustain microbial fermentation (SNEDDON & ARGENZIO 1998). Consequently, khulan need regular access to water and have been observed to drink between 12-15 litres per day, and up to 24 litres on hot days (BANNIKOV 1981, KACZENSKY et al. 2010b, ZHANG et al. 2015).

In the past, large herds of migratory wild asses (*Equus hemionus*), also known as khulan, roamed the Eurasian Steppes. Nowadays, khulan have become confined to < 3 % of their former range, with only one large population remaining in the Mongolian Gobi. Habitat loss and fragmentation, illegal hunting, and competition for pasture and water are the key factors that have led to the decline of the species (KACZENSKY et al. 2015b). In Turkmenistan, khulan have been cut off from access to water by the border fence with Iran on Turkmen territory, and poaching at the remaining waterpoints in protected areas appears high, while competition with livestock over water seems fierce outside of protected areas (KACZENSKY & LINNELL 2015). This situation has resulted in the virtual disappearance of khulan from Turkmenistan.

Hence, care must be taken that a similar situation does not occur elsewhere in the khulan range. One important precondition is a better understanding of khulan water use. However, mapping waterpoints in the highly variable drylands of Central Asia and Mongolia is difficult as water availability changes within and among years (von WEHRDEN et al. 2010). Furthermore, many waterpoints are small and practically impossible to detect on open-source remote sensing products. In the following, we report on a simple algorithm, which uses special characteristics of the GPS tracks of khulan obtained via telemetry to identify waterpoints and to characterize their use by khulan in the Great Gobi B Strictly Protected Area (SPA).

2. Materials and Methods

2.1. Study area

The Great Gobi B SPA in southwestern Mongolia covers 9,000 km^2. The SPA is dominated by plains, intermingled by small mountain ranges. In the south, mountains form the border with China and in the north rise the Altai mountains. Elevations within the SPA range from 1,000-2,840 m. The climate is strongly continental, with monthly temperatures averaging +3 °C in spring (March-May), 18 °C in summer (June-August), 2 °C in fall (September-November, and -18 °C in winter (December-February), with extremes ranging from +35 °C to -43 °C (HOBO temperature logger, Hoskin Scientific Limited, Vancouver, Canada at the Takhin Tal research station). Vegetation is dominated by Chenopodiaceae, such as saxaul (*Haloxylon ammodendron*) and *Anabasis brevifolia* in the semi-desert areas and by Asteraceae, such as *Artemisia* and *Ajania*, and Poaceae like *Stipa* in the desert-steppe zone (von WEHRDEN et al. 2006).

Average annual rainfall is 100 mm with a distinct peak in summer (> 80 %; June–August, (HIJMANS et al. 2005)). Average snow cover lasts for around 100 days. Rain and snowfall are highly variable in space and time. Due to western weather fronts that pass the Turanic highlands, snowfall is more intense and reliable than in the rest of the Gobi. In the winter of 2009/2010, the region experienced one of the worst winter conditions ever with very low temperatures and large amounts of snowfall ("dzud", KACZENSKY et al. 2011). The snowmelt resulted in an extremely wet spring and unusually large and persistent ephemeral water bodies. Open water in the SPA is rare and unevenly distributed. In locations where several springs occur together, they are often-surrounded by intermittent wetlands and form oases. Most springs are permanent, although their flow varies throughout the year and they freeze up in winter. Additional ephemeral water bodies can form in shallow depressions with compacted ground ("shals") following snow melt or heavy rain events (BURNIK ŠTURM et al. 2017).

The local economy is centered around semi-nomadic livestock husbandry. In the fall, winter, and spring, around 100 semi-nomadic herders and their livestock use Great Gobi B SPA, but they leave the protected area in summer for mountain pastures in the Altai mountain range. Consequently, livestock is almost absent from the protected area from mid-June until mid-September (KACZENSKY et al. 2017a, KACZENSKY et al. 2006).

The khulan population was estimated at 5,671 animals (95 % CI = 3611–8907) in 2010 (RANSOM et al. 2012) and at 9,337 (95 % CI = 5,337-16,334) in 2015 in the 11,027 km^2 study area (KACZENSKY et al. 2017b). Other large mammalian wildlife in the area include reintroduced Przewalski's horses (*Equus ferus przewalskii*), goitered gazelles (*Gazella subgutturosa*), ibex (*Capra sibirica*), argali wild sheep (*Ovis ammon*), grey wolf (*Canis lupus*), Eurasian lynx (*Lynx lynx*), and snow leopard (*Panthera uncia*).

