Journal of Raptor Research

Advancing the science, conservation, and understanding of birds of prey

Journal of Raptor Research 57(3):444–455
doi: 10.3356/JRR-21-70

Patterns of Water Use by Raptors in the Southern Great Plains

Clint W. Boal,[1*] Brent D. Bibles,[2] and Trevor S. Gicklhorn[3]

[1]*US Geological Survey, Texas Cooperative Fish and Wildlife Research Unit, Texas Tech University, Lubbock, TX 79409 USA*
[2]*Unity College, New Gloucester, ME 04260 USA*
[3]*Department of Natural Resources Management, Texas Tech University, Lubbock, TX 79409 USA*

ABSTRACT.—There is a paucity of data evaluating water use by raptors. Although raptors are believed to satisfy their water requirements through metabolic processes, they are known to experience reduced reproductive success during periods of drought, and there is evidence of water being important for site occupancy in arid landscapes. Several raptor species have a seasonal or year-round presence in west Texas, a drought-prone, semi-arid region of the Southern Great Plains. We examined species-specific timing of free water use by common raptors in this region, and examined environmental conditions associated with water use. We collected 4549 camera trap-days of data across 4 yr at ten human-made water sources placed for cattle. We recorded 14 species of raptors among the 1177 detections of raptors visiting water sources; of these, 1084 raptors (92.1%) perched at tanks, and 93 (7.1%) flew by tanks. Of the raptors that perched at tanks, 63.5% drank and 20.8% both bathed and drank. Barn Owls (*Tyto alba*; 35.6%), Swainson's Hawks (*Buteo swainsoni*; 32.0%), and Northern Harriers (*Circus hudsonius*; 21.0%) were the predominate species detected. Visits by Northern Harriers and Swainson's Hawks increased with increasing temperature and decreasing precipitation. Visits by Barn Owls increased with increasing drought severity. Further, detections per 100 trap-days increased substantively across our 4-yr study period during which the region experienced one of the worst droughts on record. Although our data do not demonstrate these raptors require free water, they do reveal an increasing use of free water in relation to hotter and drier conditions. How this influences survival and reproduction remains unknown, but may become a pressing question because current climate models predict the study area will experience increases in heat and decreases in precipitation.

KEY WORDS: *bird of prey*; *climate change*; *drought*; *stock tank*.

PATRONES DE USO DEL AGUA POR AVES RAPACES EN EL SUR DE LAS GRANDES LLANURAS

RESUMEN.—Hay escasez de datos que evalúen el uso del agua por parte de las aves rapaces. Aunque se cree que las aves rapaces satisfacen sus necesidades de agua a través de procesos metabólicos, se sabe que experimentan un éxito reproductivo reducido durante los períodos de sequía, y hay evidencia de que el agua es importante para la ocupación de sitios en paisajes áridos. Varias especies de aves rapaces tienen una presencia estacional o anual en el oeste de Texas, una región semiárida en el sur de las Grandes Llanuras propensa a la sequía. Examinamos el momento específico de uso de agua libre de cada especie para las aves rapaces comunes en esta región, y analizamos las condiciones ambientales asociadas con el uso del agua. Recolectamos 4549 días de datos de cámaras trampa a lo largo de cuatro años en diez fuentes de agua artificiales colocadas para el ganado. Registramos 14 especies de rapaces entre las 1177 detecciones de rapaces visitando las fuentes de agua; de estas, 1084 rapaces (92.1%) se posaron en los tanques y 93 (7.1%) volaron cerca de los tanques. De las rapaces que se posaron en los tanques, el 63.5% bebió y el 20.8% se bañó y bebió. *Tyto alba* (35.6%), *Buteo swainsoni* (32.0%) y *Circus hudsonius* (21.0%) fueron las especies detectadas predominantes. Las visitas de *C. hudsonius* y *B. swainsoni* aumentaron con el aumento de la temperatura y la

* Corresponding author: clint.boal@ttu.edu

disminución de las precipitaciones. Las visitas de *Tyto alba* aumentaron con el aumento de la severidad de la sequía. Además, las detecciones por cada 100 días-trampa aumentaron sustancialmente durante nuestro período de estudio de cuatro años durante el cual la región experimentó una de las peores sequías registradas. Aunque nuestros datos no demuestran que estas rapaces requieran agua libre, sí revelan un uso creciente de agua libre en relación con condiciones más cálidas y secas. Aún se desconoce cómo influye esto en la supervivencia y la reproducción, pero puede convertirse en una pregunta apremiante porque los modelos climáticos actuales predicen que el área de estudio experimentará aumentos en el calor y disminuciones en las precipitaciones.

[Traducción del equipo editorial]

INTRODUCTION

Water is a physiological requirement of all terrestrial vertebrate species (Westfall and Brack 2018) and can be obtained as free water (i.e., surface water), preformed water (i.e., moisture contained in food), and metabolic water (i.e., water obtained through oxidation of food; see Guthery 1999). It is commonly assumed that raptors can satisfy their water needs through preformed water and metabolic processes (Bildstein 2017). Little research has been conducted to validate this assumption (Houston and Duke 2007). Raptors regulate salt and water losses via very efficient kidneys (Houston and Duke 2007), and some species have functional nasal salt glands that can remove salts from the body (Cade and Greenwald 1966, Johnson 1969). However, the long-standing assumption that raptors do not need free water has been questioned. Bildstein (2017) noted several raptor species have been observed drinking water at migratory stopover sites and Finlayson et al. (2019) noted anecdotal observations of raptors using free water. Charlet and Rust (1991) made multiple observations of Golden Eagles (*Aquila chrysaetos*) drinking and bathing at high elevation springs and bogs. Based on similar observations of drinking and bathing by urban dwelling raptors, Boal and Mannan (1998) and Welch-Acosta et al. (2019) suggested presence and reliability of water may be a resource that draws raptors to nest in some cities. More compelling are the quantitative findings that availability of surface water was an ecological constraint for Harris's Hawks (*Parabuteo unicinctus*) in the Sonoran Desert (Dawson and Mannan 1991).

Despite a paucity of information regarding free water use by raptors in the wild, falconry literature is replete with reference to the need to provide captive birds with free water for drinking and bathing (Michell 1900, Glasier 1978). In particular, Woodford (1966; page 10) noted falconry birds will ". . . drink quite a lot of their bath water." Contemporary falconers have also emphasized the need to keep trained raptors hydrated with water (Coulson and Coulson 2012, Bradshaw 2014); well fed raptors in captivity should not need water if they could satisfy their needs from prey or metabolic action. In addition to drinking, however, surface water may be even more important for bathing to ensure health and condition of feathers (Platt et al. 2007).

