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SECTION A: RESEARCH ARTICLES

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Drinking and bathing behaviour of raptors in an arid, warm environment: Insights from a long-term camera trapping study in Namibia

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ABSTRACT

Raptors are thought to obtain much of their water from their food as pre-formed and metabolic water, and therefore not by drinking. However, there are few publications about their behaviour at waterholes to test this idea. This study analysed 6 291 camera trap observations of raptors over 11 years at waterholes in a game reserve located in the warm, arid environment of north-central Namibia. Of 45 species recorded in the area, 12 were never recorded at water, whereas another 13 species were recorded 100 or more times at water. While there, raptors spent most time drinking, standing in the water, or bathing. Diurnal raptors usually visited water in the middle – and heat – of the day while owls were present throughout the night. Most visits to water were between May and November which were the driest months of the year. We found a strong inverse correlation ($p < 0.0001$) between the number of visits and the relative humidity in that month, suggesting that water balance is an important factor driving this behaviour. In general, these findings indicate that many raptors make much greater and seasonally changing use of water than is commonly assumed and appear to do so to help meet their physiological needs for water and thermoregulation. Many other raptors, including most falcons and kestrels, however, have little or no need for drinking or bathing, begging answers to questions about why and how these differences and variations exist. This paper also raises questions about how raptors that visit water frequently will respond to increasing heat and aridity.

Keywords: aridity; bathing; birds of prey; cooling; drinking; heat; Namibia; rainfall; raptors; water requirements

INTRODUCTION

Most terrestrial vertebrates obtain water by drinking or from their food. The majority of raptors are thought to use the latter strategy, using pre-formed water in their food and water produced by the metabolism of food (Houston *et al.* 2007). The general paucity of observations of drinking by birds of prey (Boal *et al*. 2023) supports this assumption. Other than Boal *et al.* (2023), we know of only three substantive papers on drinking by raptors, each focused on one species (Haak *et al.* 2013, Kassara *et al.* 2023, Schoenjahn *et al.* 2024). Slightly more has been published on bathing by raptors; in addition to information on bathing in Boal *et al.* (2023), Haak *et al.* (2013) and Kassara *et al.* (2023) there are studies on bathing by Ristow *et al.* (1980), Holthuijzen *et al.* (1987), Schmidl (1988), Eisermann (2005) and Sazima (2018). Other anecdotal mentions of drinking and bathing are to be found in natural history studies, and falconry handbooks often describe the need to supply captive raptors with drinking and bathing water (e.g. Chitty 2008).

While raptors of some species very seldom or perhaps never visit surface water to drink, bathe or cool themselves (e.g. Schoenjahn *et al.* 2024), other raptors that make frequent use of free water may face challenges in arid environments where surface water from rain is generally seasonal and ephemeral, and access to artificial and modern water sources (such as waterholes) is often compromised, for example by the presence of congregations of larger animals. Water intake is crucial for homeostasis and animals living in these arid environments therefore need reliable strategies to acquire water. These needs may become more critical as arid parts of the earth become hotter and drier.

This paper provides information from a substantial volume of data on the daily and seasonal timing of drinking and bathing by a community of 33 raptor species in an arid environment. Another 12 species of birds of prey recorded in our study area were never recorded at water. The information presented here was recorded from images taken by camera traps placed at 12 waterholes over 11 years in northern-central Namibia, in southern Africa.

METHODS

The data were collected on the 30 000 hectare Ongava Game Reserve (or just Ongava) on the southern boundary of Etosha National Park (the centre of Ongava is roughly at 19.36 South, 15.84 East). Ongava lies about 1 100 masl in a mosaic of flat ground and gently sloping dolomite hills. About 70% of the reserve consists of shrubland and woodland dominated by mopane (*Colophospermum mopane),* purple-pod terminalia (*Terminalia prunioides)*, sicklebush (*Dichrostachys cinerea)*, trumpet-thorn (*Catophractes alexandri)* and red bushwillow (*Combretum apiculatum)*. Grass cover dominates the remaining 30% of Ongava (Figure 1).

Ongava's climate is semi-arid with an average annual rainfall of 380 mm, most of it falling in summer thunderstorms at irregular intervals between December and March (Figure 2). During these wetter months some surface water may be available in short-lived pools of rainwater and dams which soon evaporate or seep into the soil. During the dry season (May–November) surface water is only available at artificial waterholes. At Okaukuejo, 25 km north and at the same elevation as Ongava, average relative humidity at 14h00 ranges between 22% in the dry season and 44% during the wet season (Figure 2). Air temperatures are highest between September and December with average daily highs of 35°C. June is the coolest month of the year when average daily maxima are around 25°C, and night temperatures can drop to freezing point.

We collected data at 12 artificial waterholes distributed between largely open, grass covered areas and light bush and wooded areas elsewhere (Figure 1). Images were captured by Reconyx cameras (RC-55 and HC-500 models) deployed at the waterholes to record visits of mammals. Typically, several cameras were stationed to monitor each waterhole simultaneously. The cameras were generally placed between 5 and 20 metres from the water. Two sets of data collected between July 2009 and October 2019 were available for analysis. The first was from cameras deployed periodically, but more often between May and October than in other months. The second set was collected from cameras deployed continuously over longer periods of up to 20 months at five waterholes (Appendix 1). Both sets provided information on the species visiting water, but analyses of diurnal variance were limited to the 13 species recorded over 100 times at waterholes (Table 1). Information on seasonal changes in behaviour and frequency of visits were derived from the second set but limited to nine species with over 50 independent observations collected at the five waterholes and normalised by the number of days that were monitored by camera traps (Appendix 2).