2.2. Animal capture and collar details

In July 2007 and 2009 we collared a total of 24 khulan with GPS store-on-board collars (SOB; 17 custom made collars by the Research Institute of Wildlife Ecology (FIWI) of the University of Veterinary Medicine Vienna, Austria and 7 commercial collars by Vectronic Aerospace GmbH, Berlin, Germany). Khulan was darted with a CO_2-driven dartgun out of a pursuing jeep; subsequent handling and collaring took about 15 min (WALZER et al. 2007a, b).

All collars were programmed to collect GPS positions at 15-min intervals and were equipped with pre-programmed drop-offs (CR-2A, Telonics, USA), programmed to release the collars after 12 months to allow collar retrieval. We were able to retrieve all 10 collars deployed in 2007, but only 10 out of 14 deployed in 2009. Unfortunately, the FIWI SOB collars were ridden with software problems and only 7 of the 17 collars deployed provided a full dataset, and an additional 4 collars provided a partial datasets (KACZENSKY et al. 2010). The remaining 7 collars only worked for a few days (tab. 1).

For analysis of water use patterns we reduced the 15-min GPS location intervals to hourly intervals, selecting for the GPS fixes closest to the full hour. This resulted in a total dataset of 81,069 hourly GPS locations.

2.3. Mapping waterpoints

Ground mapping

In 2012, we field-checked all known waterpoints in the plains within the known khulan range (extent of khulan tracks in fig. 1) in and around Great Gobi B SPA. We additionally checked (1) clusters of GPS locations of Asiatic wild asses that suggested potential additional waterpoints and (2) all areas marked as temporal wetlands on the classic 1:50.000 Russian topographical maps. This resulted in a revised map of confirmed waterpoints (excluding the border security zone along the mountains in the south; fig. 1)(BURNIK-STURM et al. 2012).

Table 1: Khulan captured in July 2007 and 2009 in the Great Gobi B SPA in southwestern Mongolia

Collar ID	Sex	Age (years)	Capture date (DD.MM.YYYY)	N GPS fixes
660	male	>11	02.07.2007	175
300	male	>12	03.07.2007	241
340	female	6-7	03.07.2007	551
580	female	9-10	03.07.2007	22
620	female	6-7	03.07.2007	8,235
380	female	3-4	05.07.2007	627
420	female	4-5	02.07.2007	37
500	male	4	03.07.2007	288
3	female	5-6	20.07.2009	8,721
4	male	3	20.07.2009	8,715
6	male	5-6	20.07.2009	3,127
1	female	8	21.07.2009	3,952
6446	female	15	21.07.2009	8,725
2	female	15	22.07.2009	5,501
6441	male	15	22.07.2009	8,699
5	female	8-9	23.07.2009	6,133
7376	female	2-3	23.07.2009	8,664
7	female	4	21.07.2009	8,656
Total				81,069

Water finding algorithm

Looking at khulan tracks, we noticed that khulan tracks going to water tended to be characterized by long, directed movements towards water, followed by a small number (often only one or two) of GPS locations in the vicinity of the water source, followed by a sharp turn and an equally long and directed movement away from water (fig. 1).

Based on this observation we designed a two-step water-finding algorithm that in a first step identified points where individual khulan turned around sharply ("turnpoints") and in a second step discarded as false-positives those turnpoints that were not clustered together (assuming that khulan sometimes also turn around in a similar fashion for other reasons). Buffers drawn around the remaining clustered turnpoints were joined into shapes that we interpreted as a probabilistic representation of waterpoint locations.

We examined a range of lengths L for the approach and departure vectors from 1 to 4 km, and for the angles α and β from 45 to 120 degrees, for the buffer diameter d from 300 to 700 m, and threshold for dropping points t from 2 to 3 (data not shown). Several related parameter sets performed well, with the best parameter set being: L ≥ 2 km, $\alpha = \beta < 90°$, d = 700 m, and t ≥ 2 (i.e., single turnpoints that did not have at least one other turnpoint within their buffer were discarded). The final algorithm identified a total of 505 turnpoints, of which 275 were accepted and 230 rejected as probable false-positives.