Even if raptors and other wildlife normally obtain adequate amounts of water from preformed sources and metabolic activity, severe environmental conditions may reduce or prevent these means from meeting physiological needs, necessitating the availability of free water for survival (Cain et al. 2013). Under such conditions, wildlife may seek water at human-made water sources, such as livestock tanks placed on rangelands for cattle, or at wildlife water developments constructed specifically for wildlife. Wildlife water developments are typically a water catchment constructed of fiberglass, metal, or concrete and inserted into the ground so that water is available at the ground level; they are often covered with small access openings so that water is available to wildlife while minimizing evaporation and are typically fed by a rain-collecting apron and tank located upslope of the catchment (Rosentstock et al. 2004). Water developments for wildlife became commonplace in the western United States starting in the 1940s, but their benefit or detriment (e.g., drowning, disease spread) to wildlife became an issue of contention (Broyles 1995, Rosenstock et al. 1999, 2004, Krausman et al. 2006, Cain et al. 2008, Harris et al. 2015). This controversy resulted in attempts to assess wildlife use of water sources; most assessments were focused on game species (see Krausman et al. 2006). A few, however, assessed other species' use of water sources. During surveys at water developments in Arizona, Lynn et al. (2006) recorded 52 bird species using free water, but Turkey Vultures (*Cathartes aura*) were the only raptor detected. In contrast, O'Brien et al. (2006) recorded variable numbers of multiple raptor species from video imagery recorded at three water catchments in southwest Arizona.

Even less information is available regarding raptor use of water sources provided explicitly for cattle production. Water provided for cattle is usually in either above ground metal or fiberglass tanks that can hold 4.5–31.4 m^3 of water, or in dug out earthen ponds, and filled from wells by wind- or solar-powered pumps (Supplemental Material Fig. S1). Houston (1996) noted raptors may drink and bath at stock tanks, and Craig and Powers (1976) suggested tanks may be attractive to raptors if they congregate prey species. However, in the context of raptors, stock tanks are primarily known as a source of drowning mortality (Craig and Powers 1976, Whaley 1986, Mundy et al. 1992, Anderson et al. 1999), which may be a conservation concern for Bald Eagles (*Haliaeetus leucocephalus*) and Golden Eagles (Russell and Franson 2014, US Fish and Wildlife Service 2016).

An understanding of the frequency of raptor use of water sources, and associated temporal and environmental factors, is still lacking. This is especially relevant in the cattle grazing lands in the arid Southern Great Plains of Texas where, aside from rare ephemeral sources due to precipitation, free water is almost exclusively limited to stock tanks. The region is predicted to undergo a substantive increase in frequency and intensity of drought conditions due to a changing climate (Intergovernmental Panel on Climate Change 2013, Cook et al. 2015, Grisham et al. 2016a). Raptors occupying the region will likely face increased average temperatures, increased extreme temperatures, and decreased precipitation. These factors may compromise raptors' abilities to persist on preformed or metabolic water, especially during the breeding season when additional water demands are incurred for reproduction. This may be exacerbated if the changing climate also reduces prey availability, which is a source of preformed water for raptors. Further, Lee et al. (2019) suggested a lack of drinking by raptors made them less vulnerable to contaminated water sources compared to most other avian species in South Africa; this would likely change if environmental conditions necessitated increased use of free water sources.

We examined raptor visits and use of human-made water sources in west Texas to document species, frequency of use, and temporal patterns of use. We hypothesized that raptor visits to water sources would be associated with periods of high temperature, which would increase physiological water demand, and periods of low precipitation, which would reduce direct water availability for bathing. We anticipated our results may provide insights to the importance of free water for raptors in arid landscapes, and the potential value (or lack thereof) of human-made water sources as a tool for raptor conservation in arid regions.

METHODS

Study Area. Data for this study were collected from March 2009–January 2013 in Cochran, Terry, and Yoakum Counties, in the Southern High Plains region of Texas, USA (Fig. 1). The topography is generally flat with occasional low sand dunes. The shrubs sand shinnery oak (*Quercus havardii*) and sand sagebrush (*Artemisia filifolia*) are the dominant woody vegetation in this ecoregion, with blue grama (*Bouteloua gracilis*), buffalo grass (*Urochloa mutica*), purple three-awn (*Aristida purpurea*), and little bluestem (*Schizachyrium scoparium*) grasses intermixed with annual forbs (Grisham et al. 2016b). The study area is semi-arid with a 30-yr average annual precipitation of 47.6 cm and average monthly temperatures ranging from 5.1° to 27.3°C (1991–2020; National Weather Service, https://www.weather.gov/lub/climateoriginal). During the study period, the hottest months were June, July, and August (mean daily, mean high, and mean low temperatures = 26.6°, 39.1°, and 14.8°C, respectively) and the coolest months were December, January, and February (mean daily, mean high, and mean low temperatures = 4.3°, 23.7°, and –10.8°C, respectively; Plains, Texas; National Weather Service, https://www.weather.gov/wrh/Climate). Annual precipitation ranged from 58.2 cm in 2010 to 12.5 cm in 2011, with an annual average of 33.2 cm (±19.1 SD). An extreme drought occurred in the study area in 2010–2012 with an average monthly precipitation of 0.3 ± 0.3 cm per mo from November 2010 to August 2011 (Gicklhorn et al. 2020). Drought continued but was less severe from September 2011 throughout 2012, with an average of 2.3 cm (±12.0) of monthly precipitation. Periods of precipitation occasionally provided ephemeral sources of water, however, the only reliably available free water in the study area was provided by livestock tanks and their overflows.

Data Collection. We used internal battery-operated trail cameras (Reconyx Model Hc500 and Model Rc55, Holmen, Wisconsin, USA) to capture digital images of wildlife visits to a sample of stock tanks. All cameras were battery operated and motion activated.

