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Stable isotopes provide insight into the use of wildlife water developments by resident and migrant birds in the Sonoran Desert of Arizona

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STABLE ISOTOPES PROVIDE INSIGHT INTO THE USE OF WILDLIFE WATER DEVELOPMENTS BY RESIDENT AND MIGRANT BIRDS IN THE SONORAN DESERT OF ARIZONA

BY

THERESA C. HYDE

B.S., Biology, University of New Mexico, 2006

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

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Biology

The University of New Mexico
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May, 2011

Dedication

For my parents, who passed their love of the outdoors on to me.

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ABSTRACT OF THESIS

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ABSTRACT

Several studies have looked at the importance of man-made water resources to wildlife in desert regions. To our knowledge, however, none have attempted to directly quantify their importance to both resident and Neotropical migratory birds. During the spring and summer from 2007-2009, we enriched man-made water developments in the Sonoran Desert on the Kofa National Wildlife Refuge, Arizona. We enriched water developments using deuteriated water and sampled the body water pools of resident and migrant birds to quantify development use. We used a simple two end-point mixing model to estimate the proportion of an individual bird's body water pool that was derived from the development water. We mist netted birds at distances ranging from 2 to 1000 m from the development to assess the distance an individual would travel to use these permanent water sources. We analyzed samples from 1,431 birds and found that resident species (253 out of 394 individuals sampled) such as Gambel's Quail (*Callipepla gambelii*), White-winged Doves (*Zenaida asiatica*), Mourning Doves (*Zenaida macroura)*, and House Finches (*Carpodacus*

mexicanus) made extensive use of the water developments. Water developments contributed as much as 90% of the water found in the body water pools of some species (e.g. White-winged Doves, Mourning Doves and House Finches). Other species such as Northern Mockingbirds (*Mimus polyglottos)*, Gila Woodpeckers (*Melanerpes uropygialis*), and Phainopeplas (*Phainopepla nitens)* made limited use (29 out of 91 individuals sampled) of these developments during the summer months. In contrast, very few Neotropical migrants (9 out of 364 individuals sampled) used these developments during their northward migration in the spring. For small, resident species, such as Verdin (*Auriparus flaviceps)*, Black-tailed Gnatcatcher (*Polioptila melanura)*, Lucy's Warbler (*Vermivora luciae*), and Black-throated Sparrow (*Amphispiza bilineata*) these permanent water sources appear to be of limited importance to their daily water balance.

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INTRODUCTION

The deserts of the Southwest produce special challenges for resident and migratory birds during the late spring and summer. High air temperatures, scarce free water resources, and intense solar heat loads combine to push many species towards critical physiological limits (Wolf 2000). For most birds, their small size, high metabolic rates and high body temperatures coupled with significant heat loads result in high rates of evaporative water loss (Bartholomew and Dawson 1954, Bartholomew and Cade 1956, Dawson 1982). Although behavioral adjustments, such as seeking shaded microsites and limiting foraging activities to the coolest part of the day can minimize heat exposure and water losses, animals are still likely to accrue significant water deficits (Mckechnie and Wolf 2010). Because of their small size and limited capacity to store vital resources such as water, these deficits must be balanced over periods of minutes to hours to maintain homeostasis (Wolf and Walsberg 1996). Scarcity of free water resources is characteristic of arid regions and means that most animals must obtain water from food (i.e. vegetation, seeds, fruit, insects or other prey) or travel long distances to ephemeral water catchments and other water resources (natural springs, major rivers (e.g., Colorado, Gila), irrigation canals, etc.) that are sparsely distributed on the landscape. These conditions may affect persistence of resident birds and movement of Neotropical migrants that pass through hot deserts of the southwest on their way to and from more mesic breeding grounds to the north.

Since the 1940's, wildlife managers have attempted to augment scarce free water resources found in these deserts by building and maintaining water developments and today these developments (artificial catchments, modified natural tanks, developed springs and wells) are being used extensively as a tool for wildlife management (Rosenstock et al. 1999).

Now numbering in the thousands, water developments are widespread across the Western United States; the state of Arizona, for example, maintains >840 water developments alone (Rosenstock et al. 1999). Although, these water developments were originally built to support and enhance populations of large game animals they also provide water for smaller non-game species and potentially mitigate for the loss of natural water resources due to agriculture and urbanization (deVos et al. 1990, Sanchez and Haderlie 1988, Rosenstock et al. 1999, Krausman et al. 2006). Water developments are, however, subject to controversy because they are expensive to maintain, and critics question their benefit to wildlife (Rosenstock et al. 2004).

Quantifying the importance of desert water holes for resident and migrant birds in the Sonoran Desert has been of interest to researchers for some time (Elder 1956, Gubanich 1966). Most studies have relied on direct observations to quantify visitation rates and the use of these scarce water resources by wildlife (Elder 1956, Gubanich 1966, Cutler and Morrison 1998, Lynn et al. 2006). More recently, studies have relied on the use of remote videography to examine visitation rates of wildlife to water developments (O'Brien et al. 2006, Lynn et al. 2008). O'Brien et al. (2006), for example, collected and reviewed 38,000 hours of video and found that doves and quail used the resource frequently during the hot summer months and small birds, while common, could not be reliably identified. The highest rates of visitation for small birds were observed in May and September during the months of migration. Further work, by Lynn et al. (2008), used color videography and provided additional observational data on visitation rates to water developments for migrant and resident avian species. This study found limited use of water developments by migrant birds (59 of 24,153 individuals) and showed variable use by some residents (9 species made more than 100 visits during 178 full days of observations). These researchers concluded that, although color video improved the ability to identify small species, the technical challenges, expense of deploying the cameras, and the person hours required to examine thousands of hours of video provided a questionable return (Lynn et al. 2008). While these studies provide insight into the species composition and frequency of visits to water developments, they still lack quantitative information on the contribution of water developments to the water balance of resident and migrant birds, as well as the sphere of influence the water developments have at the local scale. These unanswered questions, combined with the large number of water developments on the landscape, required a new approach to gathering information on the use and importance of water developments to the bird community.

The focus of this study was to quantify the use of water developments by resident birds during the summer and Neotropical migrants in the spring. We were also interested in estimating the distance individuals would travel to use free water resources.

METHODS

Study Area

We conducted our study on the Kofa National Wildlife Refuge (KNWR) in Southwestern Arizona, 15 km south of interstate highway 10 near Quartzsite, AZ, north of interstate 8 and east of highway 95. Elevation ranged from 428-530 m, latitude 33°27'N to 33°30’N and longitude114°10'W to113°52'W. The KNWR (269,300 ha) resides in the Lower Colorado River Valley subdivision of the Sonoran Desert and consists of wide scattered valleys nestled between rocky mountain ranges. We sampled the bird community around three Arizona water developments (Tank 738, New Water Well, and Scott's Well) during spring and summer from 2007 to 2009. Tank 738 (33°27'7. 16"N, 114°10'7.07"W) consists of a metal collection surface, runoff feeds into a buried storage tank, and supplies water to the drinking basin. The drinker is an uncovered concrete basin with an access ramp. New Water Well (33°30'35.36"N, 113°52'10.48"W) consists of a concrete basin covered by a 4 x 4 m corrugated tin roof 2.5 m above ground level to slow evaporation. New Water Well pulls ground water via windmill; water is then stored in an above ground storage tank that feeds water to the drinking basin. Scott’s Well (33°30'1.16"N, 114° 3'21.76"W) is set up in the same manner as New Water well. A pipe fence to exclude livestock surrounds all the above water developments. Dominant plant species at the sites included catclaw acacia (*Acacia greggii*), creosote bush (*Larrea tridentate*), foothill palo verde (*Cercidium microphyllum*), ironwood (*Olneya tesota*), velvet mesquite (*Prosopis velutina*) and saguaro (*Carnegiea gigantea*). Temperature and precipitation data were obtained from the Kofa Mine weather station (National Weather Service, http://www.ncdc.noaa.gov/oa/ncdc.html). For 2007, mean maximum temperatures during the field season ranged from 33.8-39.8°C and monsoonal precipitation was 62 mm during July. In 2008 mean maximum temperatures ranged from 30.9-39.6°C (May-August) with 34 mm of precipitation in July. Mean maximum temperatures for 2009 (May-July) ranged from 35.1-41.4°C and 15 mm of precipitation during the month of July. Maximum air temperatures reached 41.6°C, 45°C and 44.4°C during 2007 (4 July), 2008 (6 June) and 2009 (17 July), respectively.

