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African wild ass drinking behaviour on the Messir Plateau, Danakil Desert, Eritrea

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ABSTRACT

The critically endangered African wild ass (*Equus africanus*) occurs in the Danakil Desert of Eritrea and Ethiopia. Drinking behaviour and the costs of accessing water are critical to understanding how this threatened equid survives in an arid environment. Drinking data and distance travelled to water of 24 females and five males were recorded for 83 days during four study years. Drinking frequency per individual per water source was obtained by calculating the number of water visits of an individual per successive days of observation. The travel distance to water was estimated by measuring the distance between the morning foraging location and the water point. During the dry months, female African wild ass with young foals visited permanent water once a day, travelled on average 9 km and drank only at night. Non-reproductive adult females and males travelled to water every 5–10 days. In rainfall months, females with young foals drank twice a day and on average travelled 3 km to water, but dispersed up to 7 km from temporary water sources when livestock arrived annually. This spatial exclusion from water sources due to livestock presence may reduce female African wild ass ability to provide sufficient milk to their foals.

1. Introduction

Drinking and accessibility to surface water is critical for ungulates in arid environments (Pratt and Gwynne, 1977; De Boer and Prins, 1990; Sirot et al., 2016). Equids in particular, both arid- and mesic-adapted, are dependent on water and this strongly influences their distribution and behaviour (Becker and Ginsberg, 1990; Schoenecker et al., 2016). They may reduce their movement distances (Western, 1975; Pratt and Gwynne, 1977) and remain closer to water compared to other herbivores (Becker and Ginsberg, 1990), or alternatively may need to move long distances to find forage (Becker and Ginsberg, 1990; De Leeuw et al., 2001). Mountain zebra (*Equus zebra*) living in dry areas of southern African (Watson et al., 2005; Penzhorn and Novellie, 1991) are highly dependent on daily access to water (Joubert and Louw, 1976 cited in Schoenecker et al., 2016), and their home range expands when more water points are available (Novellie et al., 2002).

Access to water and forage is crucial for a lactating female's maintenance and ability to provide milk for her foal (Loudon and Kay, 1984). Grevy's zebra (*Equus grevyi*) live in an arid environment, such as the Samburu Game Reserve, in northern Kenya. During peak lactation (birth to 3 months) female Grevy's zebra were usually observed within 2 km of water, while non-lactating females were seen up to 15 km from water (Becker and Ginsberg, 1990). Lactating Grevy's zebra visited water at twice the frequency of non-lactating females and tended to remain closer to water during the foal's first three months (Ginsberg, 1988; Becker and Ginsberg, 1990). Hypothetically, females with foals of age less than three months would be at the peak of lactation and need to drink more frequently than other adults. During this period the foal is almost entirely dependent on its mother for fluid (Ginsberg, 1988). Plains zebra (*Equus quagga*) live in relatively mesic habitats and visit water points every one or two days, but lactating females make more frequent trips to water and this may limit their access to forage (Becker and Ginsberg, 1990; Sundaresan et al., 2008).

Access to adequate forage near to water sources is critical for lactating female maintenance and foal survival in arid habitats (Williams, 1998, 2002). It is therefore important to document the drinking behaviour of African wild ass in relation to water sources, with particular attention to females with foals, which is crucial for the long-term conservation of this species. The African wild ass is listed as 'Critically Endangered' by the IUCN Red List (Moehlman et al., 2015) and an

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important populations is found on the Messir Plateau (Danakil Desert of Eritrea) which has no protected status (Moehlman, 2002; Tesfai et al., 2019). The Asaila spring is the only permanently available water source for the African wild ass on the Messir Plateau during dry months (Fig. 1), and it is shared with people and livestock.

African wild ass live in arid habitats where grass is sparse and widely dispersed. Competition between females for forage may limit their ability to form long term associations (Moehlman, 2002) and the only stable social unit is mother and offspring. The African wild ass has a resource defence polygynous mating system and territorial males dominate an area that has resources that females require and thus they indirectly control access to females in estrous (Klingel, 1972; Rubenstein, 1994; Moehlman, 1998).

The local people in the study area own an estimated 600 head of livestock mainly goats, sheep, camels, domestic donkeys, and a few cattle (Tesfai, 2006). However, the Messir Plateau is under increasing pressure from cattle coming from the highlands during the rainfall months. Competition with livestock affecting access to adequate forage and water has been identified as a major threat to the African wild ass in the Danakil ecosystem (Tesfai, 2006; Kebede et al., 2014; Moehlman et al., 2015, 2016). African wild ass must have access to water in order to survive and lactating females with foals are expected to drink more frequently than non-lactating females. Females that have young foals of less than 3 months (peak of lactation) are expected to drink even more frequently. Hence, in this study we differentiated between female African wild ass with young foals (less than three months old) and older foals (4–12 months old). We collected data on i) frequency of visits to water by adults in different sex and reproductive classes, ii) time of the day that they visited water, and iii) distances travelled between foraging areas and water sources. We compared data between dry periods when the only available water source was the Asaila spring and wet/rainfall periods when temporary surface water was available. We expected that:

(1). During dry months, all African wild ass occurring on the Messir Plateau would visit the Asaila spring since it is the only available permanent water source within 9 km of the lower elevation plains area of the Messir Plateau. The next nearest accessible permanent water is 'Alad' at distance of 30 km from the Messir Plateau to the southwest (Fig. 1).

(2). Females with foals aged three months or less, and females with foals aged between 4 and 12 months, would visit water sources more frequently than females with offspring older than twelve months and/or non-reproductive females and males. Our assumption is that water and quality forage are crucial for the maintenance of a lactating female and her ability to provide milk for her foal (Loudon and Kay, 1984; Becker and Ginsberg, 1990).