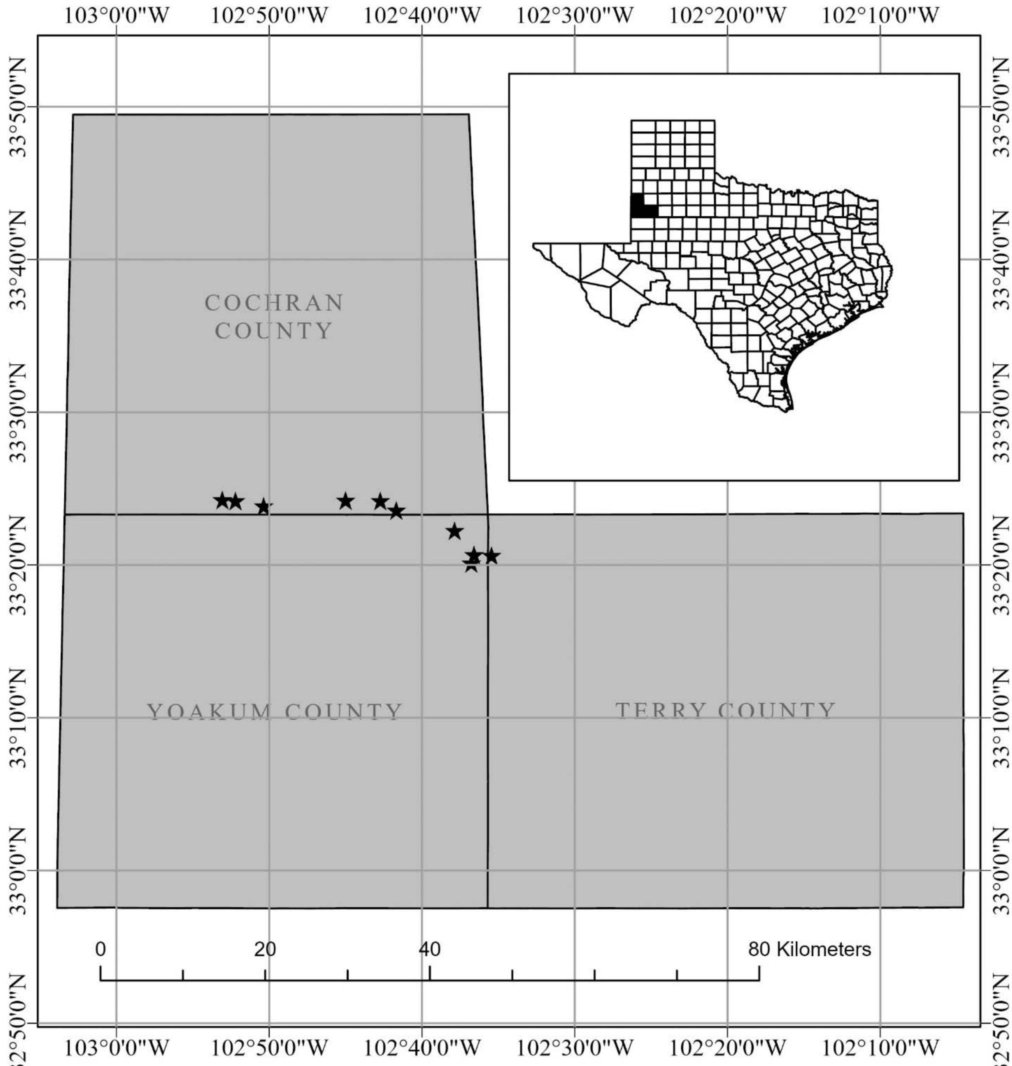

Figure 1. Locations of sampled stock tanks in Cochran, Terry, and Yoakum Counties, Texas.

We positioned cameras 1 m above ground by attaching them to posts adjacent to the tank; we used multiple cameras if the tank was too large to be monitored by one camera. Cameras were set to take either a set of three images or to continuously take images when motion was detected. We checked cameras approximately every 2 wk to replace batteries and download image data.

We selected 10 stock tanks dispersed across a west-to-east span of approximately 28 km (mean distance apart = 2.41 ± 1.82 km) among ranchland in Cochran, Yoakum, and Terry Counties, Texas (Fig. 1). We selected our sample of stock tanks based on our ability to access private properties, constant water production, and seclusion from heavy cattle use as estimated by qualitative in-field assessments. The sampled stock tanks consisted of seven metal or fiberglass above ground circular stock tanks ranging from 3.0 to 6.4 m diameter and depths from 0.6 to 0.8 m with adjacent overflow water catchments, and three earthen tanks, which were small natural or human-made depressions into which water was pumped and had the appearance of a small pond

(Fig. S1). Tanks were kept filled with fresh water by wind- or solar-powered pumps.

We obtained mean temperature (°C) and precipitation (cm) for each month of the study from the West Texas Mesonet system (http://www.mesonet.ttu.edu/obsframe.html). Specifically, we used data from the Sundown mesonet station, which is close to the border between Cochran and Yoakum Counties and approximately 9 km west of the point where all three counties meet (approximate coordinates 33°23′25″N, 102°4′32″W), and was most representative of our study area. The other closest stations in the four-county area (including Hockley County) ranged from 22 to 78 km away (mean = approximately 45 ± 16 km) and none were within the sand shinnery oak vegetation community. We obtained the Palmer Drought Severity Index (PDSI) for each week of the study from the National Oceanographic and Atmospheric Administration's (NOAA) National Centers for Environmental Information website (https://www.ncdc.noaa.gov/temp-and-precip/drought/weekly-palmers/time-series). The PDSI is calculated weekly by NOAA and denotes periods of drought or excess moisture above a long-term average; negative values represent drought and positive values represent wet periods. Weekly index values were averaged for each month of the study.

Data Analysis. To standardize data, we considered a 24-hr period (0000 to 2400 H) as a "camera trap-day" in which the camera was active at a water source. We considered a "visit" as the first sighting of a raptor and a new visit only if ≥15 min elapsed since the last image of a raptor of the same species. We used a 15-min interval as a reasonable time to ensure a raptor did not just move out of frame of the camera before returning. Our response variable for all analyses was the monthly count of visits of each species to water per 100 trap-days. We recorded species, year, water source name, camera name, time, and date for each image in which an individual was initially detected. If multiple cameras overlapped a tank, we compared data from each to avoid double counting individual raptors. We recorded detections as a "flyby," when the raptor was recorded only in flight past the tank, or as "perched" when the raptor was perched at the tank. When perched, we recorded the additional behavior data of drinking, bathing, or both. To examine species-specific use of tanks and temporal patterns of water use, we provide descriptive statistics as to proportions of individual species detected, overall detections/100 trap-hours during the 4-yr study, timing of tank visits across the 24-hr day, and behaviors while at tanks.

We examined environmental factors that may be predictive of water use for those species that we believed we had sufficient detections for meaningful analysis. We then conducted general linearized (GLM) regression analyses to assess potential influence of temperature, precipitation, and PDSI on visits per 100 trap-days for each species (the response variable). If a species exhibited a strongly bimodal pattern of visits that created a zero-inflated distribution, we conducted two analyses. We classified visit data as absent (0 visits per 100 trap-days) and present (>0 visits per 100 trap-days) and used logistic regression. We then analyzed the non-zero visit data using the appropriate GLM. We fitted response variables to an appropriate distribution using a generalized additive model location, scale, and shape algorithm. Northern Harrier (*Circus hudsonius*) and Barn Owl (*Tyto alba*) visits were fitted with an exponential distribution while Swainson's Hawk (*Buteo swainsoni*) visits were fitted with an inverse Gaussian distribution. Barn Owl presence was modeled with a binomial distribution. We normalized monthly temperatures and precipitation specific to each species and the months they were observed in. We used a candidate model set of seven models for each species. Our models tested the influence of temperature, precipitation, PDSI, temperature and precipitation as both additive and interaction effects, as well as a global model involving the temperature-precipitation interaction with PDSI included as an additive effect. An intercept-only model was tested as a null comparison to the models containing potential explanatory variables. The global model was evaluated for goodness of fit for each species. For each species we compared models and identified the best performing model as that with the lowest AIC_c value. We model-averaged parameter estimates for any analysis with more than one model having a $\Delta AIC_c \leq 2.0$ (Burnham and Anderson 2002) using the R package *AICcmodavg*.