The data from the camera traps were extracted using the Ongava Research Centre Geo Data Management System (GDMS) camera trap analysis software which processes image sequences collected simultaneously by several cameras and collates data on the species, numbers of individuals and activities seen during discrete bouts of activity (Zett *et al.* 2023). We configured the camera traps to record a burst of 10 images, separated by 1–3 seconds, for each motion-triggered sequence. We set a minimum delay interval of 30 seconds between bursts. All images and their meta-data (dates, times, locations, etc.) were then stored in a database which could be analysed using a range of filters and sorting criteria. For our raptor data set, all relevant images were exported for further analysis with their meta-data. Times reported in this paper are in the GMT + 2 time zone.

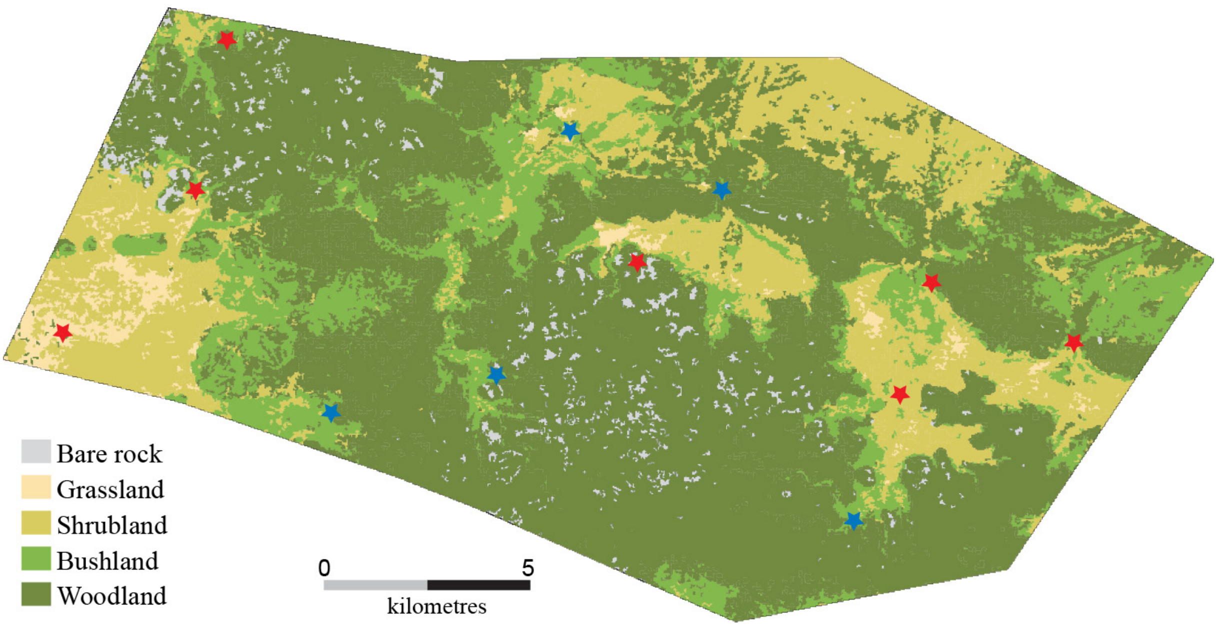

Figure 1: *The vegetation structure (de Cauwer* et al*. 2024) of Ongava Game Reserve and the 12 waterholes at which camera traps were deployed. Intensively monitored waterholes are shown by blue stars while red stars mark those which were less intensively monitored.*

The original dataset often contained multiple images from the single visit of a raptor, usually of images taken each time the bird's movement triggered one or more of the cameras. The data from images of the same species with the same age at the same waterhole within a 30-minute period were assigned to a single independent *observation*. We recorded four types of activity or behaviour during each *observation*: drinking, bathing, standing in water, and standing nearby. During any single *observation* each of these activities was recorded once only, regardless of the number of times a bird performed them; four was thus the maximum number of different activities recorded during an *observation*.

Our data are subject to several biases and constraints which we cannot control, and which limited options to test certain ideas. For example, we have no measure of bias due to the sizes of raptors, since larger birds with bigger wings (such as eagles) would activate and be recorded more consistently by camera traps than smaller birds (goshawks and falcons, for instance). Similarly, drinking and bathing involve motion which camera traps would record more often than comparatively motionless standing in water. Whether the cameras were equally sensitive during the days and nights, respectively to diurnal and nocturnal birds, is not known. To what degree the frequency that raptors visit surface water reflects their use of water or their local abundance can't be tested. Of necessity, some cameras were placed closer to waterholes than others, likely increasing the chance of them being triggered by smaller birds at the water. Some independent observations may have been lost by filtering the data into discrete observations with a maximum duration of 30 minutes, but filtering was necessary due to the large number of images that would otherwise have been treated as independent visits. It is also not known what proportion of images were triggered by movements of raptors or coincidentally by larger mammals within view of the same cameras. Thus, for example, the number of birds recorded at water during the heat of the day may be inflated by the heightened presence of large mammals drinking in hot weather. Because motion triggered the cameras, bathing and splashing (see Figure 2) could be recorded more often than drinking when birds simply dipped their beaks briefly into the water, for example. Similarly, the proportion of behaviour recorded will have been biased by the duration of that behaviour relative to the sampling frequency of the camera. Finally, access to surface water varied between waterholes; some with large expanses and margins of water within easy reach of perches that birds could use as they approached the water, but other waterholes were smaller, more often crowded with large mammals, and perhaps less accessible to birds.