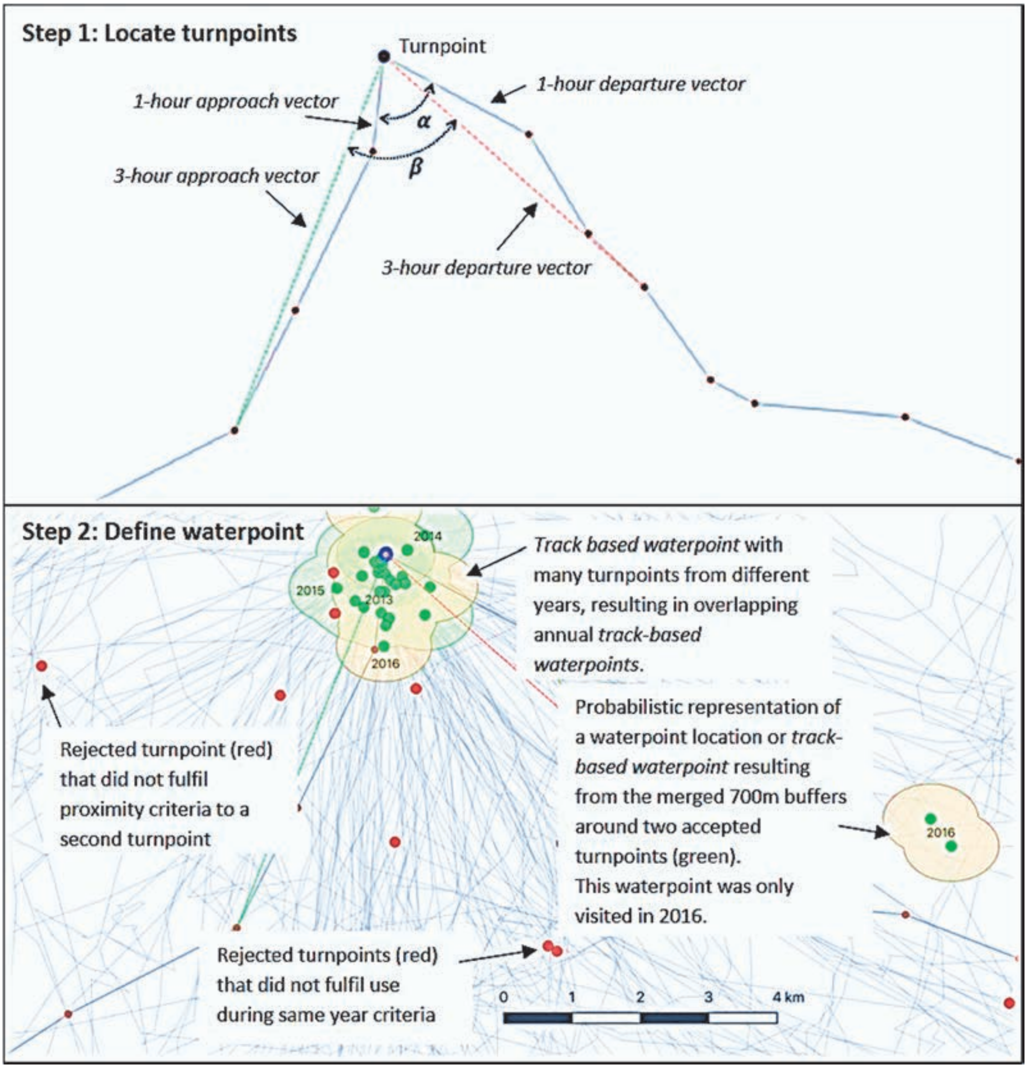

Fig. 1: The two-step water finding algorith used to detect waterpoints based on khulan trajectories.

3. Results

3.1. Waterpoints identified

Our algorithm identified 39 track-based waterpoints in Great Gobi B SPA and the immediate vicinity (fig. 2). Of those, 15 were known permanent waterpoints, 9 were confirmed or highly likely temporary water sources, and 14 were unconfirmed, unknown water sources, some of which could potentially be false (fig. 3).

Of the known waterpoints checked by us on the ground, 37 were within one kilometer (and hence within access distance) of the khulan trajectories from 2007-2010. Of those 37 potentially used waterpoints, 9 (24 %) locations were missed by our algorithm, while in cases where multiple springs clustered together, rather than each individual spring (e.g. 2 of the 6 springs in Chonin Us, 1 spring at Bosgiin Us etc.).