RESULTS

We collected 4549 camera trap-days of data at human-made water sources in our study area from March 2009–January 2013. However, worsening drought conditions across the study period led to increased cattle use of some tanks, resulting in rapidly filled video cards and little to no data on wildlife use due to the constant presence and movement of cattle. As a result, we reduced the

Table 1. Raptor species detected, percent of detections, number of different water sources (locations) they were detected at, and behaviors observed at human-made water sources in Cochran, Terry, and Yoakum Counties, Texas, April 2009–January 2013. These are detections of animals using the water sources and are not counts of individual animals.

Order and Species	*n*	%	Locations	Flyby	Perch	Drink	Bathe+Drink
Cathartiformes							
Turkey Vulture (*Cathartes aura*)	30	2.5	7	10.0	90.0	63.0	0.0
Accipitriformes							
Golden Eagle (*Aquila chrysaetos*)	1	0.1	1	0.0	100.0	100.0	0.0
Northern Harrier (*Circus hudsonius*)	248	21.0	6	12.1	87.9	86.2	40.8
Cooper's Hawk (*Accipiter cooperi*)	1	0.1	1	0.0	100.0	100.0	0.0
Swainson's Hawk (*Buteo swainsoni*)	379	32.1	10	8.7	91.3	85.5	29.2
Red-tailed Hawk (*Buteo jamiacensis*)	9	0.8	4	22.2	77.8	100.0	28.6
Rough-legged Hawk (*Buteo lagopus*)	1	0.1	1	0.0	100.0	100.0	100.0
Ferruginous Hawk (*Buteo regalis*)	12	1.0	5	16.7	83.3	70.0	30.0
Strigiformes							
Barn Owl (*Tyto alba*)	422	35.7	7	3.1	96.9	48.4	9.5
Burrowing Owl (*Athene cunicularia*)	24	2.0	4	0.0	100.0	33.3	0.0
Short-eared Owl (*Asio flammeus*)	8	0.7	2	37.5	62.5	20.0	0.0
Falconiformes							
American Kestrel (*Falco sparverius*)	34	2.9	5	17.6	82.4	53.6	17.9
Merlin (*Falco columbarius*)	3	0.3	2	33.3	66.7	100.0	50.0
Prairie Falcon (*Falco mexicanus*)	5	0.4	1	0.0	100.0	100.0	80.0
Unidentified Order							
Unidentified Raptor	5	0.4	2	80.0	20.0	0.0	0.0
Total	**1182**	**100.0**	**10.0**	**8.2**	**91.8**	**68.8**	**22.6**

number of tanks monitored from the initial sample of 10 tanks in 2009 to six in 2010, four in 2011, and three in 2012. This resulted in 1144 camera trap-days in 2009, 1779 in 2010, 1059 in 2011, and 536 in 2012. Despite the decrease in trap-days, detections/100 trap-days rose from 9.3 in 2009 to 14.3 in 2010, 45.2 in 2011, and 62.5 in 2012. Although only 35% of total trap-days occurred during the drought years of 2011–2012, this period contributed 82% of the detections.

Across the entire study period, we identified raptor species for 1177 (99.6%) of the total 1182 visits (26/100 trap-days). Among these were 14 raptor species, with three species accounting for >88% of detections: Barn Owls (35.6%), Swainson's Hawks (32.0%), and Northern Harriers (21.0%). When pooled, the remaining 11 species accounted for 135 (11.4%) detections (Table 1). Of the 1177 detections of raptors identified to species, 1084 (92.1%) were of individuals perching at tanks, and 93 (7.1%) flying by tanks. Of the identified raptors that perched at tanks, 63.5% were drinking or in positions indicative of drinking and 20.8% both bathed and drank. When examined based on taxonomic group, diurnal raptors had a higher incidence of drinking, with Cathartiformes, Accipitriformes, and Falconiformes drinking during 63.0%, 85.8%, and 62.9% of perched visits, respectively. In contrast, Strigiformes appeared to drink during fewer than half (47.3%) of their perched visits. It also appeared that Strigiformes were less inclined to bathe (8.9% of perched visits) compared to Accipitriformes (33.6% of perched visits) or Falconiformes (28.6% of perched visits); Cathartiformes were never observed bathing.

We only examined the time of visit for the three most frequently detected species. Northern Harriers and Swainson's Hawks had a similar pattern of visits, with low occurrence from sunrise until about 1100 H, then a relatively consistent visit rate until 1700 H for Swainson's Hawks and 1900 H for Northern Harriers. Barn Owls started visiting water sources after sunset, with visits peaking between 2300 H and 0300 H, then decreasing and terminating before sunrise. Visits to water sources by all three species increased substantively from 2009 through 2012 (Fig. 2A) in concert with drought conditions (Fig. 2B).

For Northern Harriers, the top model was the temperature and precipitation interaction model; the model including PDSI as an additive effect on the interaction model was the only other competitive