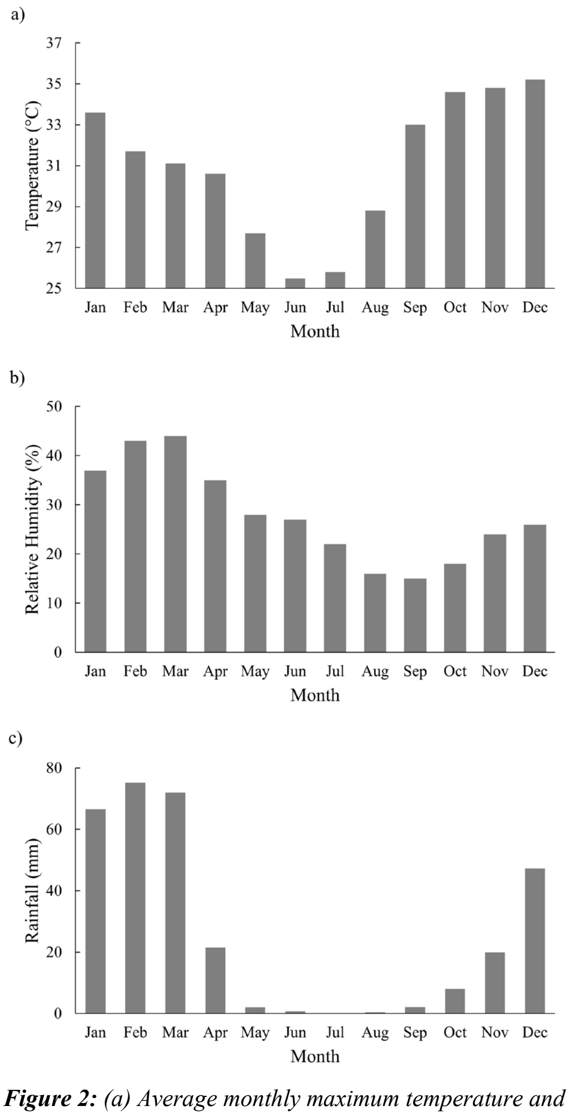

Figure 2: *(a) Average monthly maximum temperature and (b) relative humidity at 14h00 at Okaukuejo recorded by Namibia Meteorological Services http://www.meteona.com, and (c) average monthly rainfall at Ongava for 1981–2021 from https://www.chc.ucsb.edu/data/chirps.*

Sightings of raptors between 1987 and 2024 submitted to the Southern African Bird Atlas Projects (https://sabap2.birdmap.africa/) provided a measure of the presence of different raptors in the Ongava area against which records of raptors at waterholes in the reserve could be compared (Table 1). The SABAP data were limited to quarter-degree squares and pentads that overlie Ongava Game Reserve, each pentad covering an area of 5 x 5 minutes of latitude and longitude. Reporting Rate is a measure of the relative abundance of the species, given here as the percentage of times the species was recorded on full protocol cards.

These data also suffer from biases. For example, raptors vary in how easily they are identified, the times of day they and/or observers are active, the degree to which birds are easily sighted (or heard) or often inconspicuous, and how long different species are present during the year. The frequencies with which

Table 1: *Numbers of records and reporting rate of raptors in the SABAP1 (1986 to 1997) and SABAP 2 survey (2007–2024)*[1] *and photographed at waterholes by the Ongava camera traps. Records of the ten most frequently recorded species in each dataset are in bold.* migrant, ** vagrant.*