Data Collection

Using stable isotopes to trace water movement through a food web. — Our approach relies on the observation that the δD and δ^{18}O of water in the environment follows the global and local meteoric water lines (Craig 1964). This local rainwater is transferred into the food web (plants, insects and birds) either directly through drinking of free water or indirectly through consumption of plant or animal materials containing water from the local environment. Birds consuming plant or animal materials show δD and δ^{18}O body water values that reflect the values of the food and water they consume with some offset due to animal physiology (discrimination) (Mckechnie et al. 2004). Because the δD and δ^{18}O of the body water are correlated, plotting these values for the bird community produces a baseline for the bird community that incorporates physiological processes and natural variation in water resources. Use of specific water developments can then be traced by labeling water developments with small amounts (0.3-0.5L label:4800L well water) of highly enriched (98 atom%) deuterium oxide which boosts the δD of the water development by 400 to 600‰ VSMOW. Because of the large differences in the δD of the development water (+600‰) compared to natural water sources (-60‰), even modest use of the development is easily detected by sampling a bird's body water (blood plasma in this case). The use of other resources that show enriched δD values in the environment such as saguaro cactus fruit

(Wolf et al. 2002) can also be accounted for by looking for enriched $\delta^{18}O$ values in animals, which indicates that an animal has fed on an enriched natural food. The relative proportion of the animal's body water pool derived from the development can then be estimated using a two end-point mixing model (Martínez del Río and Wolf 2005). In this manuscript we report stable isotope values using the delta notation (δ) on a per mil basis (‰) compared to an international standard; for the δD and $\delta^{18}O$ of water the standard is Vienna Standard Mean Ocean Water (VSMOW). Isotopic ratios are expressed as:

$$\delta \text{ Sample} = ((R_{sample}-R_{standard})/(R_{standard})) \text{ X } 1000$$

where R_{sample} and $R_{standard}$ are the ratios of heavy to light isotopes (Craig 1964).

Spiking the water developments. — Water developments were spiked with deuterium oxide one to 3 days before each sampling period. New Water Well and Scott’s Well windmills were stopped before spiking and re-started after the last day of netting to prevent dilution of the spiked holding tank water. Holding tanks (approximately 4800 L) were spiked with 300 to 550 ml of 98 atom% deuterium oxide. Deuterated water was poured directly into the holding tank then mixed by pumping air into the bottom of the tank to mix the contents. About 80 L of water was then removed from the drinking basin to draw spiked water from the holding tank to the drinking trough. An additional 30 ml of 98 atom% deuterium oxide was added to the trough and mixed. After the spike, well δD values ranged from 250 to 825‰ VSMOW. As δD values of the developments increased seasonally because of carryover from the previous spike, we reduced the amount of deuterium oxide added during later trips in the season.

Sampling the bird community. — Animal research was conducted under the approval of the University of New Mexico’s institutional animal care and use committee, a federal permit issued by the KNWR; birds were banded under a U.S. Bird Banding Permit 22482. Eighteen trips that included 2 to 5 capture days were made to KNWR between May 2007 and July 2009. During each visit, we set up 20 to 30 Japanese mist nets (JFO Sales, 12 m x 30 mm, 36 mm, and 61 mm mesh) at 50 to 100 m intervals along xeroriparian washes adjacent to wells, out to a maximum distance 1 km from each water development. We quantified the minimum distance traveled by each species visiting the well by recording the net number of each captured bird; net numbers represented the net's distance in meters from a well. Nets were typically opened 30 to 60 minutes before civil sunrise and closed before solar heat loads and air temperatures produced significant heat stress in netted birds. All birds except those classified as game birds (doves and quail) were banded with USFWS aluminum leg bands. Blood samples were obtained by brachial veinapuncture. Between 25 and 100 µl of blood was obtained from most individuals. Tubes were then sealed and stored on ice in a cooler. Plasma and red blood cells were separated on the day of collection by using a microhematocrit centrifuge (Clay Adams Readacrit; Parsippany, NJ, USA). Plasma was transferred to a micro-pipette (100µL; Drummond Scientific Co., U.S.A.) and flame sealed for later distillation and analysis at the lab.

Background source sampling. — A limited number of samples from common perennial plants were collected around the water development from 2007-2009 to provide information on the natural range of δD and $\delta^{18}O$ in waters from the local food web. Stem, leaf and fruit samples were collected and placed in 8 dram borosilicate glass vials (VWR 66011-165; West Chester, Pa, USA), capped tightly, and stored in a cooler on ice. Plant stem samples provided an estimate of ground water values and leaf samples represent water resources obtained by herbivorous insects. During 2008 and 2009, we also sampled a limited number of arthropods from the area surrounding New Water Well and Scott's Well. Arthropods were collected opportunistically during the day and on a few occasions were collected at night using a black light. Pure water for analysis was obtained from plant stems, leaves, fruit and arthropods by cryo-distillation as described in West et al. (2006). Isotopic values for arthropods provide an estimate of the water values available for insectivorous birds.

Stable isotope analyses. — We measured the δD and $\delta^{18}O$ values of water samples obtained from water sources, plants, arthropods and birds using a Los Gatos Research Liquid-Water Isotope Analyzer (DLT-100, Part no. 908-0008), which uses off-axis integrated cavity output spectroscopy (OA-ICOS) to analyze the atomic ratio of ^{2}H (deuterium) to protium and $^{18}O/^{16}O$ of water samples. Distilled samples (10 to 100 µl) were pipetted into glass vials and sealed with caps and septa (C4013-40A, National Scientific; Rockwood, TN, USA). During analysis, water samples were bracketed by laboratory standards, so that, two unknowns were bracketed by a known standard to correct raw data values (Lis et al. 2001).