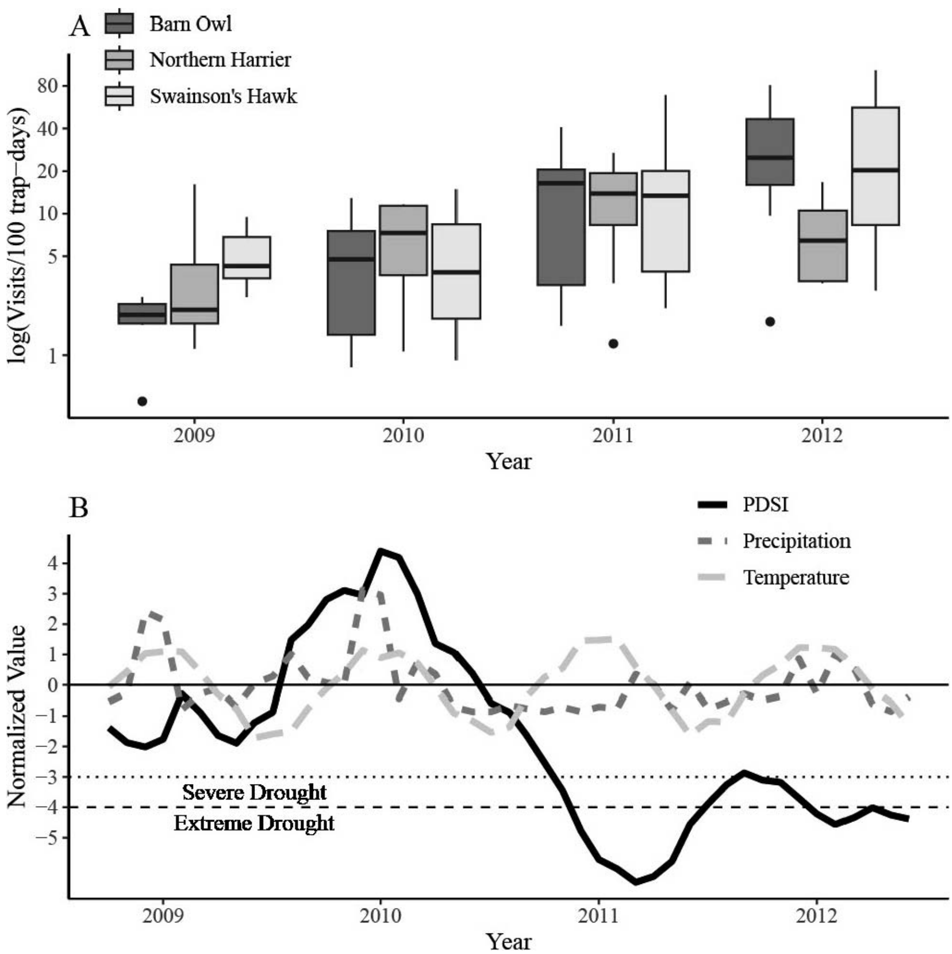

Figure 2. Boxplots of monthly detections of (A) Barn Owls, Northern Harriers, and Swainson's Hawks by year, and (B) variation in precipitation, temperature, and Palmer's drought severity index (PDSI) by year. Detections of each species are in number of visits per 100 trap-days on a logarithmic scale. Precipitation and temperature are centered to the mean value observed during the study and scaled by standard deviation. PDSI is not standardized to the same center or scale as precipitation and temperature. Values indicating severe and extreme drought based on PDSI are illustrated. Data are from 2009–2013, Cochran, Terry, and Yoakum Counties, Texas.

model ($\Delta AIC_c = 0.77$; Table 2). Visits to tanks generally decreased as precipitation increased, but at higher temperatures an increase in precipitation was associated with higher visitation (Fig. S2). There is some evidence that visits to tanks increased as PDSI decreased (i.e., with stronger drought). Precipitation was the most important explanatory variable in the best model with the 95% confidence intervals on the slope coefficients for precipitation and the interaction not including 0 (Temperature = [–0.10, 0.47]; Precipitation = [–0.60, –0.04]; Interaction = [0.07, 0.58]). When model-averaged, all climate slope coefficients overlapped 0, but only slightly for precipitation and PDSI (Temperature = [–0.12, 0.47]; Precipitation = [–0.61, 0.01]; PDSI = [–0.21, 0.03]).

Both temperature and precipitation appeared to influence visitation of tanks by Swainson's Hawks. The additive model best fit these data with the interaction model being competitive ($\leq 2.0\ \Delta AIC_c$; Table 2). Visits to tanks showed a positive relationship with monthly temperature and a negative relationship with monthly precipitation. Ninety-five percent confidence intervals on the slope coeffi-

Table 2. Model results for all analyses for the candidate model set. Four analyses were used including three analyses with the response variable of visits per 100 trap-days for Swainson's Hawk, Northern Harrier, and Barn Owl, as well as one analysis with the response variable of presence or absence of Barn Owls. Candidate model set includes the explanatory variables temperature (°C), precipitation (cm), and the Palmer Drought Severity Index (PDSI) independently, as well as temperature and precipitation in combination additively (Temp+Precip) and as an interaction model (Interaction). A global model consisted of the interaction model with PDSI included as an additive effect. An intercept only model with no explanatory variables was also included. Model results include the number of model parameters (K), the small sample corrected Akaike's Information Criterion (AIC_c), the change in AIC_c from the best model (ΔAIC_c), the model likelihood (ModelLik), and the Akaike weight of each model (w_i).

Species	Model	K	AIC_c	ΔAIC_c	ModelLik	w_i
Swainson's Hawk	Temp+Precip (Additive)	4	186.654	0.000	1.0000	0.6041
	Temp*Precip (Interaction)	5	188.229	1.576	0.4549	0.2748
	Temperature	3	191.221	4.568	0.1019	0.0616
	Interaction+PDSI(Global)	6	191.364	4.710	0.0949	0.0573
	PDSI	3	198.495	11.841	0.0027	0.0016
	Intercept Only	2	201.300	14.647	0.0007	0.0004
	Precipitation	3	202.870	16.216	0.0003	0.0002
Northern Harrier	Temp*Precip (Interaction)	5	80.852	0.000	1.0000	0.4590
	Interaction+PDSI(Global)	6	81.619	0.767	0.6815	0.3128
	Precipitation	3	84.261	3.409	0.1819	0.0835
	Temp+Precip (Additive)	4	84.608	3.756	0.1529	0.0702
	PDSI	3	86.055	5.202	0.0742	0.0341
	Intercept Only	2	86.886	6.034	0.0490	0.0225
	Temperature	3	87.323	6.470	0.0394	0.0181
Barn Owl (Presence)	PDSI	2	36.213	0.000	1.0000	0.3672
	Interaction+PDSI(Global)	5	36.433	0.220	0.8959	0.3289
	Temp+Precip (Additive)	3	37.654	1.441	0.4865	0.1786
	Temp*Precip (Interaction)	4	39.330	3.117	0.2105	0.0773
	Precipitation	2	40.780	4.567	0.1019	0.0374
	Intercept Only	1	44.214	8.000	0.0183	0.0067
	Temperature	2	45.324	9.110	0.0105	0.0039
Barn Owl (Visits > 0)	PDSI	3	124.645	0.000	1.0000	0.8944
	Interaction+PDSI(Global)	6	129.746	5.101	0.0780	0.0698
	Intercept Only	2	133.129	8.484	0.0144	0.0129
	Temperature	3	133.246	8.601	0.0136	0.0121
	Temp+Precip (Additive)	4	135.052	10.408	0.0055	0.0049
	Precipitation	3	135.418	10.774	0.0046	0.0041
	Temp*Precip (Interaction)	5	137.049	12.404	0.0020	0.0018

cients for both variables did not encompass 0 for the best model (Temperature = [0.93, 1.79]; Precipitation = [–1.27, –0.43]), but did when model-averaged (Temperature = [–0.25, 2.86]; Precipitation = [–2.35, 0.55]).