(3). African wild ass would visit the Asaila spring that is near settlements and livestock only at night, while they would visit temporary water sources that occur at a distance of 9–10 km from settlements during the day.

(4). Distance travelled between foraging areas and temporary water sources during rainfall months would be less than the distance travelled between foraging areas and the Asaila spring in the dry months. We assume that temporary water sources are widely distributed during these months and that better-quality forage is also more widely available in the study area.

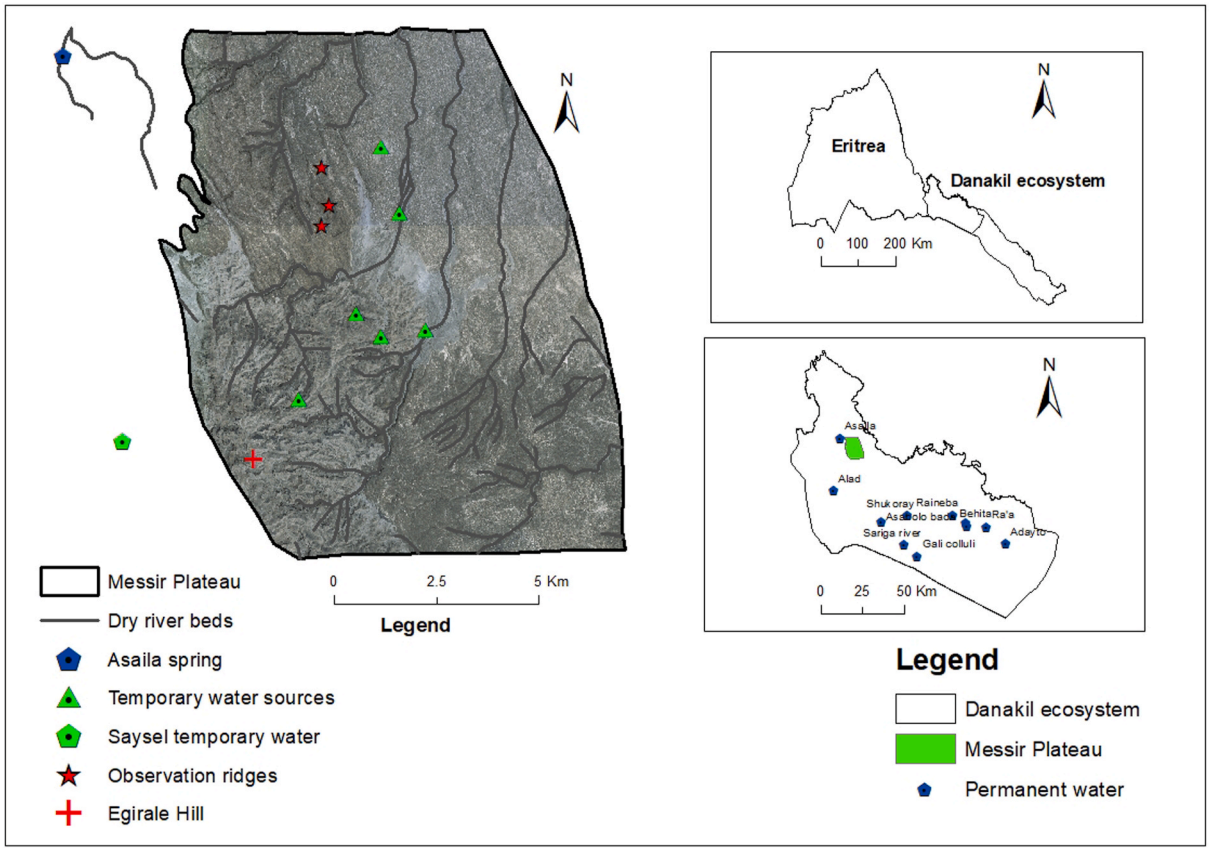

Fig. 1. Map of the study area (Messir Plateau) showing the location of the permanent water source Asaila spring and at least six temporary water sources that occur after rainfall events, and other permanent water points in the Danakil ecosystem (Eritrea). Asaila spring is the nearest permanent water available for the African wild ass occurring on the Messir Plateau. The second closest permanent water source is 'Alad' at distance of 30 km to the southwest of the Messir Plateau at the bottom of the western escarpment.

2. Materials and methods

2.1. Study site

The study was conducted on the Messir Plateau (15°00′ N, 40°02′ E) in the Danakil ecosystem (Fig. 1) from October to December 2016, March to June 2017, February to April 2018 and January to March 2019. The Danakil ecosystem is classified as a semi-desert or desert climate zone in Eritrea and Ethiopia (Department of Land, 1998; Kebede et al., 2014). The climate of the study area is arid with extremely hot summers which have a mean daily maximum temperature of 35 °C and peaks of 45 °C between June and September. During the study period, the mean daily temperature was 26.9 °C in wet/rainfall months and 30.2 °C in dry months (Tesfai, personal observation). Mean annual rainfall averages about 160 mm with a high annual variability (coefficient of variation: 0.73 over 50 years) as recorded at the Massawa meteorological station (Ministry of Agriculture, 2002). In rainfall months the plains area of Messir Plateau has relatively better vegetation cover than higher on the plateau and water is widely available (Tesfai, 2006). The Asaila spring, a perennial water source, is located approximately 9 km northwest of the plains area of the Messir Plateau (Fig. 1). During the study periods, sunrise was around 06h00 and sunset at about 18h00 with dawn and dusk being approximately 20 min before and after.

Reliable monthly rainfall records were not available for the study area during the study period. Therefore, we obtained the 'Climate Hazards Group Infrared Precipitation with Station' (CHIRPS) monthly data at 0.05° (5 km) spatial resolution (U.S. Agency for International Development, USAID, 2019) from an online portal (https://earlywarning.usgs.gov/fews) (Table 1). These rainfall data are created by combining satellite data, interpolation of rain gauge data and topographic information of a given area. These rainfall data were then correlated with the field observation reports (Tesfai, personal observation). Fieldwork was conducted from October to December 2016 when the study area was dry. From March to June 2017 there were showers. In 2018 (February to April) and 2019 (January to March) the area experienced no rainfall, except for isolated showers (Table 1).