Data Analysis

Estimation of proportion of body water derived from water developments. — Enrichment of δD of avian body water above the baseline values was used to estimate the percentage of an individual's body water pool derived from the labeled development. To estimate the proportion of body water derived from the enriched water resources we used a two end-point mixing model (Martínez del Río and Wolf 2005):

$$\delta D_{bird}=(P)*\delta D_{spike} + (1-P)* \delta D_{baseline}$$

simplified to: $P= \delta D_{bird} - \delta D_{baseline}/\delta D_{spike} - \delta D_{baseline}$

Here, P is the proportion of body water that was derived from the water development. δD_{spike} is the value in ‰ VSMOW of the enriched resource at the time of sampling. $\delta D_{baseline}$ is the baseline value in δD‰ VSMOW of the sampled bird based on the regression of $\delta^{18}O$ and δD for all non-users. This baseline value for δD was used to provide the second end-point for the mixing model. We produced baseline regressions for residents and Neotropical migrants. Because the natural variation in the δD of water resources (insects, plant materials and other free water sources) was approximately 150‰ VSMOW, we used the $\delta^{18}O$ values from each individual sampled and the regression line generated for $\delta^{18}O$ and δD from all birds not using the well to generate a baseline δD value for each individual. Any individual value falling to the right of the 95% confidence interval of the appropriate baseline was considered to be using the water development. This procedure enabled us to estimate the proportion of a bird's body water that came from the spiked water development even when the individual was using other naturally enriched water sources such as saguaro fruit. This procedure also compensated for enrichment of the individual's body water due to physiological processes (McKechnie et al. 2004).

RESULTS

Bird Captures

During the 3-year study period, nets were open for a total of 6200 net hours (# nets x hours open x # days); we captured 1,944 birds, representing 21 families and 59 species. Mourning Doves (*n*=112; 7.8%), Ash-throated Flycatchers (*Myiarchus cinerascens* [*n*=115; 8%]), Verdins (*n*=125; 8.7%), and House Finches (*n*=198; 13.8%) made up the majority of captured resident species for all three years. Pacific-slope Flycatchers (*Empidonax difficilis* [*n*=50; 3.5%]), Western Tanagers (*Piranga ludovicana* [*n*=55; 3.8%]), Warbling Vireos (*Vireo gilvus* [*n*=60; 4.2%]) and Wilson's Warblers (*Wilsonia pusilla* [*n*=66; 4.6%]) were the most commonly sampled Neotropical migrant (Corman and Wise-Gervais 2005) species (Table 1). *Water development and Plant samples*. — Water samples were obtained from water developments each sample period on days when the nets were open, the ranges for each year and sample site are found in Table 2. The δD and δ^{18}O of water extracted from plant tissues varied extensively, with stem samples representing ground water values and leaf and fruit samples representing the enriched water sources accessed by many animals in the food web (Figure 1). Fruit and leaf samples enrich (more of the heavy isotope is present) due to transpiration and evaporation. Mistletoe (*Phoradendron californicum)* fruit showed the highest enrichment in both δ^{18}O and δD (Table 3a) followed by Saguaro and Wolfberry (*Lycium sp*). Leaf samples represent water available to herbivorous insects (Arthropod values are listed in (Table 3b)). Arthropods represent available sources for insectivorous birds. Stem values indicate ground water values and remain close to rainwater samples collected during the monsoon season.

Baseline Regression Lines for the Bird Community

To determine if a member of the bird community was using a water development we plotted a regression line for each year using the δD and $\delta^{18}O$ and values of birds clearly not using the enriched resource. The resulting regression line and the δD and $\delta^{18}O$ values obtained from the enriched water developments were used to estimate the relative contribution of the water development to an individual's body water pool. Birds with δD values falling to the right of the 95% confidence interval line (dashed) were considered to be using the well. Birds whose data points fell furthest from the line had the greatest reliance on the well water. The regression line used for resident non-users for 2007 ($y = 0.2034x + 7.131$, $r^2=0.95$, $P<0.0001$), 2008 ($y = 0.1962x + 8.119$, $r^2=0.85$, $P<0.0001$) and 2009 ($y = 0.1818x + 6.852$, $r^2=0.81$, $P<0.0001$) are illustrated (Figures 2-4). Animals falling to the left side of the 95% confidence interval have been left out for clarity and the range of well values for each year is represented by the horizontal line showing enriched δD values. We combined all non-user data for 2007 to 2009 to produce a single regression to illustrate how each feeding guild (i.e. insectivores, neotropical migrants, etc.) used the water developments, however; for the calculations in the mixing model, we used the regression line of each sample bird's year of capture and the water development value closest to the date of capture.

Water Development Use by Resident and Migrant Birds

A summary of captures, isotopic samples and most common species using the well each year shows that birds visiting the wells had 13% or more of their body water derived from these sources (Table 4). Granivorous birds relied the most heavily on water developments for supplementary water. Among resident birds, Mourning Doves showed the highest individual body water pool derived from the water developments at 48.8% or more each year. Large granivores including Gambel's Quail (*Callipepla gambelii*), White-winged Doves (*Zenaida asiatica*), and Mourning Doves showed a high reliance on water developments (161 of 196 samples showed enriched δD values, Figure 5). Mourning Doves accounted for 55% (*n*=89) of users, followed by Gambel's Quail 26% (*n*= 42), White-winged Dove 19% (*n*= 30).

Granivorous resident passerines captured (*n*=275) included Black-throated Sparrows (*Amphispiza bilineata*), Brown-headed Cowbirds (*Molothrus ater*), House Finches, and Lesser Goldfinches (*Carduelis psaltria*). House Finches (*n*=92) and Lesser Goldfinches (*n*=8) were the only species from this group detected using the water developments (Figure 6).

We obtained 477 isotopic samples from passerines birds considered to be resident insectivores Nine species (Ash-throated Flycatcher, Brown-created Flycatcher [*Myiarchus tyrannulus*], Say's Phoebe (*Sayornis saya*), Verdin, Cactus Wren [*Campylorhynchus brunneicapillus*], Black-tailed Gnatcatcher, Northern Mockingbird, Phainopepla and Scott's Oriole [*Icterus parisorum*]) showed enriched body water δD values indicating use of the water developments (Figure 7). Apparent use percentages were highest in Northern Mockingbirds (*n*=9) and Phainopeplas (*n*=13). Northern Mockingbirds were most reliant on the water developments with half of all captured individuals (9 of 18) showing enriched body water δD values during 2008 and 2009. Phainopeplas were not detected using the water developments during 2007 and 2008, but showed extensive use during June 2009. Of 40 Northern Mockingbirds and Phainopeplas captured during May and June, 12 of 13 enriched samples were obtained from juvenile birds captured during June. Of the three species of woodpeckers sampled (*n*=55), [Gilded Flicker (*Colaptes chrysoides*), Gila Woodpecker and

Ladder-backed Woodpecker (*Picoides scalaris*)] only the Gila Woodpecker showed occasional use of the water developments (Figure 8).

Sixty two nocturnal residents including the Western Screech Owl (*Megascops kennicottii*), Elf Owl (*Micrathene whitneyi*), Lesser Nighthawk (*Chordeiles minor*), and Common Poorwill (*Phalenoptilus nuttallii*) were captured during the evening or early morning. Thirty individuals obtained water from the water developments (Figure 9). Common Poorwills accounted for 57% (*n*=17) of the 30 enriched samples, followed by Western Screech Owls 37% (*n*=11) and Lesser Nighthawks 7% (*n*=2). Elf Owls captured during 2007 and 2009 were not detected to be using the water developments.

Neotropical migrants showed very limited use of water developments during the 3-year sampling period. Of 364 migrants sampled only nine species, with one individual from each species, showed enriched body water δD values indicating water development use (Figure 10): Black headed Grosbeak (*Pheucticus melanocephalus*), Bullock's Oriole (*Icterus bullockii*), Lark Sparrow (*Chondestes grammacus*), Lazuli Bunting (*Passerina amoena*), Swainson's Thrush (*Catharus ustulatus*), Warbling Vireo, Western Tanager, Willow Flycatcher (*Empidonax traillii*), and Yellow-rumped Warbler (*Dendroica coronata*).