The PDSI model best fit presence of Barn Owls at tanks, although the global and additive models were competitive (Table 2) indicating that the species' presence was likely influenced by all three climate variables. Barn Owl presence at tanks showed a negative relationship with monthly PDSI and evidence of a positive relationship with monthly temperature and a negative relationship with monthly precipitation. The best model produced a 95% confidence interval on the slope coefficient for PDSI that did not encompass 0 (PDSI = [–0.86, –0.17]). When model-averaged, the temperature slope coefficient slightly overlapped 0 (Temperature = [–0.04, 2.52]), but the coefficients for precipitation and PDSI did not overlap 0 (Precipitation = [–2.69, –0.04]; PDSI = [–0.86, –0.07]). The PDSI model best fit the number of visits of Barn Owls at tanks (visits per 100 trap-days > 0), and no other models were competitive (Table 2). Drought severity appeared to strongly influence the number of Barn Owl visits as detections per 100 trap-days increased as drought severity increased (i.e., PDSI decreased). The PDSI model produced a 95% confidence interval on the slope coefficient for PDSI that did not encompass 0 (PDSI = [–0.41, –0.11]).

DISCUSSION

Our study was not designed to determine if raptors require free water, but rather to obtain insights as to the extent of, and possible environmental correlates of, water use. Although we detected 14 different raptor species, detections were predominated by three species. We suspect this disparity in detections is an actual reflection of the local raptor community throughout the year. Behney et al. (2012) found diurnal raptor diversity was low in our study area during summer month surveys in 2007 and 2008, with Swainson's Hawks accounting for 90.3% of detections. When pooling winter surveys with spring and fall migration surveys, Behney et al. (2012) found similar detections of Swainson's Hawks (28.4%), Northern Harriers (31.4%), and Red-tailed Hawks (*Buteo jamaicensis*; 26.7%), which combined for 86.5% of detections. Swainson's Hawks detected during the migration and winter surveys would primarily be spring and autumn migrants; therefore, it appears the wintering diurnal raptor community is dominated by Northern Harriers and Red-tailed Hawks. This similarity in survey detection rates did not manifest in detections at water sources, with Red-tailed Hawks accounting for only 0.8% of detections in our study. Red-tailed Hawks have been noted to use water catchments. O'Brien et al. (2006) recorded 557 observations of Red-tailed Hawks during 37,989 hr of video imagery in southwest Arizona, with Red-tailed Hawks being the third most common raptor species observed. The climate of the O'Brien et al. (2006) study location is notably hotter and drier than our study area, and Red-tailed Hawks were rare in our area during the summer (Behney et al. 2012). It is possible that the conditions we observed when hawks were present did not reach a threshold that required Red-tailed Hawks to use free water. Whether Northern Harriers and Red-tailed Hawks have different water requirements due to physiology (metabolic water) or diet (preformed water) remains unknown, but it is clear that Northern Harriers frequented water for both drinking and bathing.

There are no substantive nocturnal raptor survey data for the region. Our anecdotal data suggests Barn Owls are year-round, even if sparsely distributed, residents in the area. During monthly, year-round surveys of the same study area, Behney et al. (2012) detected one Great Horned Owl (*Bubo virginianus*) and two Burrowing Owls (*Athene cunicularia*) but no Barn Owls. This is not surprising as Great Horned Owls may be spotted at day roosts and Burrowing Owls may be active during daylight whereas Barn Owls typically retreat to cavities during daylight. Our lack of observations of Great Horned Owls at water sources is notable. O'Brien et al. (2006) recorded 1195 visits of Great Horned Owls at water catchments in Arizona, making them the second most observed raptor in their study. Also, the apparent abundance of Barn Owls in a landscape generally devoid of nest cavity opportunities was unexpected. We suspect the Barn Owls are occupying abandoned houses, barns, and deer hunting blinds that, though very sparsely distributed, are present across the landscape.

Assessing behaviors from trail cameras can be problematic in that, depending on programming for image capture rate and delays between new image captures, some actions may be missed. With that caveat, we documented that most visits to water appeared to include drinking for Cathartiformes (63.0%), Accipitriformes (85.8%), and Falconiformes (62.9%). In contrast, Strigiformes appeared to drink in only 47% of visits. In addition to drinking, some species appeared especially prone to engage in bathing, which may be an important self-maintenance behavior contributing to health and condition of feathers (Platt et al. 2007). Bathing was prevalent among Accipitriformes, especially Northern Harriers (40%), Ferruginous Hawks (*Buteo regalis*; 30%), and Swainson's Hawks (29%). Falconiform detections were generally low, but those detected did appear to favor bathing during water visits (28.6%), especially Prairie Falcons (*Falco mexicanus*; 80%). In contrast, Strigiformes appeared to rarely bath and Cathartiformes were never detected bathing. At water catchments in Arizona, all detected raptor species were observed drinking during the large majority ($\geq$85%) of visits (O'Brien et al. 2006). We observed higher rates of bathing by diurnal raptors, but lower rates of bathing for owls than O'Brien et al. (2006).

Visits by raptors to human-made water sources was clearly influenced by environmental conditions. Temperature was included as an explanatory variable in the best model for both Northern Harriers and Swainson's Hawks and was included in a competitive model for Barn Owl presence. Increased use of, or presence at, water in response to increased temperatures has been observed for birds in general (Bartholomew and Dawson 1954, Bartholomew and

Cade 1956, Lynn et al. 2006) and specifically for raptors (O'Brien et al. 2006). However, Rich et al. (2019) found that temperature negatively influenced occupancy for 13 of 28 bird species they observed at artificial water catchments in the Mojave Desert, while finding a positive association for only three species.

Precipitation was included as an explanatory variable in the best models for both the Northern Harrier and the Swainson's Hawk and was included in a competitive model for Barn Owl presence. The observations of drinking at the majority of visits by diurnal raptors during our study and in O'Brien et al. (2006) suggests that at temperatures currently observed in the desert and steppe environments of the US southwest, freely available water may be an important resource during periods of low precipitation. Although temperature and precipitation were included in competitive models for Barn Owl presence at water sources, drought severity (as measured by PDSI) was the most important explanatory variable for both Barn Owl presence at and visitation rate to water sources. As drought measured by PDSI represents a long-term disturbance to the area that results in lower soil moisture due to a longer period of moisture deficit than normal, it is unlikely that this influence on Barn Owls is due to a physiological need for water. For example, our assessment of digital images suggests Barn Owls drank during fewer than half of their visits and had very low rates of bathing. Given that Barn Owls are strongly nocturnal, they are active during periods of lower temperature and may not be exposed to conditions that would require access to free water. Rather, Barn Owl use of water sources may be a result of increased prey abundance in the vicinity of these sources. O'Brien et al. (2006) found that black-tailed jackrabbit (*Lepus californicus*) and desert cottontail (*Sylvilagus audubonii*) visits to water catchments were common. However, Kleuver et al. (2016) and Cutler and Morrison (1998) did not find evidence that artificial water sources influenced small mammal abundance directly, so a mechanistic tie of Barn Owl use to water remains unknown.