2.2. Water source availability to the African wild ass on the Messir Plateau

To determine if there were any permanent water sources other than Asaila spring, an intensive survey, on foot and with camels, was conducted between January and March 2019 within a radius of approximately 30 km to the west and south of Messir Plateau. East and north of Messir Plateau are settlement areas, and there is no available water except some water wells and boreholes which are not accessible to wildlife because they are covered by wood or concrete. The next nearest available permanent water source (Alad) is at a distance of 30 km southwest from Messir Plateau (Fig. 1). This water source is in an extremely rocky area and the nearest source of vegetation is at a distance of approximately 15 km.

Therefore, during the field work from October to December 2016 (dry months), the only available water source for the African wild ass on the Messir Plateau was the Asaila spring. In rainfall months from March to June 2017 at least six temporary water sources were located on the lower elevation plains area of the Messir Plateau (Fig. 1). The following year (February to April 2018), there was no surface water, and the Asaila spring was again the only available water source for the African wild ass on the Messir Plateau. From January to March 2019 the area again experienced low rainfall, with only isolated showers which created temporary water on the Messir Plateau and at Saysel for a few days (Fig. 1).

In March 2019, the distribution pattern of the African wild ass was concentrated to the southwest of the Messir Plateau and animals were observed travelling towards Saysel water point late in the afternoon or at night. Therefore, during the field work in March 2019, Saysel water point (Fig. 1) was targeted for collecting drinking data. During the day the plains area close to Saysel was monopolized by livestock and people.

Table 1
Monthly rainfall on the Messir Plateau for the study period. Data obtained from CHIRPS online portal (https://earlywarning.usgs.gov/fews). Two camera traps were used at seven different water sources (one permanent and six temporary) to monitor the drinking behaviour of African wild ass on Messir Plateau, Eritrea (Oct 2016–Mar 2019).

Year	Rainfall (mm)	Water sources	African wild ass observed (number)	Method used	Days of observation
Oct–Dec 2016	0 (Dry)	Asaila	10 Adult females 1 Territorial male	2 camera traps	19
Mar–Jun 2017	24 (wet)	6 temporary water sources	15 Adult females 1 Territorial male 3 Bachelor adult males	Direct observation and 2 camera traps	22
Feb–Apr 2018	0 (Dry)	Asaila	17 Adult females 1 Territorial male 1 Sub-adult male	2 camera traps	21
Jan–Mar 2019	0 (Dry, except isolated showers in Jan and Mar)	Asaila and 1 temporary water source	17 Adult females 1 Territorial male 2 Bachelor adult males 1 Sub-adult male	2 camera traps and direct observation	21
Total			**29 (24 females and five males)**		**83**

Note. In 2019 two bachelor males and two non-reproductive adult females were observed around the Alad permanent water which is approximately 30 km from Messir Plateau (Fig. 1). However, it was difficult to determine their identity and confirm if these individuals had been observed on the Messir Plateau.

2.3. African wild ass data collection

Field research on the African wild ass in the Danakil Desert presents many physical challenges. The habitat is remote, extremely rocky and the climate is very hot. Conventional sampling methods for monitoring a large herbivore population for an extended period of time are not possible because African wild ass are few in number and scattered in small isolated groups. Direct observation and camera traps were used to collect drinking data (Table 1). To ensure that the maximum population size was sampled, all African wild ass in the study area were identified by their unique leg stripes. Individual ID sheets were drawn in the field and photos of individuals from both sides were recorded throughout the study period. This was a pre-requisite to ensure that each individual's records were independent and to avoid double counting of individuals during sampling. Foal age classification photos for the African wild ass supplied by the Saint Louis Zoo (USA) were used to distinguish between a foal of less than 3 months and one above three months. Approximate birth dates of the foals born on Messir Plateau were known and recorded by the local scouts who monitor the study area regularly. The pregnant

females recorded during the study period were in their last trimester and they were easily individually identified.

Previous research indicated that births in African wild ass on the Messir Plateau peaked between December and April (1995–2007) (Tesfai, 2006; Moehlman, personal observation). Therefore, the drinking behaviour data collection on the African wild ass on the Messir Plateau was planned for the months from December to April. However, only two females were observed with young foals (aged $\leq$ 3 months) between February to March in 2017, and one in early 2018. In 2016, 2018 and 2019, a total of seven females with older foals (4–12 months) were observed. Females and foals were individually identified and the three females with young foals were observed the subsequent year with their yearling offspring. Four of the seven females with older foals were observed the subsequent year and the foals had survived and were yearlings (12–24 months). This is a limited sample size but provides crucial detailed data on drinking behaviour of lactating females. A total of twenty-four individual adult females (in each year a minimum of 10 and maximum of 18) and their foals and five adult and sub-adult males were identified (Table 2) and monitored. This represents the maximum adult population utilizing the Messir Plateau from Oct 2016 to Mar 2019. Previous research documented approximately 18 individual adult females at any one time in the study area (Moehlman et al., 1998; Moehlman, 2002; Tesfai, 2006).