Those waterpoints detected were the Bij river, the Uvchoo river the large oasis Takhi Us and Khonin Us, the large waterpoints Gun Tamga, Toodog, Khairkhan Bulag, Bosgiin Us, Shirin Us, Elsen Us, plus several smaller waterpoints (Suhaitin Dud Us, Takhinn Tsavchaal, Burgast Bulag, Adag Bulag, and Khooloin Dugui).

The algorithm missed the large Yolkhum oasis altogether but picked up 9 known temporary waterpoints. The remaining 14 locations are unconfirmed but judging from the number of visits and visitors, khulan seemed to have been attracted to these locations.

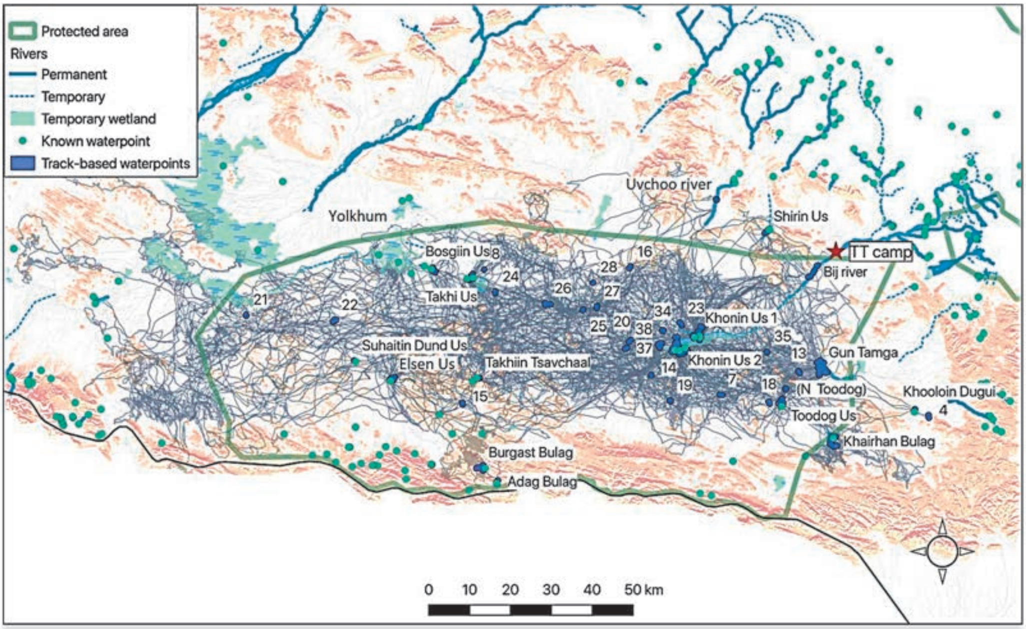

Fig. 2: Locations of track-based waterpoints identified based on the tracks of 18 khulan monitored up to 12 months between 2007-2010 in the Great Gobi B SPA in SW Mongolia.

3.2. Use of track-based waterpoints by khulan

Khulan visited track-based waterpoints a total of 1,011 times. By far the most visits were to the large central oasis complex of Chonin Us, where there are several springs, and depending on season also flooded areas. The second most-visited water point was Gun Tamga, from which in 2010 a river was flowing for an extended period due to meltwater from the heavy snows of the dzud winter of 2009/10.

Most track-based waterpoints received visits from multiple animals (median: 6, mean: 5.7, range: 1-12). Only seven waterpoints received just 1 or 2 visitors, but 2 of those waterpoints (Burgast Bulag and Adag Bulag) were permanent springs; both located at the very southern edge of the khulan range in Great Gobi B SPA.

In the eastern part of Great Gobi B SPA, visits occurred primarily in summer and in the western part additionally or primarily in spring and fall. In winter, when snow covered the ground, khulan rarely visited track-based waterpoints. Overall, track-based waterpoints in the eastern part of Great Gobi B SPA received more visits than those in the western part (fig. 4).