Stock tanks and similar structures are a noted source of drowning mortality for a variety of wildlife species (Rosenstock et al. 1999, Boyd et al. 2014, Jeal et al. 2019). Indeed, the documentation of raptors using water to drink or bathe have primarily been associated with drowning mortality at cattle stock tanks (Craig and Powers 1976, Whaley 1986, Mundy et al. 1992, Houston 1996, Anderson et al. 1999). Several Bald Eagle and Golden Eagle mortalities were identified as drowning but the types of water source were not identified (Russell and Franson 2014). In Spain, both Bonelli's Eagles (*Hieraaetus fasciatus*) and Spanish Imperial Eagles (*Aquila adalberti*) are known to experience mortalities at human-made water sources (Real et al. 2001, González et al. 2007). In perhaps the most comprehensive examination of the issue, Anderson et al. (1999) documented drowning deaths of 322 raptors of 29 species in southern Africa. Little information is known about owl mortalities by drowning, but Glue (1971) reported multiple individuals of three owl species drowning in tanks, troughs, and other human-made structures. Thus, it is interesting that during our 4-yr study we never documented the drowning mortality of a raptor. This is undoubtedly due to the majority of our observations being of raptor use of earthen tanks and overflow areas. However, we did record numerous incidences of raptors using above ground tanks and several cases of individuals landing in the deep water (Fig. S3). In all cases, the raptor was able to become airborne and exit the tank. It would be prudent, however, to have wildlife escape ramps and ladders in the tanks for egress by any species that becomes trapped (Gurrieri 2020). Providing an overflow from tanks could also possibly reduce drowning risk by providing shallow puddled water next to the tank.

Southwestern North America, already an arid region, is projected to become even more arid as the result of anthropogenic climate change (Seager et al. 2007, Intergovernmental Panel on Climate Change 2013). The drought encountered in 2011–2012 in our study area was among the most severe on record. Future droughts in this region will be driven by different climate processes than previous droughts and are predicted to be more severe than those in the historical record (Seager et al. 2007). The response of raptor species currently occupying this region to the increasing temperature and changing availability of water is currently unknown, but our results suggest that availability of free water, and risk of contaminated water, may be important factors that wildlife managers will need to consider in their plans to mitigate the effects of predicted changes.

SUPPLEMENTAL MATERIAL (available online). Figure S1: Examples of stock tank types monitored in this study of raptor use of water sources in Cochran, Terry, and Yoakum Counties, Texas, 2009–2013. Figure S2: Predicted visitation of water sources by Northern

Harriers based on the best model, which involved interaction of temperature and precipitation. Figure S3: Examples of raptors entering and exiting water in an above ground stock tank in Cochran County, Texas, 2010 and 2011.

ACKNOWLEDGMENTS

We thank the private landowners who provided us access to their ranchlands for this study. We also thank P. K. Borsdorf and the many technicians that assisted with the original study during which these data were collected. An earlier version of the manuscript was improved by the comments of M. Kochert, A. Lee, C. McIntyre, and an anonymous reviewer. Data in this paper come from a study funded by the Texas Parks and Wildlife Department. This study was conducted under research protocol 10052-08 approved by the Texas Tech University institutional animal care and use committee. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the US Government.

LITERATURE CITED

Anderson, M. D., A. W. A. Maritz, and E. Oosthuysen (1999). Raptors drowning in farm reservoirs. Ostrich 70:139–144.

Bartholomew, G. A., and T. J. Cade (1956). Water consumption of house finches. The Condor 58:406–412.

Bartholomew, G. A., and W. R. Dawson (1954). Body temperature and water requirements in the mourning dove. Ecology 35:181–187.

Behney, A. C., C. W. Boal, H. A. Whitlaw, and D. R. Lucia (2012). Raptor community composition in the Texas Southern High Plains Lesser Prairie-Chicken range. Wildlife Society Bulletin 36:291–296.

Bildstein, K. L. (2017). Raptors: The Curious Nature of Diurnal Birds of Prey. Cornell University Press, Ithaca, NY, USA.

Boal, C. W., and R. W. Mannan (1998). Nest-site selection by Cooper's hawks in an urban environment. Journal of Wildlife Management 62:864–871.

Boyd, C. S., J. L. Beck, and J. A. Tanaka (2014). Livestock grazing and sage-grouse habitat: Impacts and opportunities. Journal of Rangeland Applications 1:58–77.

Bradshaw, J. (2014). The Passage Merlin. Publisher Services, Chicago, IL, USA.

Broyles, B. (1995). Desert wildlife water developments: Questioning use in the Southwest. Wildlife Society Bulletin 23:663–675.

Burnham, K. P., and D. R. Anderson (2002). Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. Second Ed. Springer-Verlag, New York, NY, USA.

Cade, T. J., and L. Greenwald (1966). Nasal salt secretion in Falconiform birds. The Condor 68:338–350.

Cain, J. W., III, P. R. Krausman, J. R. Morgart, B. D. Jansen, and M. P. Pepper (2008). Responses of desert bighorn sheep to removal of water sources. Wildlife Monographs 171:1–32.

Cain, J. W., III, P. R. Krausman, and S. S. Rosenstock (2013). Water and other welfare factors. In Wildlife Management and Conservation: Contemporary Principles and Practices (P. R. Krausman and J. W. Cain, Editors). Johns Hopkins University Press, Baltimore, MD, USA. pp. 174–194.

Charlet, D. A., and R. W. Rust (1991). Visitation of high mountain bogs by Golden Eagles in the northern Great Basin. Journal of Field Ornithology 62:46–52.

Cook, B. I., T. R. Ault, and J. E. Smerdon (2015). Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances 1:e1400082. http://dx.doi.org/10.1126/sciadv.140008229.

Coulson, J., and T. Coulson (2012). The Harris's Hawk Revolution. Parabuteo, Pearl River, LA, USA.

Craig, T. H., and L. R. Powers (1976). Raptor mortality due to drowning in a livestock watering tank. The Condor 78:412.

Cutler, T. L., and M. L. Morrison (1998). Habitat use by small vertebrates at two water developments in southwestern Arizona. Southwestern Naturalist 43:155–162.

Dawson, J. W., and R. W. Mannan (1991). The role of territoriality in the social organization of Harris' Hawks. The Auk 108:661–672.

Finlayson, D. K., R. L. Larsen, R. N. Knight, S. E. Phillips, and S. J. Slater (2019). Golden Eagle use of water features in the west desert of Utah. Abstract, Annual Meeting of the Raptor Research Foundation, 5–10 November. Fort Collins, CO, USA.

Gicklhorn, T. S., C. W. Boal, and P. K. Borsdorf (2020). Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*) use of man-made water sources. Southwestern Naturalist 65:197–204.