The study project had two Reconyx Hyperfire HC500 camera traps. We moved the two camera traps to seven different locations at different times to document individual female visits to water. Females with young foals and females with older foals and yearlings were easily identified (see above) when accessing water sources. In dry months, camera traps were sited on both sides of the narrow main access path at approximately 3 km from Asaila spring for at least three to five successive days. Camera traps were also placed closer to Asaila (10–20 m), but few data were recorded because the water point is about 25 m by 80 m and camera traps could not provide full coverage. The detection range of the Reconyx camera is about 60 ft (18.29 m). The camera traps recorded date and the time per photo of each individual African wild ass walking to and from Asaila spring. The narrow path site was selected based on previous observations that females with young foals and other resident females and males used this route from the Messir Plateau to travel to Asaila. During rainfall months, when temporary water points were available on the Messir Plateau, direct observations were used to document individual female visits to water during the day. A temporary water point was selected based on the presence of fresh African wild ass faeces and hoof prints. African wild ass hoof prints are larger than those of domestic donkeys. Direct observations and camera traps were used at the targeted temporary water sources for multiple 24 h periods to document individual African wild ass drinking behaviour during the day and at night. The same sampling technique was repeated at all the six temporary water points within the study area. The two camera traps were shifted to a targeted temporary water source and monitored for at least three successive days for a total of 22 days of observation.

Although the field survey for drinking behaviour was focused on the Messir Plateau, some individuals were observed going to Saysel temporary water source (Fig. 1). Hence, camera traps were deployed outside the study area at the Saysel temporary water source for a total of 13 successive days when isolated erratic rainfall was reported in that area in late April 2018 and March 2019. Only one female with a young foal was documented travelling about 4.4 km to the Saysel water point (Table 1). Females with older foals and non-reproductive females and males were recorded at Saysel water point for several days in late April 2018 and March 2019 (Table 1; Appendix A.6). The total field days of observations (direct observation and camera traps) documenting African wild ass drinking data on the Messir Plateau are provided in Table 1.

To estimate the distance travelled to water sources, African wild ass were located by scanning the entire study area (approximately 124 sq km) from the highest ridges (220 m above sea level), using a Nikon field scope and/or 7 × 42 binoculars during the early hours of the day (05h00 – 06h00). If any individual African wild ass was spotted on the plains area, we walked to the site using GPS navigation and geographical features and recorded the individual and its location. If no individual was spotted from the first high view point, we walked to the 2nd and 3rd ridges (201 and 150 m a.s.l. respectively) and scanned the area again (Fig. 1). If it was still not possible to visually locate any African wild ass, we walked to the plains area (approximately 100 m a.s.l.) and followed tracks of fresh hoof prints to locate the African wild ass foraging sites. Individual African wild ass leaving the Asaila water source usually walked over the high ridges (Fig. 1) in the early hours of the day and descended to forage on the plains area. They started to walk back to water from the plains late in the afternoon or evening. These movements were regularly observed on the Messir Plateau (Tesfai, personal observation). Once an African wild ass was located and confirmed foraging, individual identification (ID), date, ambient temperature and GPS location of the site were recorded using a Garmin Montana 600™ Global Positioning System (GPS). For each observed individual African wild ass, the travel distance between the morning foraging location and the closest water point was calculated.

Table 2
Individual African wild ass observed during the field period on Messir Plateau (Oct 2016–Mar 2019).

Reproductive status	Observed African wild ass			
	2016	2017	2018	2019
Female with young foals	0	2	1	0
Female with older foals	2	0	3	2
Female with yearlings	3	2	2	2
Pregnant female	3	1	1	0
Non-reproductive female	2	10	10	13
Territorial male	1	1	1	1
Bachelor adult male	0	3	0	2
Bachelor sub-adult male	0	0	1	1
Total	**11**	**19**	**19**	**21**

2.4. Data analysis

2.4.1. Frequency of visits to water

Drinking frequency per individual per water source (dry vs. rainfall months) was obtained by calculating the number of visits to water of an individual over successive days of observation. Drinking interval was estimated for each individual by calculating the number of hours between the 1st visit and the 2nd visit, the 2nd visit and the 3rd visit up to the last visit for successive days of observations. Subsequently, we calculated the mean, minimum and maximum drinking intervals per individual, for permanent (dry) and temporary water points (rainfall months) separately. When only one drinking observation was made, the minimum interval was based on the number of successive days of observation. To determine whether the mean number of visits (frequency) to water (dry vs. rainfall months) was affected by water source (permanent vs. temporary) and if it differed between sex and reproduction categories, loglinear analyses were performed. Each individual was classified into one of five female reproductive categories (adult female with young foal, adult female with older foal, adult female with yearling, pregnant female and non-reproductive female) or male. The male group was classified into three categories (territorial, bachelor adult and bachelor sub-adult males) because of differences in their interactions with the females and as a basis for comparison with the drinking frequency of females. The territorial male was usually observed on the plains area of the Messir Plateau and/or going to water with adult females. Bachelor adult males were occasionally seen on the Messir Plateau and recorded going to Asaila spring once per several days.

The daily maximum and minimum temperatures of each observation day for each sex and reproduction categories (Appendix A.1-4) were subsequently compared with number of visits (frequency) and time of visits to water sources using Kruskal-Wallis test to identify any

significant differences at the 95% significance level ($P < 0.05$) between drinking frequency and time of visits to water sources vs maximum and/or minimum daily temperature.

2.4.2. Time of day and drinking behaviour

The time of the visit to water sources (permanent vs. temporary) for each female and male category was assigned to one of four-time categories (18h00 – 24h00; 00h00 – 06h00; 06h00 – 12h00 and 12h00 – 18h00) and subsequently the proportion of visits in each time category was calculated for each female and male category.

2.4.3. Distance travelled to water

The travel distance to water was estimated by measuring the distance between the morning foraging location and the closest water point using the geographic information system [ArcGIS 10.5] (ESRI, 2017) distance and proximity (near) analysis tool. We calculated the mean, minimum and maximum travel distances per individual for permanent (dry) and temporary water points (rainfall months) by day separately. Each individual was classified into one of the female or male categories as described above in section 2.4.1. To test if there was a significant difference in the mean distance travelled to permanent (dry) vs. temporary water points (rainfall months) between the five female and three male categories a Generalized Liner Model (GLM) repeated measures procedure was used and the effect of the number of observations (co-variate) was controlled in order to remove/minimize a sampling bias in the data collection. Each individual observation of distance travelled to water sources (independent variable) represents one data point. All statistical analyses were carried out using STATISTICA 8.0 software (Tulsa, OK: StatSoft, USA).