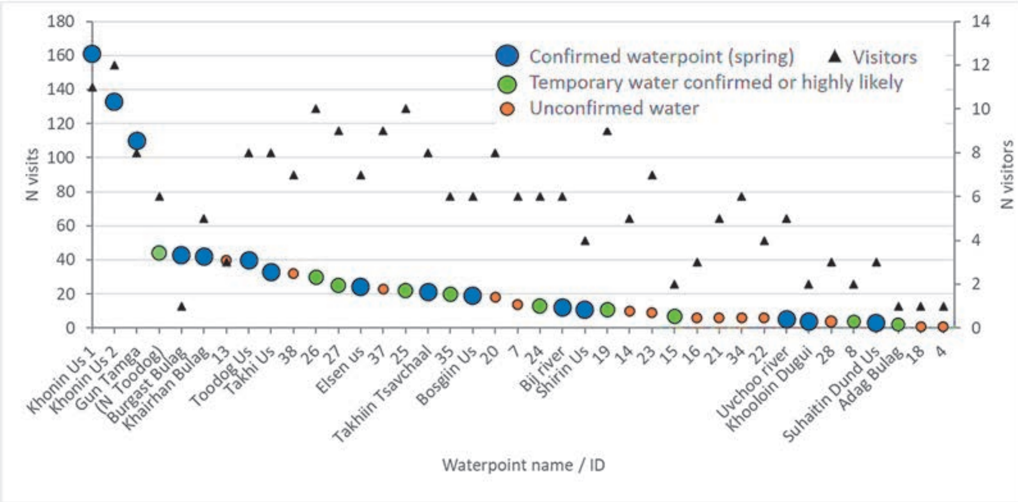

Fig. 3: Track-based waterpoints identified in the Great Gobi SPA, plotted by number of visits and khulan visitors, and symbols indicating the level of certainty that each track-based point was a real waterpoint.

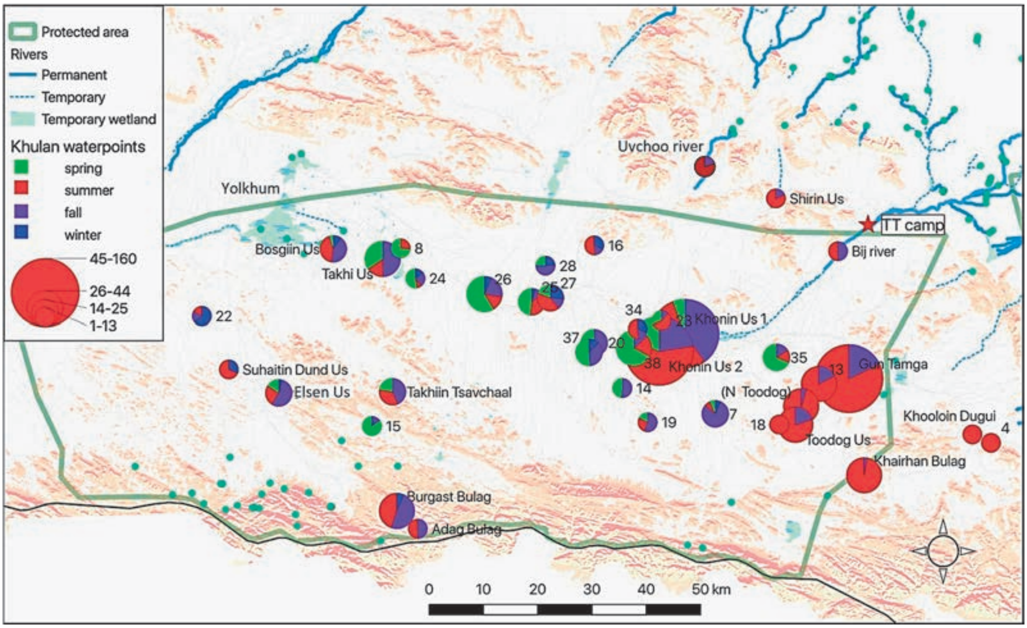

Fig. 4: Seasonal of use of 39 waterpoints identified based on the tracks of 18 khulan that were monitored for up to 12 months between 2007-2010 in the Great Gobi B SPA in SW Mongolia. Symbol sizes are scaled by number of visits.

The seven individual khulan were monitored for close to a full year. Together, they used 36 of the 39 track-based waterpoints, and individually they used between 10 and 27 different waterpoints (fig. 5).