Common name	**Scientific name**	**SABAP records**	**SABAP reporting rate %**	**Records at water**
Pale-chanting goshawk	*Melierax canorus*	**116**	41.1	144
Tawny eagle	*Aquila rapax*	**89**	31.6	**524**
Bateleur	*Terathopius ecaudatus*	**61**	21.6	77
Secretary bird	*Sagittarius serpentarius*	**55**	19.5	**289**
Pearl-spotted owlet	*Glaucidium perlatum*	**54**	19.1	0
Lanner falcon	*Falco biarmicus*	**49**	17.4	2
Barn owl	*Tyto alba*	**47**	16.7	**324**
Greater kestrel	*Falco rupicoloides*	**45**	16	1
Gabar goshawk	*Micronisus gabar*	**42**	14.9	**395**
White-backed vulture	*Gyps africanus*	**39**	13.8	**353**
Lappet-faced vulture	*Torgos tracheliotos*	32	11.3	**196**
Black-chested snake-eagle	*Circaetus pectoralis*	26	9.2	**161**
Black-winged kite**	*Elanus caeruleus*	25	8.9	1
Red-necked falcon	*Falco chicquera*	19	6.7	1
Martial eagle	*Polemaetus bellicosus*	16	5.7	48
African harrier-hawk**	*Polyboroides typus*	15	5.3	15
African hawk-eagle	*Aquila spilogaster*	15	5.3	**2 928**
Shikra	*Accipiter badius*	14	5	100
Spotted eagle-owl	*Bubo africanus*	14	5	**148**
African scops owl	*Otus senegalensis*	11	3.9	0
Rock kestrel	*Falco rupicolus*	11	3.9	2
Common buzzard*	*Buteo buteo*	10	3.5	12
Black kite/yellow-billed kite*	*Milvus migrans/parasitus*	8	2.8	5
Brown snake-eagle	*Circaetus cinereus*	8	2.8	41
Pygmy falcon	*Polihierax semitorquatus*	8	2.8	0
Southern white-faced scops owl	*Ptilopsis granti*	6	2.1	1
Verreaux's eagle	*Aquila verreauxii*	6	2.1	**355**
Little sparrowhawk**	*Accipiter minullus*	5	1.8	2
Bat hawk**	*Macheiramphus alcinus*	2	0.7	0
Cape vulture**	*Gyps coprotheres*	2	0.7	2
Ovambo sparrowhawk	*Accipiter ovampensis*	2	0.7	2
Wahlberg's eagle*	*Hieraaetus wahlbergi*	2	0.7	0
White-headed vulture**	*Trigonoceps occipitalis*	2	0.7	8
Booted eagle**	*Hieraaetus pennatus*	1	0.4	0
Dark chanting goshawk**	*Melierax metabates*	1	0.4	0
Giant eagle-owl	*Bubo lacteus*	1	0.4	7
Hooded vulture**	*Necrosyrtes monachus*	1	0.4	0
Lesser kestrel*	*Falco naumanni*	1	0.4	0
Lizard buzzard**	*Kaupifalco monogrammicus*	1	0.4	0
Marsh owl**	*Asio capensis*	1	0.4	7
Peregrine falcon**	*Falco peregrinus*	1	0.4	0
Red-footed falcon*	*Falco vespertinus*	1	0.4	0
Augur buzzard	*Buteo augur*	0	0	139
Lesser spotted eagle*	*Clanga pomarina*	0	0	1
Steppe eagle*	*Aquila nipalensis*	0	0	1
TOTAL		865		6 292

[1]SABAP1 quarter-degree squares covering the Ongava Game Reserve were 1915BD and 1915BC for which 142 cards were submitted. For SABAP2 140 cards were submitted for the pentads covering the same area: 1915_1540, 1915_1545, 1915_1550, 1915_1555, 1920_2040, 1920_2045, 1920_2050, 1920_2055. The SABAP2 data were retrieved from https://sabap2.birdmap.africa/ on 10 August 2024.

different species were recorded (Table 1) thus only provide an approximation of their abundance in and around Ongava.

We used simple linear regression to test for relationships between selected dependent and independent variables. In each case we checked that the dependent variable was continuous and then normally distributed using the Shapiro-Wilk test (shapiro.test, R, V4.0.0, R Core Team, 2024). If this test showed that the distribution of the dependent variable was not significantly different from a normal distribution ($p > 0.05$), we used the Regression tool in Microsoft Excel to calculate correlation coefficients (r^2) and p-values; p-values < 0.05 were considered to indicate a significant linear relationship.

RESULTS

A total of 6 291 observations of raptors were recorded from 3 868 trap days (24h period) between July 2009 and October 2019. Of the 45 species recorded in and around Ongava, 34 were recorded at water and 13 of them were recorded 100 or more times at water (Table 1).

There was a considerable disparity between the species recorded by the SABAP surveys and those recorded at waterholes in the same area at Ongava (Table 1). We found no correlation between SABAP reporting rate (%) and our record counts ($r^2 = 0.0006$, $p > 0.5$). For example, African hawk-eagles and Verreaux's eagles were frequent visitors to water but seldom recorded by SABAP observers. Augur buzzards were recorded at water in 139 separate camera trap observations but were never reported in the SABAP data. Augur buzzards and Verreaux's eagles usually nest on tall cliffs, of which there are none in the Ongava area, but both are known to nest in trees (Hockey *et al*. 2005), as did at least one pair of Verreaux's eagles at Ongava (personal observations). We also found no correlation between the average mass for a raptor species (see Table 2) and our record counts ($r^2 = 0.0034$, $p > 0.5$, $n = 21$ for species counted more than 5 times).

The predominance of African hawk-eagles, which were recorded during 2 928 separate observations – or 46.5% of all the observations of raptors at water – was perhaps partly due to their relative abundance, there being three or four African hawk-eagle pairs resident on the Ongava Game Reserve, compared to one pair of martial eagles and secretary birds, and one or two pairs of Verreaux's eagles and black-breasted and brown snake-eagles (personal observations). Gabar and pale-chanting goshawks and barn owls were recorded at water relatively infrequently but were the most abundant raptors on Ongava (personal observations).

By contrast, 22 raptor species recorded in the SABAP data were seldom (3 or fewer times) recorded drinking, bathing or standing in water. Ten of these species were never recorded at water. Of eight species of falcons and kestrels reported in the area, four were never recorded at water while the other four were recorded just once or twice at water, suggesting that this group of raptors obtain all or the great majority of their water from prey (Table 1). Migrant and vagrant raptors were seldom recorded at water.