3. Results

3.1. The African wild ass population and permanent water sources on the Messir Plateau

Two hundred and fifty-three camera trap photos recorded individual African wild ass travelling to water in 2016, 2018 and 2019 when Asaila spring was the only available water source. However, only 87% of the photos provided a reliable identification of individuals. Twenty-four females and five males were recorded for 83 days during four study years. All individual African wild asses identified and monitored for the drinking behaviours are provided in Appendices A.1-4.

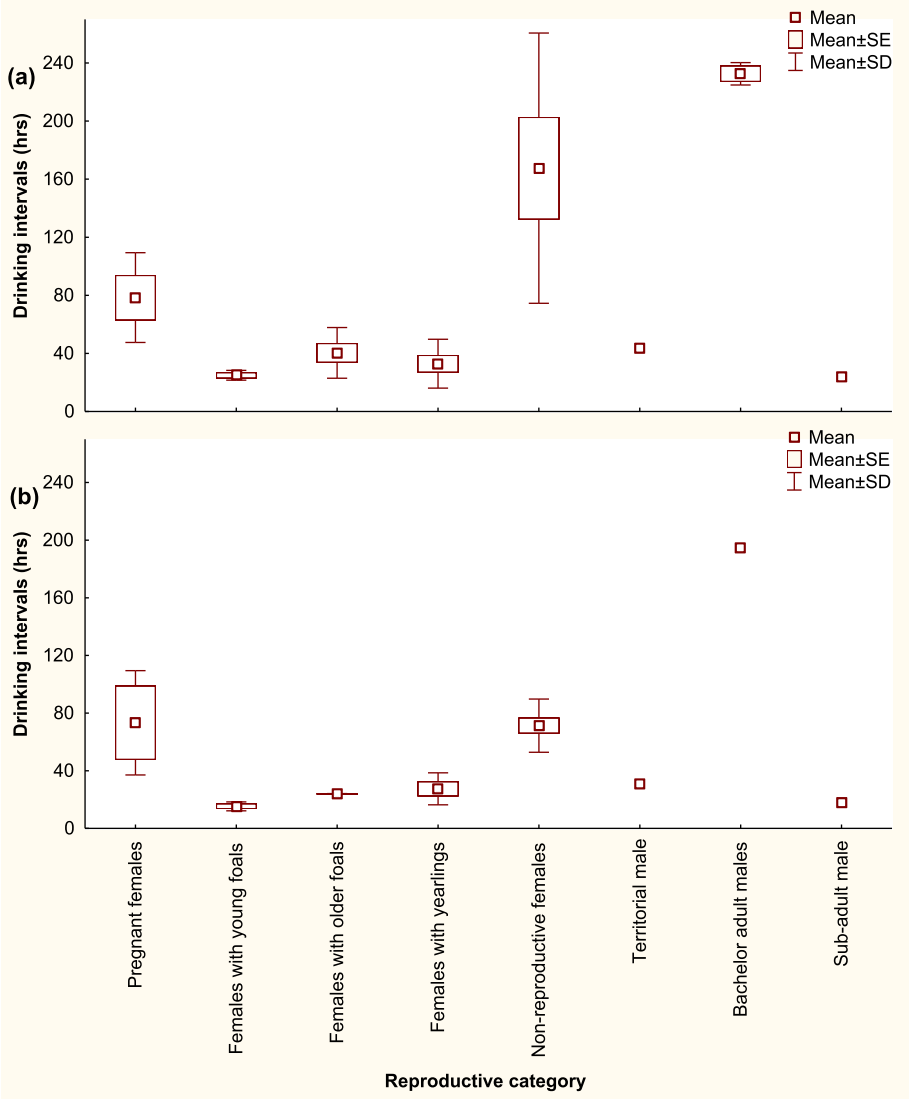

Fig. 2. Mean drinking intervals (hrs) between successive visits to water sources (dry vs. rainfall months) per each sex and reproductive category of African wild ass on the Messir Plateau, Eritrea. (a) when Asaila spring was the only available water source for the African wild ass on Messir Plateau (Oct–Dec 2016, Feb–Apr, 2018 and Jan–Mar 2019), and (b) when temporary water sources were available on Messir Plateau from March to June 2017 and in January and March 2019.

3.2. African wild ass frequency of visits to water sources

The number of visits (frequency) to water sources differed significantly between the eight sex and reproduction categories ($\chi^2 = 111.24$, df = 7, $p < 0.0001$), but did not differ between permanent (dry months) and temporary water sources (rainfall months), except for females with young foals ≤ three months. Females with young foals visited temporary water sources more frequently when they were available compared to visits to Asaila spring during the dry months ($t = 3.68$, $p = 0.0213$, Fig. 2). During the dry months of 2017 and 2018 (Fig. 2a; Appendix A.2 and 3) female African wild ass with young foals (n = 3) were recorded by camera traps travelling daily to the Asaila water (Fig. 2a; Appendix A.3). When temporary water sources were available in 2017, females with young foals (n = 2) travelled to water twice as often as other adult females (Fig. 2b; $p = 0.0028$). Four of the females with older foals (i.e. F2016-6; F2016-7; F2016–10 and F2017-3) were recorded by camera traps travelling daily to the Asaila water during dry months (Appendix A.1, 3 and 5). The other three (F2016-3; F2018–1 and F2018-2) were recorded by camera traps travelling to Asaila every two to three days when the foals were older (Appendix A.3 and 4). Females with older foals were observed visiting temporary water every day in 2017 (Fig. 2b; Appendix A.4 and 5).