Distance Traveled to Use Water Developments

Some birds are known to travel considerable distances to reach water, for example, Mourning Doves and White-winged Doves travel 8 to 16 km to obtain water on a daily basis (Gubanich 1966). However, little is known about how far other species will travel reach water resources. The minimum observed distance traveled by birds to water developments ranged from 1 to 960 m (Table 5). Several species apparently traveled more than 250 m to use water developments, including Gila Woodpecker (488 m), Brown-Crested Flycatcher

(704 m), Cactus Wren (356 m), Northern Mockingbird (354 m), and House Finch (289 m). Neotropical migrants using the water developments were all netted within 200 m of the water development. Gambel's Quail were trapped out to a distance of 360 m and 82% of samples showed enrichment, suggesting that they relied heavily on water developments. We were unable to determine the actual distance that nocturnal birds traveled to use the water development because night trapping was focused on bats and only occurred at the water development site.

DISCUSSION

Water developments have been used as a management tool for game and non-game species since the 1940's (Rosenstock et al. 1999), but their contribution to the water budgets of free-ranging wildlife has not been quantified. Although a number of studies have documented visitation rates to water developments by resident and migratory birds (Elder 1956, Gubanich 1966, Cutler and Morrison 1998, Lynn et al. 2006, O'Brien et al. 2006 and Lynn et al. 2008), this is the first study that directly quantified the importance of water developments to a bird community. We found that water developments make a significant contribution to the water balance of a limited subset of the resident bird community and that these resources can account for > 90% of the body water pool of some species. We observed some resident insectivores traveling several hundred meters to access these reliable surface water resources. Resident granivores such as doves moved large distances to access water resources, but constraints inherent in our sampling approach precluded meaningful estimates of the scale of these movements. In the following paragraphs, we examine our results in detail by discussing: 1) the importance of water developments to resident birds and how our data compare to other studies, 2) the distances individual species travel to access free water, 3) the apparent lack of importance of water developments to Neotropical migrants, and 4) the potential implications of these resources on desert bird communities.

Resident Use of the Water Developments

Surface water is scarce during most of the year in the Sonoran Desert. Consequently, only resident species that can fly long distances to reliable water sources or that live nearby these sources can depend on surface water on a day-to-day basis. The lack of surface water resources during the hottest and driest periods of summer (May, June and July) over most of the region has lead to a diversity of strategies (insectivory, frugivory, evasion-migration, daily flights to water) by birds to balance their water budgets during times of heat and water stress. Our work suggests that many avian species may not have the behavioral flexibility needed to exploit the more abundant surface water resources provided by humans and available today. Our observations support those of earlier researchers (Gubanich 1966, Lynn et al. 2006, 2008; O'Brien et al. 2006), and reveal that most resident species only make occasional visits water developments. There were, however, some exceptions to this rule, Mourning and White-winged Doves accounted for the majority of visits to water developments, demonstrating their significant dependence on these water sources. Among the 145 doves sampled, for example, 119 of 145 birds had isotopic values that indicated an average of 58% of their body water pool was derived from the water development where they were captured (Table 5). Doves are known to fly substantial distances (8-16 km) to exploit surface water resources and are dependent on these resources for breeding (Walsberg and Voss-Roberts 1983). Both dove species breed during June and their nests are often placed in sites exposed to intense solar radiation (BO Wolf personnel com.). High air temperatures and large solar heat loads require incubating to birds cool their eggs via evaporating large amounts of water from their skin and respiratory tract and result in high water requirements for all birds. Male and female doves share incubation duties and both sexes must make daily visits to surface water. Water developments, thus potentially increase breeding densities and reproductive success in desert dove populations, as well as mitigate the demands of modest environmental temperature increases.

Although Gambel's Quail use surface water resources when they are available, no studies have shown that they are reliant on free water for survival during the summer. This species appears to acquire the water they need from succulent vegetation, fruits and insects (Vorhies 1928, Lowe 1955), but cannot survive on a diet of dry seeds alone (McNab 1969). During the summer, however, succulent plant material may be in short supply and increased water losses due to high environmental temperatures produces water demands that can only be met through extensive drinking (Bartholomew 1972). We found that Gambel's Quail and their young were frequent visitors to water developments throughout the summer. Of the 51 quail sampled, isotopic analyses showed that 42 individuals were using the water development with an average of 44% of their body water pool derived from these man-made developments. Some of these water requirements may be mitigated by constraints on activity. In deserts of the southwest, quail limit foraging activity to the early morning hours and the late afternoon and evening (Goldstein 1984). During the hottest parts of the day, quail remain inactive and seek shaded microsites, which minimizes thermal stress and rates of evaporative water loss. Goldstein (1984) showed that this reduction in activity and retreat to shaded microsites may be critical to their survival in hot in environments. By using operative temperature measurements, which describe the thermal stress imposed by complex thermal environments, Goldstein (1984) showed that when air temperatures ranged above 45°C, activity in sunlit sites longer that a few minutes would lead to heat stroke.

Smaller birds such as House Finches and Lesser Goldfinches have high water demands during the summer and were expected to frequent the water developments. House Finches were the most frequently captured species near water developments. Most House Finch captures occurred within 10 m of the water developments and included flocks of 10 to 20 individuals and family groups. Of the 198 birds sampled, 92 showed recent use of the water development (within a few days). On average, 41 % of the body water pools of House

Finches were derived from water developments. House Finch captures decreased as the summer progressed and as environmental temperatures increased. Lesser Goldfinches were also detected using the water developments, but were not captured after the first week in May. Of the nine birds captured in 2009, 8 were found to be using the water developments with an average of 36% of their body water derived from the water development. As summer progresses increasing air temperatures and declining availability of succulent fruit produce an increasingly challenging environment. Bartholomew and Cade (1956) studied water requirements for House Finches and found that as ambient temperature increased so did water consumption. As a consequence, granivores such a House Finches and Lesser Goldfinches appear to withdraw from parts of the desert where water is scarce during the hottest period of the summer when water demands are highest.

Black-throated Sparrows, were common year-round residents in the Sonoran Desert and were less frequently captured during our netting operations. Of the 57 birds sampled in May, June and July during this study, none were detected using the water developments. Our data thus differ from those of Smyth and Bartholomew (1966) who frequently observed Black-throated Sparrows visiting a natural tank in the southern Mojave Desert of California during August through October. Our observations may reflect the greater abundance of vegetation and insects present in the Sonoran Desert during this period and the extensive use of these succulent foods by Black-throated Sparrows (Johnson et al. 2002). These feeding behaviors provide for the continuous occupancy of desert regions by Black-throated Sparrows, which contrasts with the limited periods of occupancy observed in House Finches and Lesser Goldfinches.