Table 2: *Percentages of different behaviours or activities in waterholes recorded in the camera trap images for 13 species recorded 100 or more times at waterholes. The raptors are grouped according to their preferred prey[1]. Records of birds standing away from water are not included. Average mass is from AVONET (Tobias* et al*. 2022) which in turn derives mass data from Dunning (2008). Entries for African hawk-eagle and gabar goshawk are indexed in AVONET by their synonyms* Hieraaetus spilogaster *and* Melierax gabar *respectively.*

Species	Drinking (%)	Standing in water (%)	Bathing (%)	Prey group	Average mass (g)
African hawk-eagle	48.7	43.6	7.7	1	1 466
Verreaux's eagle	70.7	21.4	7.8	1	4 195
Tawny eagle	59.0	36.2	4.8	2	2 236
White-backed vulture	76.7	9.5	13.7	3	5 433
Lappet-faced vulture	86.8	2.8	10.4	3	6 969
Black-chested snake-eagle	81.2	17.8	1.0	4	1 500
Secretary bird	89.0	10.1	0.9	5	4 017
Augur buzzard	42.3	39.7	18.1	5	1 099
Pale chanting-goshawk	69.4	26.1	4.5	5	663
Spotted eagle-owl	56.4	38.3	5.4	5	645
Barn owl	72.5	25.7	1.8	5	403
Gabar goshawk	72.4	22.2	5.4	6	169
Shikra	75.0	22.6	2.4	6	131

[1] Prey groups: 1 – large birds and mammals; 2 – carrion, mammals and birds; 3 – carrion; 4 – snakes and small mammals; 5 – small animals; 6 – small birds.

a) Verraux's eagle bathing

b) Pale chanting goshawk bathing

c) Shikra standing in water

d) African hawk-eagle standing in water

e) Secretary bird drinking

f)Tawny eagle drinking

g) Augur buzzard landing

h) Barn owl standing at edge of waterhole

Figure 3: *Examples of images recorded at waterholes of birds of prey at Ongava Game Reserve, Namibia.*