Out of the nine females with yearlings, eight (3 in 2016; 2 in 2017; 2 in 2018 and 1 in 2019) were recorded by the camera traps travelling daily to the Asaila spring in dry months (Fig. 2a; Appendix A.1-5) but were observed visiting temporary water every-one to two days (Fig. 2b; Appendix A.4 and 5). No drinking data were recorded for the other female (F2016-3) with yearling (Appendix A.4) even though this female and her yearling were observed on Messir Plateau during the field study in 2019.

During dry months, pregnant females were observed visiting the Asaila spring every two to ten days (Fig. 2a; Appendix A.1,3 and 5) and they visited temporary water sources every two to four days (Fig. 2b; Appendix A.2 and 5). Limited data indicate that non-reproductive

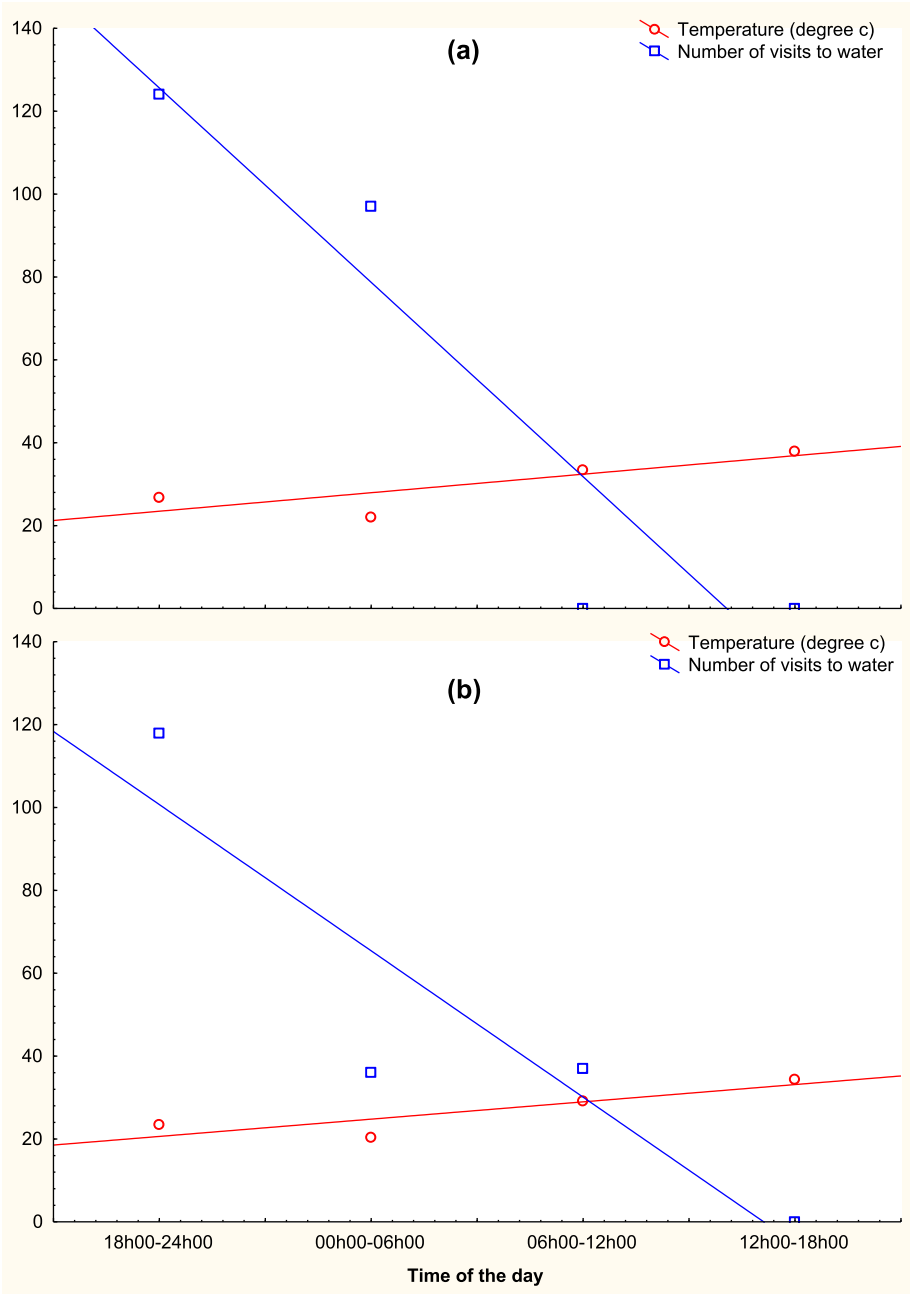

Fig. 3. Temperature vs. time of visits to water sources (permanent vs temporary) of reproductive category of African wild ass on the Messir Plateau, Eritrea. (a) when Asaila spring was the only available water source for the African wild ass on Messir Plateau (Oct–Dec 2016, Feb–Apr, 2018 and Jan–Mar 2019), and (b) when temporary water sources were available on Messir Plateau from March to June 2017 and in January and March 2019. In dry months the time was recorded by camera traps when African wild ass were travelling to Asaila and during the rainfall months data were recorded at the temporary water sources.

females visited the Asaila spring during the dry months every five to ten days (Fig. 2a; Appendix A.5) and visited the temporary water sources every three days (Fig. 2b; Appendix A.5).

Only one territorial male was observed on the Messir Plateau throughout the study period (October 2016–March 2019). During the dry months he was recorded travelling to the Asaila spring about every second day and he travelled daily to temporary water sources (Fig. 2a and b; Appendix A.1-5). The three bachelor adult males were occasionally observed on Messir Plateau and recorded going to Asaila spring once per seven to ten days in dry months and once per seven days to seasonal water.