ID	Waterpoint name	Khulan collar ID							N visitors
		3	4	7	620	6441	6446	7376	
1	Adag Bulag							C	1
32	Bij river	C	C	C	C		C		5
31	Bosgiin Us	C	C		C		C		4
2	Burgast Bulag							C	1
9	Elsen Us	C		C	C		C		4
12	Gun Tamga	C	C	C	C	C	C		6
5	Khairhan Bulag	C	C		C		C		4
33	Khonin Us 1	C	C	C	C	C	C		5
36	Khonin Us 2	C	C	C	C	C	C	C	7
30	Shirin Us	C			C		C		3
11	Suhaitin Dund Us							C	1
29	Takhi Us		C		C	C	C		4
10	Takhiin Tsavchaal	C	C	C		C	C		5
17	Toodog Us	C	C	C	C	C	C		6
6	(N Toodog)	C	C	C	C				4
40	Uvchoo river				C	C			2
7	7		U		U	U	U	U	5
8	8	T			T				2
13	13		U			U	U		3
14	14		U	U	U	U		U	5
15	15	T	T						2
16	16	U			U		U		3
19	19	T	T	T	T	T	T	T	7
20	20	U	U	U	U	U	U		6
21	21		U	U		U			3
22	22		U		U		U		3
23	23	U	U	U	U				4
24	24	T		T	T	T	T		5
25	25	T	T	T	T	T	T	T	7
26	26	T	T	T	T		T		5
27	27	T	T	T	T	T	T		6
28	28	U	U		U				3
34	34	U	U	U		U	U		5
35	35	T		T		T	T	T	5
37	37	U	U	U	U		U	U	6
38	38	U	U	U	U		U		5
N waterpoints used		26	26	21	27	18	25	10	

Waterpoint:
Confirmed (C)
Temporary (T)
Unconfirmed (U)

Fig. 5: The track-based waterpoints used by the 7 khulan that were monitored over a nearly 12-month period.

A total of 5,831 hourly GPS locations, representing 7.2 % of the total locations, intersected the track-based waterpoints. Khulan visited or stayed at track-based waterpoints almost equally during all hours of the day (fig. 6).

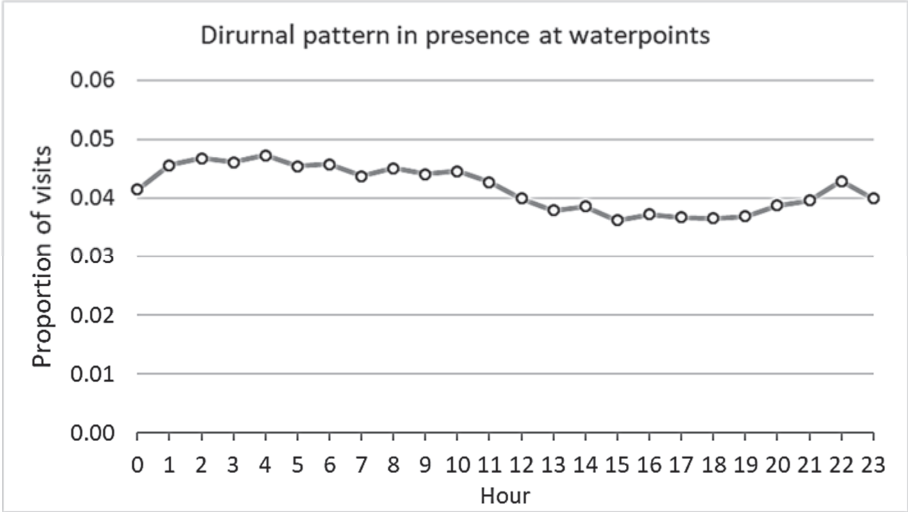

Fig. 6: Time of the day collared khulan stayed at track-based waterpoints.

4. Discussion

4.1. Using khulan to detect waterpoints

Given the high number of visitors at almost every track-based waterpoint, we are fairly confident that the number of false negatives (i.e. places where there is no permanent or temporary water) was small. However, the ratio of all turnpoints to visits (505 to 1,011; i.e. only half the visits showed the track pattern "typical" for an approach to a waterpoint) suggests that the algorithm is conservative (i.e. miss waterpoints). This is likely the case because khulan do not always commute between a certain pasture and a specific waterpoint, causing long and directed approach and departure tracks and a sharp return angle. At times, khulan also switched between different waterpoints or just passed by waterpoints without turning back, thus failing to produce turnpoints needed to identify track-based waterpoints.

Topography and other environmental features likely also influence the a khulan's approach of a waterpoint (e.g. Zadgaai Us in the southern hills was not picked up despite several tracks converging). At large oases or temporarily flooded areas, lush pasture and water become intermixed. As a consequence, khulan can drink and graze in close proximity, which leads to a track patterns that do not include turnpoints that match the water-finding algorithm's criteria for fast and directed approach and departure tracks. We believe that this was the reason why we did not pick up the large Yolkum oasis complex in the northwestern corner of the protected area. Furthermore, springs in close proximity to each other are difficult to identify individually because khulan more often than not spend only short time at water, resulting in turnpoints often falling short of the actual spring. This was one of the reasons we introduced the 700 m buffer around turnpoints to define the area of a track-based waterpoint; but it also means that the location is less spatial explicit.