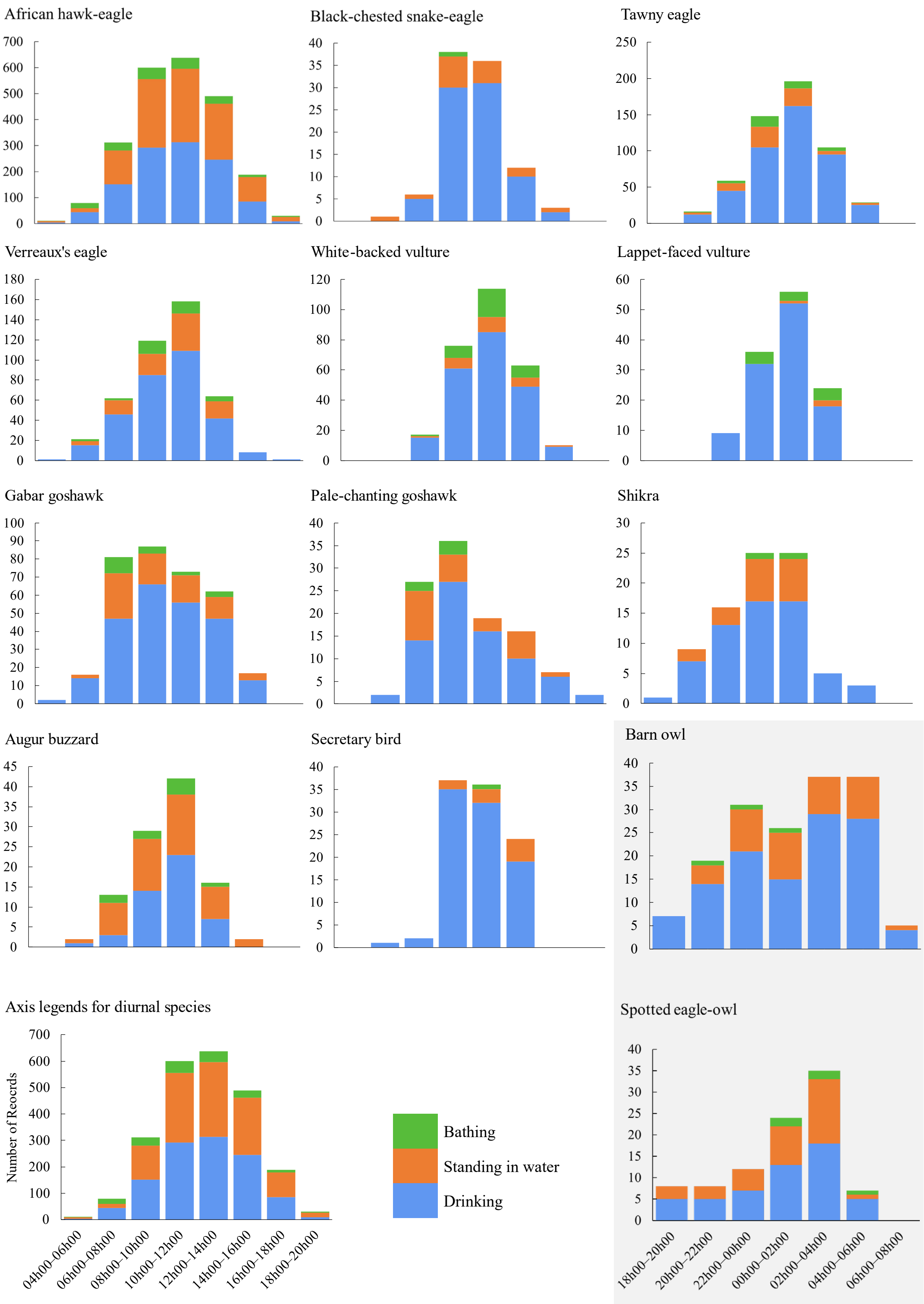

Figure 4: *Numbers of records of drinking (blue), standing in water (orange) and bathing (green) during the day for the 13 raptor species most frequently recorded at waterholes. Note that the x-axis is different for diurnal (white background) and nocturnal (shaded background) species.*

Nine other species were recorded between 5 and 99 times using water, and 13 more species were recorded 100 or more separate times at waterholes (Table 1).

Secretary birds and vultures were only observed at waterholes in open, sparsely vegetated areas. By contrast, sparrowhawks, goshawks and owls were more frequently recorded in wooded areas. Eagles were observed regularly in both wooded and open areas but were absent from waterholes in densely wooded areas.

Drinking usually occurred when a bird perched on the lip of a waterhole or stood in shallow water at its edge (Figure 3). While standing in water birds typically stood motionless, often with their bellies submerged. To bathe, all species usually waded into deeper water where they would splash water over their feathers and then preen before leaving the water. Behaviour recorded as ‘standing nearby’ normally referred to birds perched on a branch or on the ground near the waterhole edge. Two or more of these behaviours were often recorded during an observation. For example, a bird would first drink, then stand in the water for a while, then bathe, and later stand nearby on the ground, perhaps to dry off.

We could not measure the duration of bathing, standing in water and drinking, but the frequencies reported in Table 2 provide approximations of the proportions of times spent engaged in the three activities. Drinking predominated, for most species making up 70% or more of the recorded behaviour. Exceptions are the even higher frequencies of drinking records by secretary birds, lappet-faced vultures and black-chested snake-eagles, but lower frequencies of drinking by augur buzzards, and African hawk-eagles (Table 2).

After drinking, standing in water accounted for the majority of other records for most species. Exceptions were the short times spent standing in water by lappet-faced and white-backed vultures and secretary birds. African hawk-eagles, augur buzzards, tawny eagles and spotted eagle-owls were recorded standing in water most often.

Ten of the 13 species listed in Table 2 were recorded bathing less than 10% of the time, and for most species bathing was noted in 5% or less of the records. Exceptions were higher frequencies of bathing by the two vultures and augur buzzards. By contrast, black-chested snake-eagles, barn owls and secretary birds seldom bathed.

Datasets for proportion of time spent drinking, standing in water and bathing were all found to be normally distributed (Shapiro Wilk $p > 0.5$ in each case. We found no significant correlation between either drinking or bathing (%) and the average mass of a species ($r^2 = 0.2265$, $p > 0.1$ and $r^2 = 0.1259$, $p > 0.2$ respectively). However, there was a significant inverse correlation between the percentage of time spent standing in the water and average mass ($r^2 = 0.4618$, $p < 0.02$) – larger species spent less time standing in the water.

Several species spent considerable time perched in nearby trees or standing a few meters from waterholes, such as the two owls, black-chested snake-eagles and secretary birds, while others seemed not to dally much near water, such as tawny eagles, Verreaux’s eagle, shikras and gabar goshawks.

Diurnal raptors usually visited waterholes during the middle of the day (Table 3 and Figure 4). The smallest of them – shikras and gabar goshawks –

Table 3: *Mean and standard deviation of the times that raptors arrived at waterholes. Times are expressed using the 24-hour clock starting at midnight (GMT + 2 hrs). The standard deviations and means are in hours and minutes.*

Species	Mean time of day	Standard deviation
Spotted eagle-owl	00h13	2h 58m
Barn owl	01h26	3h 19m
Shikra	11h15	2h 26m
Gabar goshawk	11h51	2h 35m
Verreaux’s eagle	11h57	2h 12m
Pale chanting goshawk	12h17	2h 54m
Black-chested snake-eagle	12h25	1h 44m
Lappet-faced vulture	12h26	1h 32m
Augur buzzard	12h28	2h 07m
African hawk-eagle	12h31	2h 39m
Tawny eagle	12h42	2h 12m
Secretary bird	12h45	1h 55m
White-backed vulture	13h09	1h 55m

Table 4: *Mean and standard deviation of the time of day when African hawk-eagles were recorded arriving at waterholes each month, and the time of solar noon at Okaukuejo in Etosha National Park (on the 15th of each month in 2013, GMT + 2hrs). Sample sizes were very small in February, March, April and December thus standard deviations were not calculated for those months.*

Month	Mean time of day	Standard Deviation	Mid-month solar noon
January	12h53	2h 30m	13h05
February	13h41		13h10
March	10h23		13h04
April	11h45		12h56
May	12h29	2h 38m	12h52
June	12h38	2h 43m	12h56
July	12h37	2h 36m	13h01
August	12h55	2h 38m	13h00
September	12h03	2h 38m	12h51
October	12h25	0h 39m	12h41
November	12h45	2h 39m	12h40
December	13h09		12h51

often visited waterholes earlier in the morning than other diurnal raptors. African hawk-eagles were observed at waterholes on average at 12:31 (standard deviation 2 hours 39 minutes). The averages for each month were usually between 12:00 and 13:00, but somewhat later in February and earlier in March (Table 4).