3.3. Time of the day African wild ass visit water sources

The time of day African wild ass visited water showed no significant correlation with temperature both in dry ($r = 0.8236$, $p = 0.1764$) and wet months ($r = 0.8705$, $p = 0.1295$). Out of the total of 221 photos of containing African wild ass travelling to Asaila water source, 124 (56.1%) were taken between 18h00 and 24h00 and 97 (43.9%) between 00h00 and 06h00 (Fig. 3a). During the wet months females with young foals and other females and males were observed visiting the temporary water sources during the night and into the early hours of the day (Fig. 3b). Out of the total of 191 camera trap photos and direct observations of African wild ass travelling to temporary water sources, 118 (61.1%) of the observations were recorded between 18h00 and 24h00, 36 (18.8%) between 00h00 and 06h00, and 37 (19.4%) during the day from 06h00–12h00 (Fig. 3b).

3.4. The travel distance of African wild ass to water sources

In the rainfall months when temporary water sources were available, the travel distance from the foraging area to the water source was significantly less (average distance and standard error) than the travel distance to the permanent water source during the dry months (average distance and standard error) (Wilks' Lambda: $H = 35$; $df = 1$, $P \leq 0.012$; Fig. 4a and b, Appendix A.6). In rainfall months from March to June 2017 when six temporary water sources were located on the Messir Plateau, two females with young foals were observed within 3 km of the water source but were observed at a distance of up to 7 km when livestock arrived on the plains area annually from the highlands when there was sufficient rainfall ($N = 60$, Fig. 4b; Appendix A.6). During the dry months females with young foals were found on average at a distance of about 9 km from Asaila permanent water ($N = 36$, Fig. 4a; Appendix A.6).

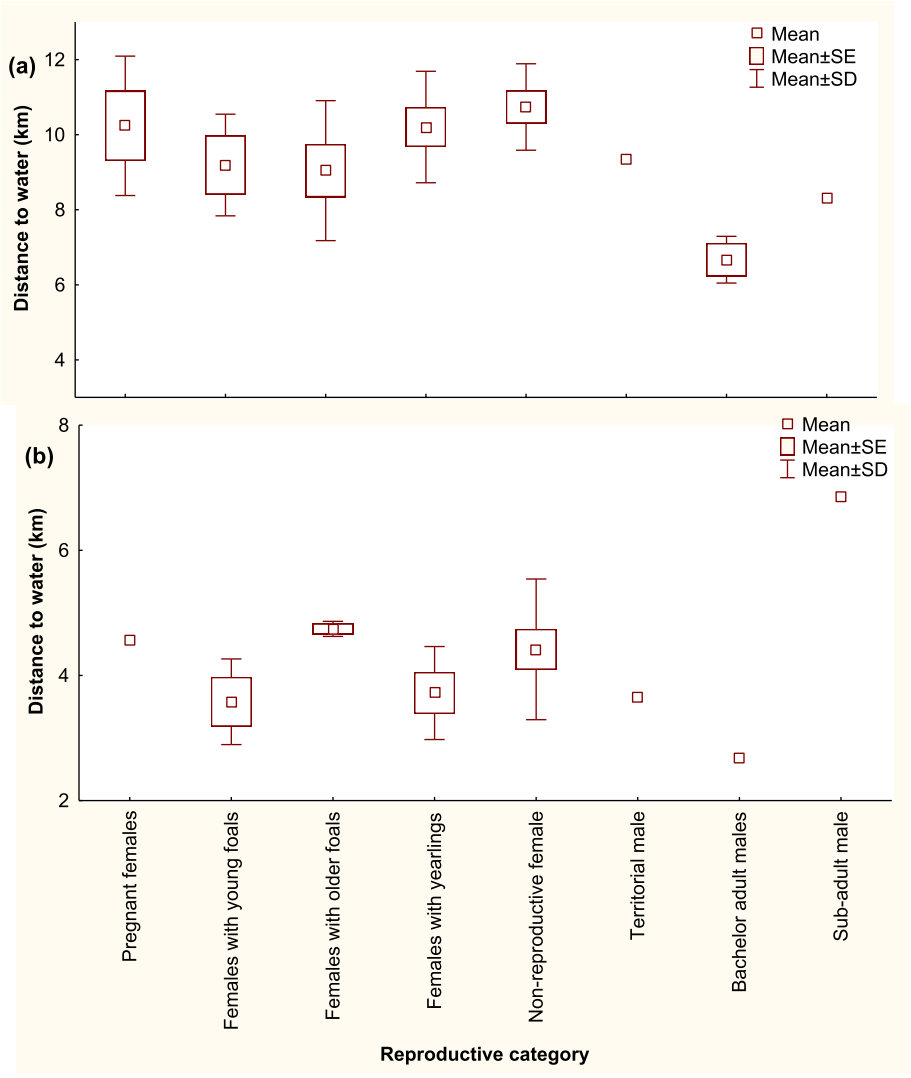

Fig. 4. Travel distance between morning foraging and drinking sites (dry vs. rainfall months) for each sex and reproductive category of African wild ass on the Messir Plateau, Eritrea. (a) when Asaila spring was the only available water source for the African wild ass on Messir Plateau (Oct–Dec 2016, Feb–Apr, 2018 and Jan–Mar 2019), and (b) when temporary water sources were available on Messir Plateau from March to June 2017 and in January and March 2019.

4. Discussion

Asaila spring was the only permanent water available year-round on the Messir Plateau. During the dry months females with young foals, and females with older foals visited this water source daily. Pregnant females, females with yearlings, non-reproductive females and males visited the water source at longer intervals, i.e. one to nine days. Females with foals are lactating and physiological constraints would select for more frequent drinking behaviour in order to provide sufficient milk for their foals (Loudon and Kay, 1984; Becker and Ginsberg, 1990). During the wet months, females with young foals were documented visiting temporary water sources more frequently than they had visited the Asaila spring during the dry months and twice as often as other females and males. The more frequent visits to water sources during the wet period, when it is cooler than in the dry period, is probably due to their closer proximity to grazing areas. The frequency of visits by females with older foals, non-reproductive female and males did not differ statistically between dry and rainfall/wet months.