Glasier, P. (1978). Falconry and Hawking. Charles T. Branford Co., Newton Center, MA, USA.

Glue, D. E. (1971). Ringing recovery circumstances of small birds of prey. Bird Study 18:137–146.

González, L., A. Margalida, S. Mañosa, R. Sánchez, J. Oria, J. Molina, J. Caldera, A. Aranda, and L. Prada (2007). Causes and spatio-temporal variations of non-natural mortality in the vulnerable Spanish Imperial Eagle *Aquila adalberti* during a recovery period. Oryx 41:495–502.

Grisham, B. A., A. J. Godar, and C. P. Griffin (2016a). Climate change. In Ecology and Conservation of Lesser Prairie-Chickens (D. A. Haukos and C. W. Boal, Editors). Studies in Avian Biology (No. 48). CRC Press, Boca Raton, FL, USA. pp. 221–242.

Grisham, B. A., J. C. Zavaleta, A. C. Behney, P. K. Borsdorf, D. R. Lucia, C. W. Boal, and D. A. Haukos (2016b). Ecology and conservation of the Lesser Prairie-Chickens in the sand shinnery oak prairie. In Ecology and Conservation of Lesser Prairie-Chickens (D. A. Haukos and C. W. Boal, Editors). Studies in Avian Biology No. 48. CRC Press, Boca Raton, FL, USA. pp. 315–344.

Gurrieri, J. T. (2020). Rangeland Water Developments at Springs: Best Practices for Design, Rehabilitation, and Restoration. Gen. Tech. Rep. RMRS-GTR-405. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA.

Guthery, F. S. (1999). The role of free water in bobwhite management. Wildlife Society Bulletin 27:538–542.

Harris, G., J. G. Sanderson, J. Erz, S. E. Lehnen, and M. J. Butler (2015). Weather and prey predict mammals' visitation to water. PLoS One 10:e0141355. doi:10.1371/journal.pone.0141355.

Houston, D. C. (1996). The effect of altered environments on vultures. In Raptors in Human Landscapes (D. M. Bird, D. E. Varland, and J. J. Negro, Editors). Academic Press, San Diego, CA, USA. pp. 328–335.

Houston, D. C., and G. E. Duke (2007). Physiology A. Gastrointestinal. In Raptor Research and Management Techniques, Second ed. (D. M. Bird and K. L. Bildstein, Editors). Hancock House Publishers, Blaine, WA, USA. pp. 267–277.

Intergovernmental Panel on Climate Change (2013). Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (T. F. Stocker, D. Qin, G. Plattner, M. M. B. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley, Editors). Cambridge University Press, New York, NY, USA. http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf.

Jeal, C., V. Perold, S. Ralston-Paton, and P. G. Ryan (2019). Impacts of a concentrated solar power trough facility on birds and other wildlife in South Africa. Ostrich 90:129–237.

Johnson, I. M. (1969). Salt and water balance, and nitrogen excretion of the Red-tailed Hawk, *Buteo jamaicensis*. Ph.D. dissertation, University of Montana, Missoula, MT, USA.

Kleuver, B. M., E. M. Gese, and D. J. Dempsey (2016). The influence of wildlife water developments and vegetation on rodent abundance in the Great Basin Desert. Journal of Mammalogy 97:1209–1218.

Krausman, P. R., S. S. Rosenstock, and J. W. Cain, III (2006). Developed waters for wildlife: Science, perception, values, and controversy. Wildlife Society Bulletin 34:563–569.

Lee, A. T. K., C. Geary, D. R. Wright, and W. R. J. Dean (2019). Vulnerability of birds to contaminated water sources in the Karoo region of South Africa. Ostrich 90:397–406.

Lynn, J. C., C. L. Chambers, and S. S. Rosenstock (2006). Use of wildlife water developments by birds in southwest Arizona during migration. Wildlife Society Bulletin 34:592–601.

Michell, E. B. (1900). The Art and Practice of Hawking. Reprinted 1984 by Holland Press, West Yorkshire, UK.

Mundy, P., D. Butchart, J. Ledger, and S. Piper (1992). The Vultures of Africa. Academic Press, San Diego, CA, USA.

O'Brien, C. S., R. B. Waddell, S. S. Rosenstock, and M. J. Rabe (2006). Wildlife use of water catchments in southwestern Arizona. Wildlife Society Bulletin 34:582–591.

Platt, J. B., D. M. Bird, and L. Bardo (2007). Captive breeding. In Raptor Research and Management Techniques, Second Ed. (D. M. Bird and K. L. Bildstein, Editors). Hancock House Publishers, Blaine, WA, USA. pp. 383–400.

Real, J., J. M. Grande, S. Mañosa, and J. A. Sánchez-Zapata (2001). Causes of death in different areas for Bonelli's Eagle *Hieraaetus fasciatus* in Spain. Bird Study 48:221–228.

Rich, L. N., S. R. Beissinger, J. S. Brashares, and B. J. Furnas (2019). Artificial water catchments influence wildlife distribution in the Mojave Desert. Journal of Wildlife Management 83:855–865.

Rosenstock, S. S., W. B. Ballard, and J. C. DeVos, Jr. (1999). Viewpoint: Benefits and impacts of wildlife water developments. Journal of Range Management 52:302–311.

Rosenstock, S. S., M. J. Rabe, C. S. O'Brien, and R. B. Waddell (2004). Studies of Wildlife Water Developments in Southwestern Arizona: Wildlife Use, Water Quality, Wildlife Diseases, Wildlife Mortalities, and Influences on Native Pollinators. Arizona Game and Fish Department Technical Guidance Bulletin 8. Phoenix, AZ, USA.

Russell, R. E., and J. C. Franson (2014). Causes of mortality in eagles submitted to the National Wildlife Health Center 1974–2013. Wildlife Society Bulletin 38:697–704.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. Huang, N. Harnik, A. Leetmaa, N. Lau, C. Li, et al. (2007). Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316:1181–1184.

US Fish and Wildlife Service (USFWS) (2016). Bald and Golden Eagles: Population Demographics and Estimation of Sustainable Take in the United States, 2016 Update. USFWS Division of Migratory Bird Management, Washington, DC, USA.

Welch-Acosta, B. C., B. R. Skipper, and C. W. Boal (2019). Comparative breeding ecology of Mississippi Kites in urban and exurban areas of West Texas. Journal of Field Ornithology 90:248–257.

Whaley, W. H (1986). Population ecology of the Harris' Hawk in Arizona. Journal of Raptor Research 20:1–15.

Woodford, M. H. (1966). A Manual of Falconry, Second Ed. A. and C. Black, London, UK.

Received 21 October 2021; accepted 8 December 2022
Associate Editor: Petra Sumasgutner