Insectivorous birds are under much different constraints compared to granivores because of their succulent insect diet, which allows them to obtain water and energy from a single source. Arthropods are composed of 70 to 75% water by mass (2.33-3.0 ml H_2O/ 1g dry mass) and thus represent an abundant and continuous source of water for resident birds (Bell 1990). Diurnal resident insectivores such as the Northern Mockingbird, Phainopepla, Gila Woodpecker, Ash-throated and Brown-crested Flycatchers showed varying use of water developments. The greatest use by insectivores occurred during June, the driest and one of the hottest months of the year. Interestingly, only juvenile Northern Mockingbirds and Phainopeplas used the water developments; adult birds captured in May and June showed no evidence of visits to water developments. Nine of the18 mockingbirds sampled showed an average of 59% of their body water derived from the water developments with a maximum of 86% of body water in some individuals. Northern Mockingbirds are year-round residents in the Sonoran Desert and their diets are composed of insects and berries (Derrickson and Brietwisch 1992). The use of water developments by juvenile birds may be a facultative response driven by lower foraging efficiencies in young birds (Weathers and Sullivan, 1989) that may have difficulty balancing their water budgets during periods of severe heat stress. Although fruits and insects often contain > 50% water by mass, during periods where environmental temperatures exceed body temperature (i.e. June, July and August) birds maintain body temperatures below lethal limits by evaporating large quantities of water. Of the 40 Phainopeplas sampled, use of the water developments was detected in 13 juveniles with an average of 46% of their body water pool being derived from the water developments. Phainopeplas and Northern Mockingbirds may be under similar constraints where late breeding adults produce young that become independent in May and early June. Although most of the adult birds have left the desert by early June (Miyoko and Walsberg 1999), a few recently fledged juvenile birds and their parents may remain. Although Phainopepla diets consist of berries and insects (Miyoko and Walsberg 1999), young birds may have difficulty in balancing water budgets during this period of significant heat stress when their foraging efficiency is still low. Young birds also may not be prepared to migrate out of the desert immediately after fledging and thus may have to cope with a periods of heat stress as they are preparing for migration.

Locally, nocturnal insectivorous species such as the Common Poorwill, Lesser Nighthawk and Western Screech Owl showed frequent use of the water developments. Nocturnal birds were trapped at or near the water developments, during bat netting sessions, and 50% of all birds sampled (with the exception of Elf Owls) demonstrated consistent use of the water developments. Our stable isotope data indicate that the contributions of water developments to the body water pools of nocturnal species ranged from 9 to 47%.

Neotropical Migrants and the Importance of Water Developments

Avian migration is known to have high costs associated with the maintenance of energy requirements and water loss (Dawson 1982, Miller 1963, Carey 1996). Therefore, it is assumed that birds migrating through xeroriparian washes in the Sonoran Desert would readily exploit free water resources such as water developments during the course of their movements across these regions. Our labeling study supports the interesting observations of several researchers (Gubanich 1966 and Lynn et al. 2006 and 2008) showing that Neotropical migrants largely ignore water developments. We found that less than 3% (9 of 364 individuals sampled) of the migrants sampled within 1 km of the water development used the available surface water. Although we found that 9 of 25 migrant species used the water developments, only a single individual from each species used these resources (e. g. 1 of 60 Warbling Vireos and 1 of 55 Western Tanagers). Lynn et al. (2006) observed hundreds of migratory birds in the xeroriparian washes near water developments during fall migration, but they rarely used these water resources irrespective of winter precipitation. At their field sites, 18 species (21 individuals total) were observed using water developments over a two-year period, which included five species common to this study (Western Tanager, Warbling Vireo, Yellow-rumped Warbler, Lazuli Bunting and Bullock's Oriole). When migrants used water developments, Lynn et al. (2006) observed that sites with the greatest vegetation cover had the highest rates of visitation and that bird species richness and abundance at water developments was similar to habitats without water developments. Taken together, these observations suggest that water developments are not a "magnet" for migrant birds and do not appear to provide a critical resource to Neotropical migrants crossing the Sonoran Desert during the Spring or the Fall. Why migrant birds fail to make significant use of water developments remains unclear. Spring migration occurs during resource abundance (fruit, flowers and insects); given that this also is a period of moderate temperatures, there may be little demand for free water resources. Both insects and plant materials, such as fruits, mean that water is available and thus migrants may not be motivated to seek other sources of water.

MANAGEMENT IMPLICATIONS

Influence of WD on Surrounding Community

Our data show that water developments are of limited importance to the bird community in general. There are a number of species such doves, quail and a few other granivores (e.g. House Finches) that may be dependant on these water resources, but the few other species exploiting the resource appear to do so only occasionally. Our data generally support the findings of studies using other methods of observation such as videography (Lynn et al. 2008), but provide greater detail by providing verified identifications, quantitative estimates of the contribution of water developments to avian water balance, and estimates of the minimum distance traveled by species that are users. Increasing global temperatures combined with diminished precipitation inputs in many arid regions (IPCC 2007) suggests that surface water resources will become increasing scarce and thus potentially more important to a numbers of species that depend on free water for breeding or survival. Finally, isotopic labeling of water resources and using this approach to trace water movement through the food web shows significant promise for looking at the importance of scarce water resources to animal communities and can lend significant insight into the role that these waters play in arid landscapes.

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FIGURES

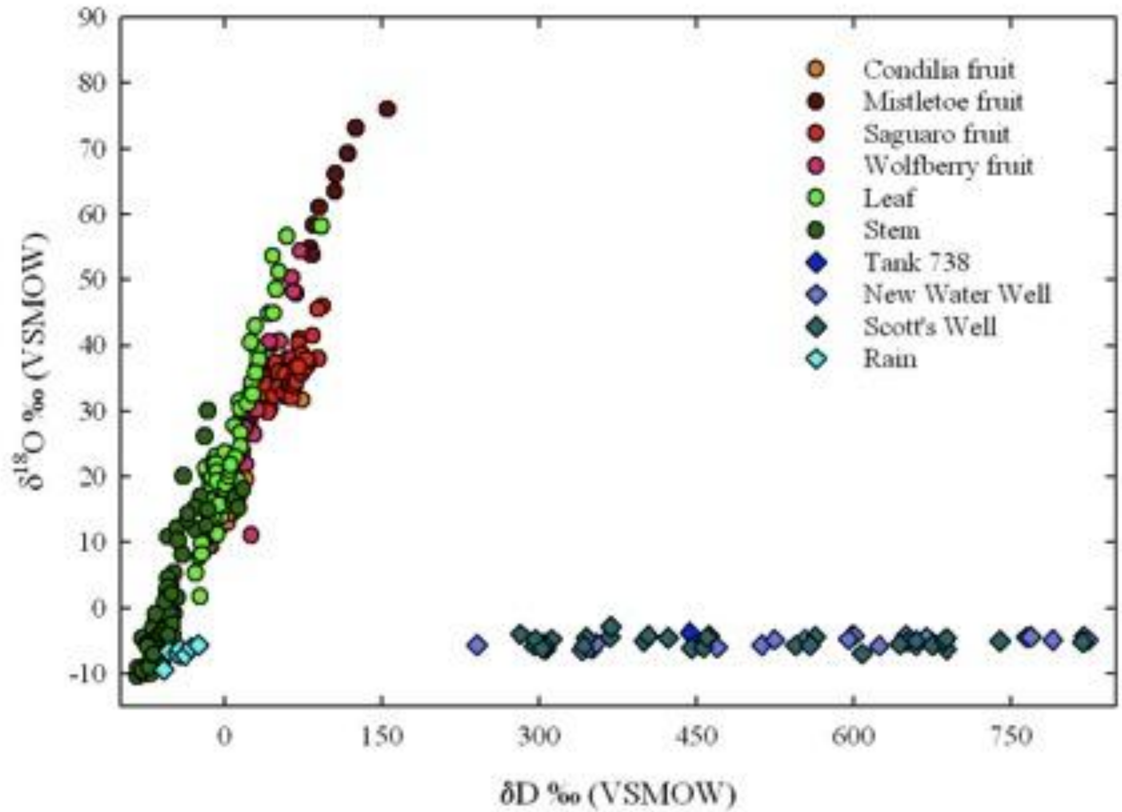

FIGURE 1. δD and $\delta^{18}O$ per mil (‰) VSMOW values from plant (fruit, leaf and stem) water samples, rain and water developments (Tank 738, New Water Well and Scott's Well) during the 2007-2009 seasons.