Most of the khulan tracks west of Great Gobi B SPA are from the dzud winter 2009/10, when large amounts of snow covered the Dzungarian Gobi well into March (KACZENSKY et al. 2011). Observational evidence and data from regular wildlife surveys has already shown that khulan are free to roam far from water during winter, when snow covers the ground (KACZENSKY et al. 2015a). Hence it is not surprising that our algorithm failed to detect waterpoints west of Great Gobi B SPA – khulan likely did not drink at all, but instead ate snow to cover their daily water needs. The reliable winter snow is also what allows local herders and their livestock to utilize winter camp sites that don't have access to a well. Finally, tracking effort (e.g. the number of khulan tracks in an area) also influences the ability to detect track-based waterpoints. Hence, at the edge of the range, or in areas used by only few individuals, the chances to detect waterpoints was reduced.

Despite these constraints, our simple water-finding algorithm identified a large number of waterpoints, both permanent and temporary. The algorithm also allowed us to detect additional points which very likely provided water at least temporarily. In 2012, the khulan tracks allowed us to rediscover two waterpoints which had not been in the GIS database of the protected area, although they were known to locals (i.e. Elsen us and Takhin Tsavaal). The algorithm also picked-up khulan use along a line of points in the dry riverbed connecting the Uvchoo river with Takhi Us and Yolkhum oasis (points 24-27). Rangers and local people knew about temporary pools in this region, but this information had not been formally communicated. In 2013, a solar well was established between the track-based waterpoints 25 and 26, which quickly received visits by khulan (OG pers. Obs.). This now comes as little surprise, as obviously khulan had already been investigating this riverbed in the past.

4.2. Khulan use of waterpoints in Great Gobi B

Using khulan tracks from by GPS telemetry, we were able to obtain the first landscape-scale information on the use of waterpoints by khulan in Great Gobi B SPA. Individual khulan used some 25 different waterpoints during a one-year monitoring period. Different khulan did not use the same set of waterpoints but overlapped in their use of some of the top-ranking waterpoints, namely Chonin Us, Gun Tamga, and Toodog. These latter waterpoints have previously been speculated to be of key importance during the mating season in July (PK, OG, CW pers. Obs.). During this time, large groups of females with foals have been observed here, as well as stallions spaced in what appears to be mating territories (PK, CW pers. obs.). Potentially, these waterpoints also have a functional role in maintaining social cohesiveness and information transfer (RUBENSTEIN et al. 2015).

Fig. 7: Khulan at waterpoint Toodog in Great Gobi B SPA in June 2013 (photo: P. KACZENSKY).

In summary, the khulan data suggest that although the well-known, large waterpoints Chonin Us, Gun Tamga, Khairhan Bulag, Toodog (fig. 7) and Takhi us are highly important for the khulan population. However, there are an additional number of waterpoints, which are also used, distributing the grazing pressure by khulan more widely and additionally may be quite important seasonally.

Khulan visited track-based waterpoints almost equally throughout the 24-hour day. This is in contrast to previous statements which claimed that khulan in Great Gobi B SPA "never came to drink before dawn or after dusk" (FEH et al. 2001) and observations from elsewhere (SCHOENECKER et al. 2016, ZHANG et al. 2015). We believe that the lack of a strong diurnal pattern may be the consequence of a currently very low disturbance levels in the environment during summer. During this time, no herders and virtually no livestock are using the SPA. Hence, human presence in the summer is almost exclusively restricted to border security personnel in the south, and ranger presence in the reminder of the SPA. Poaching occurs, but appears to happen at a low level, a conclusion which is also reinforced by the older average age of recovered khulan skulls from the southwestern Gobi, as compared to the southeastern Gobi (LKHAGVASUREN et al. 2017).

4.3. Conclusion

Using characteristics of khulan tracks to identify waterpoints and to further characterize their use seems to be a promising approach. It is particularly useful for the many small water sources that are difficult or impossible to detect in remote sensing products. Because water is such a key resource for wildlife, livestock and people throughout the arid Gobi of southern Mongolia, this simple approach can also be expected to have high conservation value.

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