During the dry months some pregnant females, non-reproductive females and bachelor adult males were not recorded at Asaila spring for several days (n = 9). The reason for these long intervals may be because they were 'photographed' by the camera trap, but not identified or they travelled to this water source by a different path. Females with foals were more easily identified. Grevy's zebra females often leave their foals behind in a 'creche' while they travel to water which may be an adaptive behaviour to reduce the risk of predation (Becker and Ginsberg, 1990). But African wild ass were do not observed leave their foals behind (i.e. crèched) when travelling to water during the night. Non-reproductive females and bachelor males are seen on the Messir plateau but may not need to travel frequently to water. These individuals may be foraging farther from the Messir plateau and utilizing other permanent water sources such as Alad, Asabolo-bada and Shukoray (Fig. 1). This finding is similar with information on another wild equid that occurs in an arid habitat: Grevy's zebra. Rubenstein (2010) and Sundaresan et al. (2012) documented that most Grevy's zebra in Laikipia, Kenya did not go to water for up to five days, but females with young foals were observed drinking daily.

In our field study, African wild ass visited the permanent water source 'Asaila' only at night, probably because it is in an area close to settlements and livestock. In dry months, people and livestock were observed near Asaila during the day (Tesfai, personal observation). Previous studies in the Danakil ecosystem, both in Eritrea and Ethiopia, have indicated that African wild ass visit water points that are near to human settlements and domestic livestock only during the night when these localities are free from disturbance by people and livestock (Kebede, 1999; Tesfai, 2006). Travel at night when temperatures are cooler may be less costly energetically and physiologically, but may result in an increased risk of predation. However, the incidence of predation on African wild ass by spotted hyena on Messir Plateau is currently very low or non-existent (Tesfai et al., 2019). When water sources are monopolized by domestic livestock, Grevy's zebra in Kenya are forced to drink at night (Williams, 2002). This is in direct contrast to those in protected areas, where the Grevy's zebra drink during a brief window of time during the middle of the day (Williams, 1998, 2002).

During wet months when temporary water sources were available and distant from human settlements and livestock, lactating female African wild ass on the Messir Plateau sometimes visited temporary water sources during the day (06h00-12h00). In rainfall months, African wild ass, particularly females with young foals, were observed within 3 km of the nearest temporary water point, but were found at a greater distance (up to 7 km) when there were high concentrations of livestock, particularly cattle, in this area. This was apparent soon after the rains began in May 2017 when an estimated 150 cattle arrived in the area from the highlands (Tesfai, personal observation).

In dry months, lactating females foraged at mean distance of 9 km from the only available water source. Approximately 200 km to the south in the Danakil in Ethiopia, Kebede et al. (2014) observed African wild ass within a radius of 10–25 km from permanent water sources in an area of high livestock abundance. In the Danakil, African wild ass live in an arid environment where grass occurs in widely dispersed patches and displacement by livestock may limit access to water and quality forage. This spatial exclusion from water sources due to livestock presence may reduce the ability of African wild asses to provide sufficient milk to their foals. Availability and accessibility of adequate and quality forage closer to water can affect nutrition and energetic costs. Becker and Ginsberg (1990) suggested that wild equids in arid areas may reduce milk production when females are denied access to water sources and adequate forage. In our study, lactating females with young and older foals travelled to water daily. In rainfall months, the study area had widely distributed temporary water sources (Tesfai, 2020). Females with foals went more frequently to water and travelled shorter distances.

During rainfall months, the territorial male (M2016-1) was usually observed in the plains area close to temporary water. This may increase his access to females in estrous that are located near the temporary water sources. Females with young foals were usually seen in association with other females and the territorial male in plains area. Non-reproductive females and bachelor males were seldom observed in the plains area, especially when livestock were present in the dry months. Non-reproductive females and bachelor males may be less dependent on access to water and can travel farther to find better foraging areas not used by livestock.

This study and a previous study by Williams (1998) indicated that travelling long distance to access forage and water because of the presence of livestock may compromise foal survival and recruitment of endangered equids in arid habitats. Therefore, any conservation strategies for rare and endangered herbivore species such as the African wild ass in the Danakil Desert should consider the impact of domestic herbivores, particularly cattle on access to water sources and forage. The sustainable use of Asaila for humans and wildlife is crucial. Artificial water points are often constructed to attract wildlife in a protected area (Owen-Smith, 1996). However, the establishment of water points for the African wild ass on Messir Plateau is not a good option because of potential major negative repercussions of attracting more livestock.

CRediT author contribution statement

Redae T. Tesfai: Conceptualization, Methodology, Formal analysis, Data curation, Writing - original draft, Conceptualized the research work and development or design of methodology, collected the data, analysed the data and determined the results, prepared the first draft of the manuscript and led the subsequent revisions. **Francesca Parrini:** Supervision, Formal analysis, Data curation, Writing - original draft, Supervise/ oversight and guidance for design the research work, analyzing data and participated/contribute on revision of the draft manuscript and subsequent revisions. **Norman Owen-Smith:** Supervision, Formal analysis, Data curation, Writing - original draft, Supervise/ oversight and guidance for design the research work, analyzing data and participated/contribute on revision of the draft manuscript and subsequent revisions. **Patricia D. Moehlman:** Supervision, Formal analysis, Data curation, Writing - original draft, Supervise/ oversight and guidance for design the research work, analyzing data and participated/ contribute on revision of the draft manuscript and subsequent revisions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaridenv.2020.104327.

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