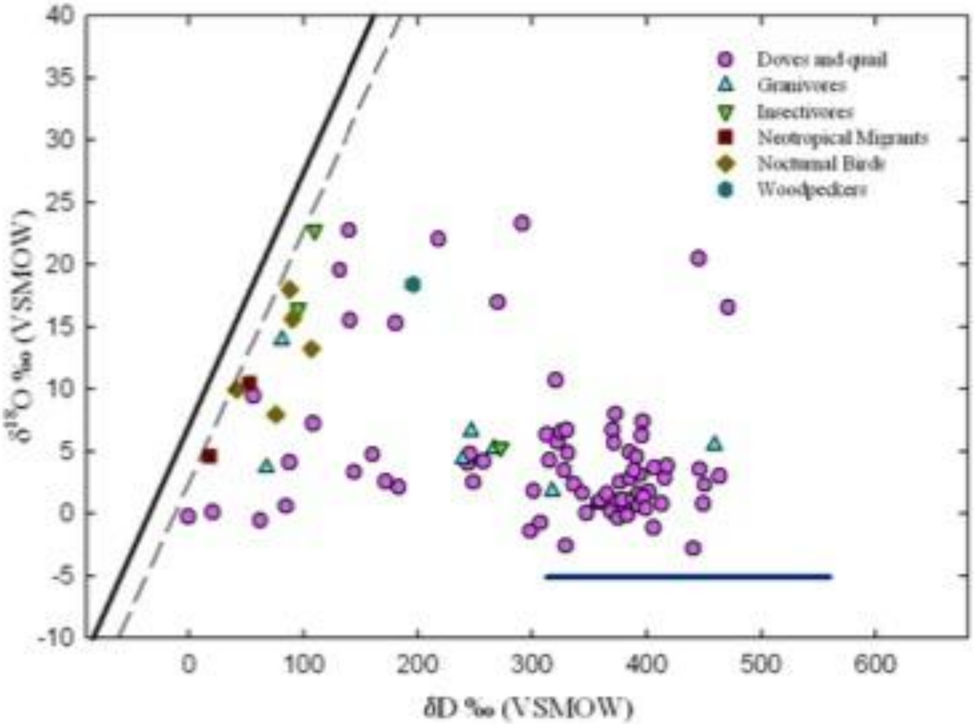

FIGURE 2. δD and $\delta^{18}O$ per mil (‰) VSMOW values from birds trapped at Tank 738 and New Water Well during spring and summer of 2007. Blue line represents the deuterium isotope values of both water developments for the total sample period. The regression line represents resident non-user values (y= 0.2034x +7.131, r^2=0.95, P<.0001). The dashed line represents the lower line of the 95% confidence interval; any birds falling to the right of the line were considered to be using the water developments.

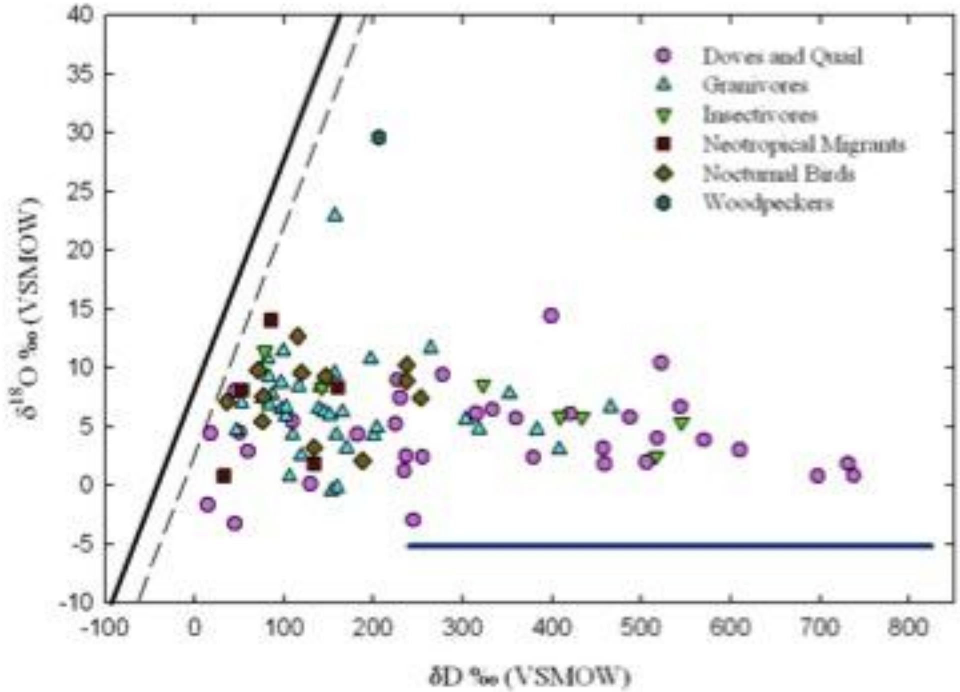

FIGURE 3. δD and δ^{18}O per mil (‰) VSMOW values from birds sampled at New Water Well and Scott's Well during spring and summer of 2008. Blue line represents the range of deuterium isotope values for both water developments during the sample period. Regression line (y= 0.1962x +8.119, r^2=0.85, P<.0001) is based on non-user values for 2008. Dashed line represents the lower line of the 95% confidence interval; any birds falling to the right of the line were considered to be using the water developments.