Secretary birds, white-backed and lappet-faced vultures concentrated their visits during the middle of the day between 10h00 and 16h00, whereas visits to water by other diurnal species increased gradually from about 07h00 until midday and then declined until about 18h00. Most visits by diurnal raptors were thus during the heat of the day. Owls visited water throughout the night, with the frequency of their visits increasing from dusk until one or two hours before dawn (Figure 4).

Bathing occurred most often in the first half of the day or night; indeed, bathing by diurnal raptors was seldom recorded after 15h00. Drinking was recorded throughout the day, and the proportion of drinking and standing in water varied in approximate unison during the day (Figure 4), perhaps because it was easier to drink while standing in the water than from the edge of a waterhole.

African hawk-eagles visited waterholes most frequently during the driest months of the year (May to November) (Figure 5). The same pattern held for an aggregation of other species, including owls. Of visits to water by barn owls, 67% were in August, September and October, and 75% of observations of spotted eagle-owls were in September and October. Among some exceptions were Verreaux's and tawny eagles which were recorded at water only in the hottest months of October, November and December.

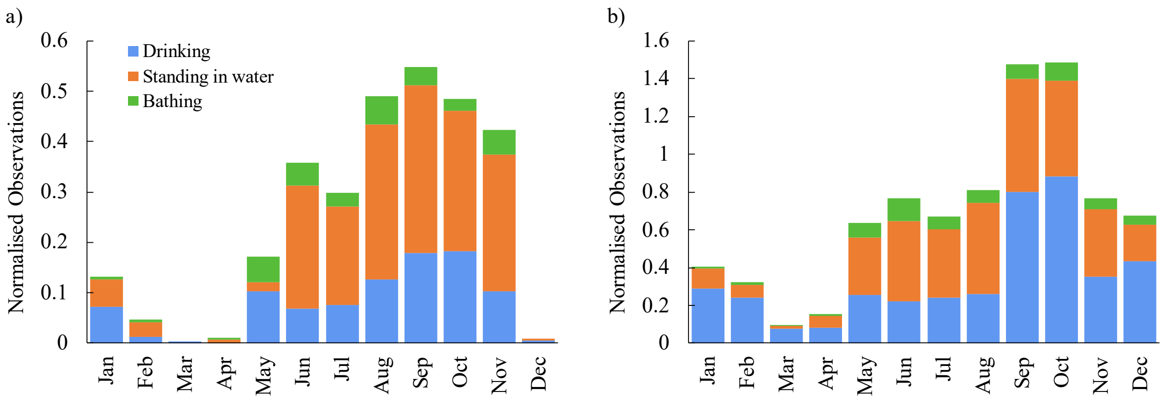

Figure 5: *Numbers of observations of raptors drinking (blue), standing in water (orange) and bathing (green) each month divided by the number of days per month monitored with camera traps (Appendix 2) for (a) African hawk-eagles and (b) the eight other raptors most frequently recorded at waterholes.*

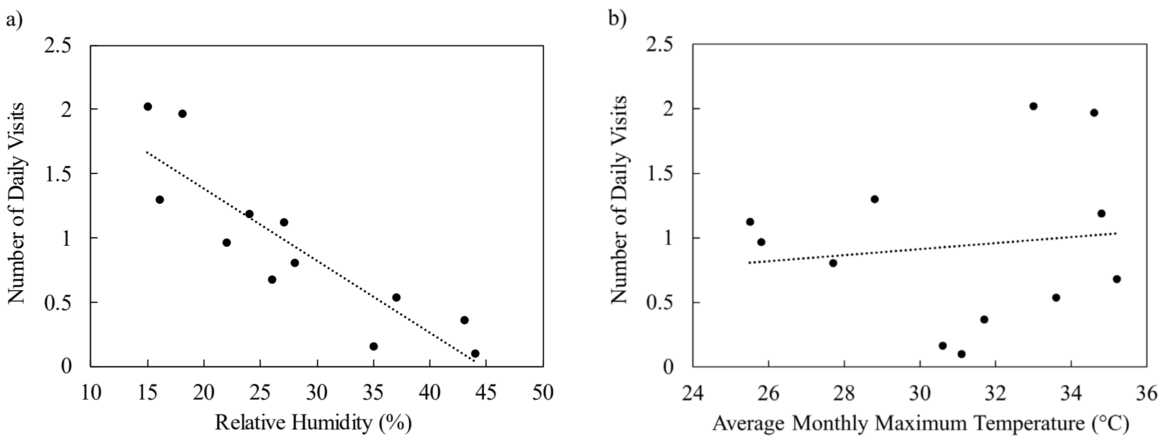

Figure 6: *The correlation between (a) average relative humidity at 14h00 per month and (b) average monthly maximum temperatures with the number of visits to water by all raptors per day divided by the number of days per month monitored with camera traps (Appendix 2, Shapiro-Wilk W = 0.941, p = 0.511). For humidity there is a significant inverse correlation ($r^2 = 0.7831$, $p < 0.0001$), but there is no significant correlation for temperature ($r^2 = 0.0161$, $p > 0.5$).*

While waterhole visits were generally most frequent in the coolest and driest months, the strongest (inverse) correlation with waterhole visits was relative humidity (Figure 6), with an r-squared value of 0.78 ($p = 0.00013$) between the frequency of waterhole visits per month and relative humidity. Indeed, waterhole visits were several times more frequent in in the driest months than in the wetter and hotter months.