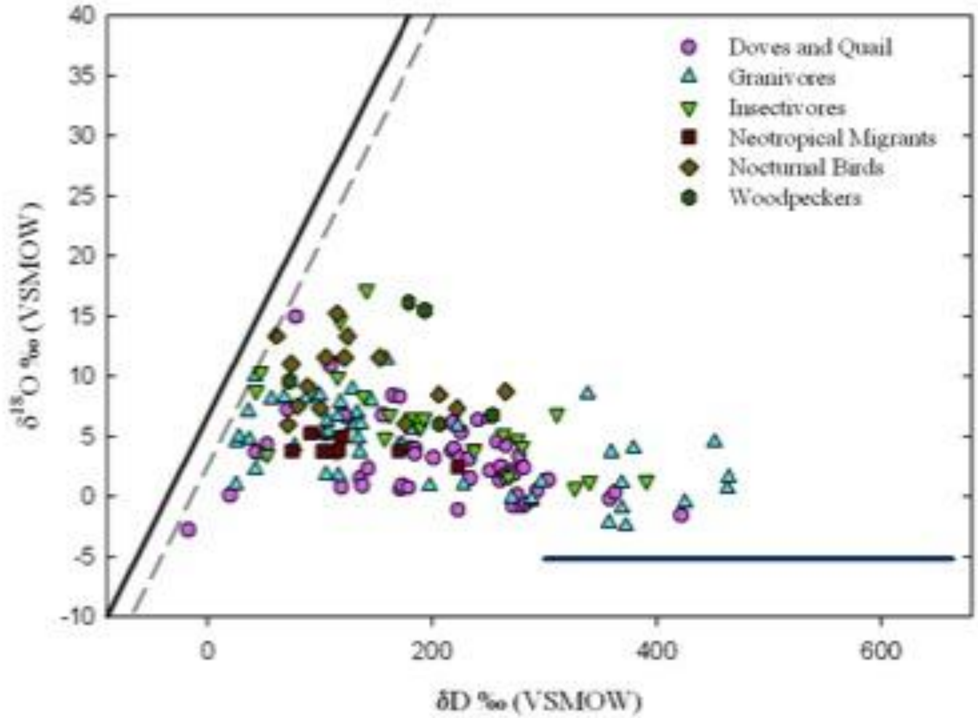

FIGURE 4. δD and δ^{18}O per mil (‰) VSMOW values from birds sampled at Scott's Well during the spring and summer of 2009. Blue line represents the deuterium isotope values of both water developments for the total sample period. The regression line (y= 0.1818x + 6.852, r^2=0.81, P<.0001) represents non-users for both wells. The dashed line represents the lower line of the 95% confidence interval; any birds falling to the right of the line were considered to be using the water developments.

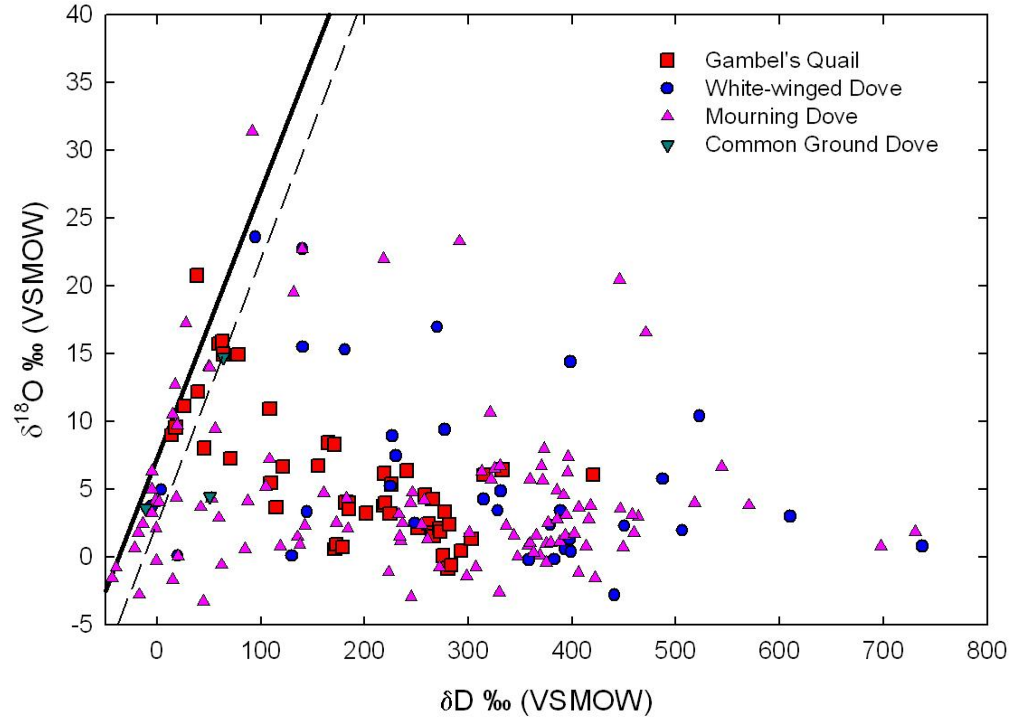

FIGURE 5. δD and δ^{18}O per mil (‰) VSMOW values from resident game birds sampled during the spring and summer of 2007-2009. The regression line (y= 0.1963x + 7.353, r^2=0.87, P<.0001) represents all non-user birds for the 2007-2009 seasons. The dashed line represents the lower line of the 95% confidence interval; any birds falling to the right of the line were considered to be using the water developments.

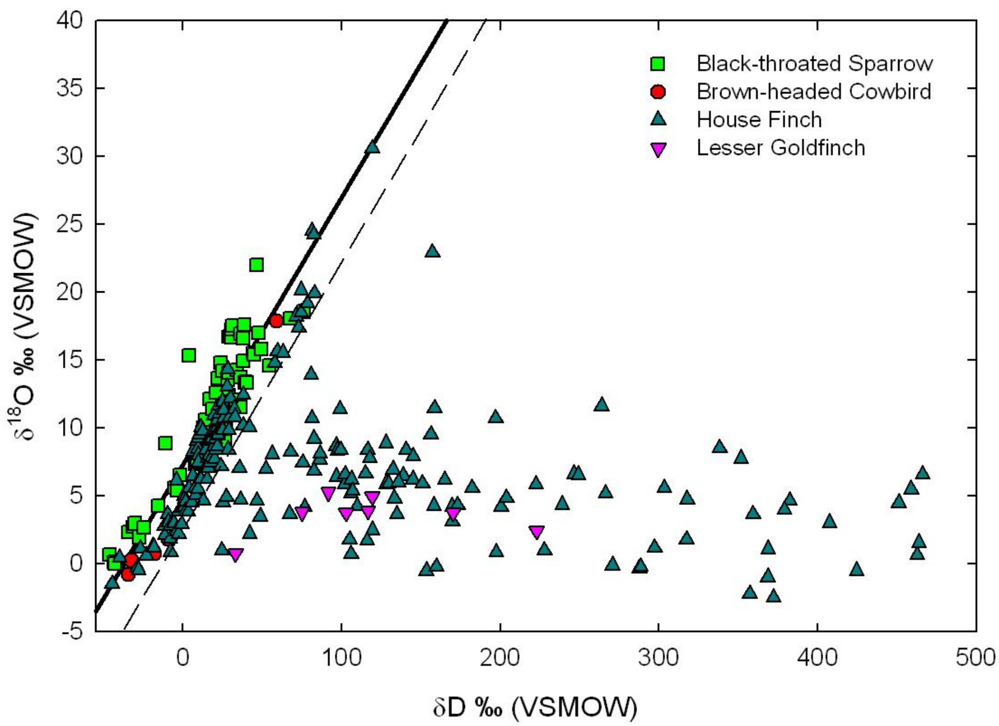

FIGURE 6. δD and $\delta^{18}O$ per mil (‰) VSMOW values from resident granivorous birds sampled during the spring and summer of 2007-2009. The regression line (y= 0.1963x + 7.353, r^2=0.87, P<.0001) represents all non-user birds for the 2007-2009 seasons. The dashed line represents the lower line of the 95% confidence interval; any birds falling to the right of the line were considered to be using the water developments.