DISCUSSION

The findings presented here indicate that many raptors make more use of standing surface water than implied by the paucity of published information. This is true for the 11 diurnal raptors and two owls that were recorded 100 or more times using surface water. However, comparisons of the frequency of records at water and field sightings indicate that many species make little or no use of surface water.

Some differences between species were likely due to their respective sizes, larger birds being more likely to trigger camera traps than smaller ones (Glen *et al.* 2013; Mills *et al.* 2019). However, small gabar goshawks, barn owls and shikras were also often recorded by the camera traps and much more often than many larger raptors in the area. Indeed, we found no correlation between average adult raptor mass and frequency of drinking. Taken together, these data and observations indicate that there is a great deal of variation in the use of surface water between species and at different times of the year and day. Very small raptors, such as pygmy falcons, pearl-spotted owlets and African scops-owls, may just be too small to trigger cameras reliably. From the list of species recorded in the Ongava area and at waterholes, we detected no obvious patterns between the frequencies with which different raptors used surface water and their phylogeny, habitat, or food preferences.

However, among species that made frequent use of surface water their visits to waterholes were most frequent during the hottest times of the day and during the driest times of the year than during the most humid and rainy months. Those patterns together with their frequent drinking, bathing and standing in water behaviour suggest that the maintenance of water balance and, to a lesser extent, direct cooling are important motives for visiting water holes. It is also possible that raptors had been attracted to waterholes to hunt, as reported by Cade (1965) and Jenkins & Davies (2005) and had then stopped incidentally to drink, bathe or stand in the water. Our camera traps recorded several images of prey being caught at waterholes in Ongava.

Possible interspecific differences in needs for surface water are also reflected by the different frequencies with which they were recorded drinking, standing in water and bathing. For instance, drinking and standing in water might have been most important for African hawk-eagles, while the two vulture species and augur buzzards bathed more frequently than other species. And several species first bathed before drinking and standing in water, suggesting a different ordering of apparent priorities.

But some – such as martial eagles, augur buzzards, black-chested snake-eagles, barn owls and secretary birds – seldom bathed and thus perhaps had little need to bathe. Most of these are large birds with little risk of drowning or attack by other predators while being waterlogged in shallow waterholes, reasons that have been advanced by Anderson (2000), Anderson *et al.* (1999) and Peeters & Peeters (2005) to explain the relative infrequency of bathing by other species. Our results show that larger birds spend relatively less time standing in the water which supports this reasoning. While drinking and cooling may be important uses of surface water during the heat of the day and in the driest months, other species-specific factors may be at play. For example, gabar and pale chanting goshawks usually visited waterholes earlier than other diurnal raptors, and Verreaux's eagles were only recorded at water in December. Most species also began making frequent visits to waterholes in the coolest winter months of May, June and July, just a few months after the summer rains.

Our findings suggest that some raptors make frequent use of water, perhaps even relying on surface water to help meet their physiological requirements for water and temperature regulation, and perhaps to maintain their plumage. Moreover, this reliance seems to be driven by relative humidity, rather than temperature. Other raptors have little or no such need for standing or surface water, which raises questions around water balance maintenance and cooling – noting the high metabolic costs of thermoregulation that accompany hot conditions (Gerson *et al.* 2014; Van Dyk *et al.* 2019). We wonder too about the value and use of water by raptors to counter the hotter and drier weather that southern Africa can expect in the future (Engelbrecht *et al.* 2024). To what degree these birds will require greater use of surface water for cooling remains unknown. We encourage studies to investigate these and other questions. Camera-trap and video monitoring (e.g. Smit *et al* 2019) together with computer-based processing to identify birds and their behaviour should make these studies easier and more enlightening.

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Appendix 1: *Dates and days of camera trap deployment at waterholes in Ongava monitored over long periods in 2012-2015. All recordings made from 01/01/2012 to 31/12/2014 were used in the monthly behavioural analysis.*

Waterhole	Start	Stop	Duration in days
Margo	10/01/2012 24/04/2013	05/11/2012 30/12/2014	300 615
Onduri	17/07/2012 27/04/2013 05/03/2014	01/11/2012 28/09/2013 04/01/2015	107 154 305
Roland's Pos	05/01/2012 04/05/2013	03/11/2012 05/01/2015	303 611
Suiderkruis	01/01/2012 30/04/2013 10/03/2014	02/11/2012 24/09/2013 18/10/2014	306 147 222
Tiervlei	30/04/2012 24/04/2013	31/10/2012 29/12/2014	184 614
Total			3 868

Appendix 2: *The number of days each month that waterholes were monitored in Ongava over long periods between 2012 and 2015.*

Month	Days monitored
January	182
February	171
March	235
April	260
May	431
June	420
July	449
August	465
September	442
October	390
November	222
December	214