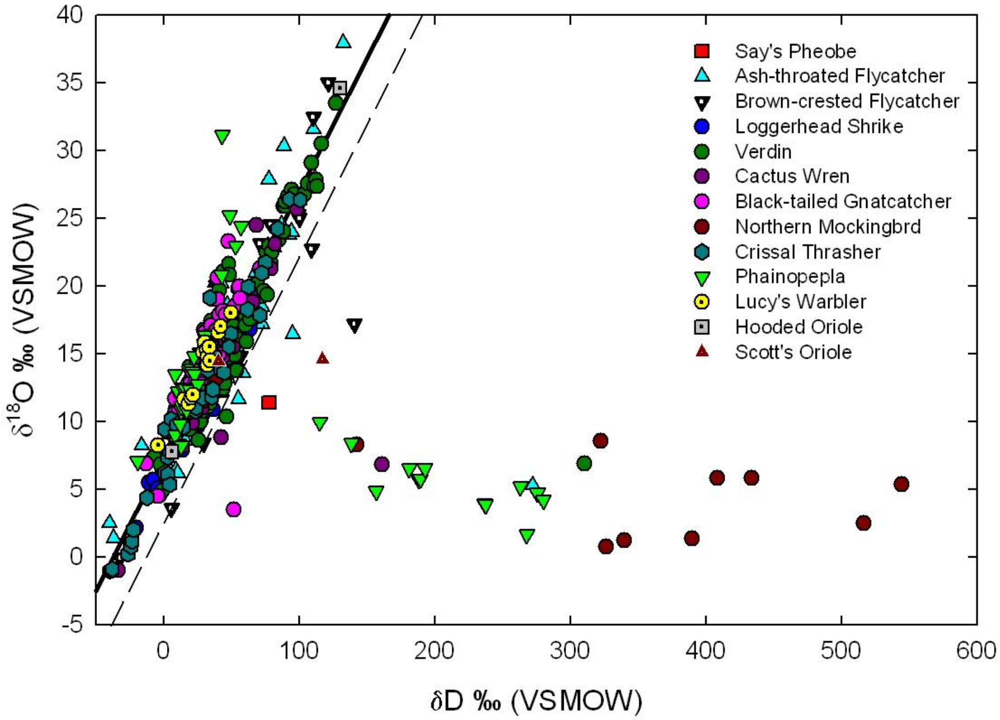

FIGURE 7. δD and $\delta^{18}O$ per mil (‰) VSMOW values from resident insectivorous birds sampled during the spring and summer of 2007-2009. The regression line ($y= 0.1963x + 7.353$, $r^2=0.87$, $P<.0001$) represents all non-user birds for the 2007-2009 seasons. The dashed line represents the lower line of the 95% confidence interval; any birds falling to the right of the line were considered to be using the water developments.

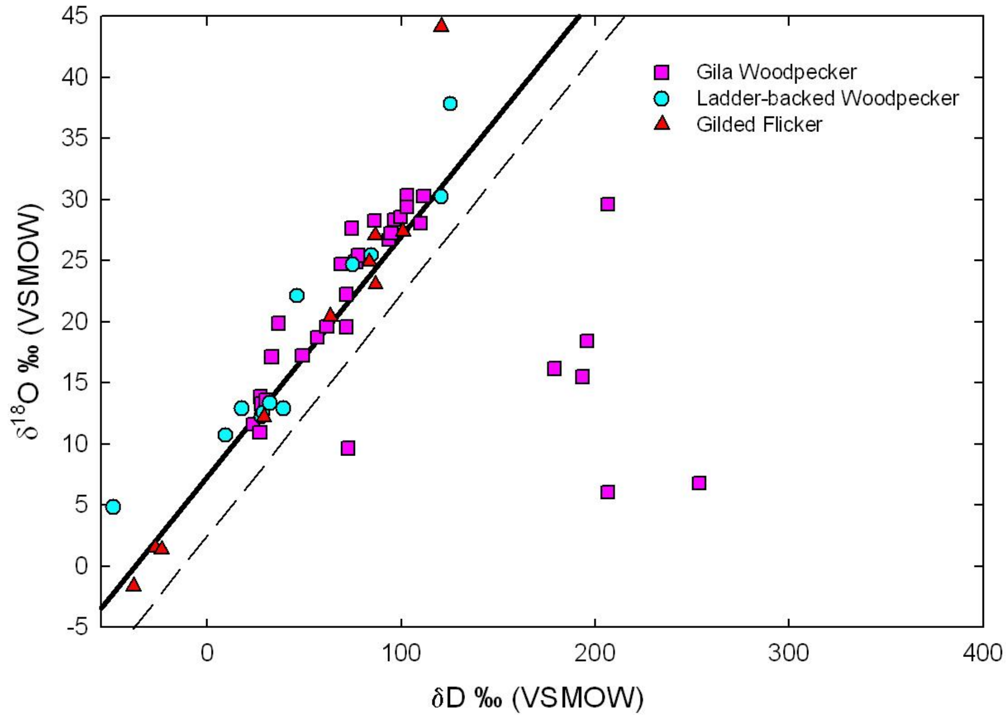

FIGURE 8. δD and $\delta^{18}O$ per mil (‰) VSMOW values from resident woodpeckers sampled during the spring and summer of 2007-2009. The regression line (y= 0.1963x + 7.353, r^2=0.87, P<.0001) represents all non-user birds for the 2007-2009 seasons. The dashed line represents the lower line of the 95% confidence interval; any birds falling to the right of the line were considered to be using the water developments.

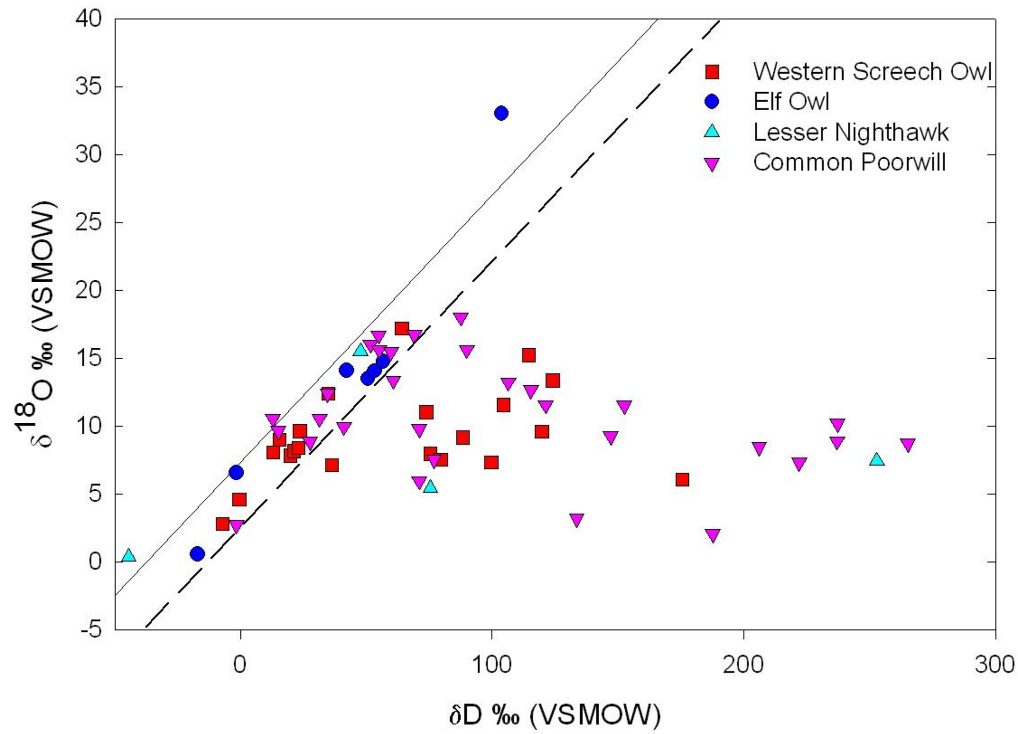

FIGURE 9 δD and $\delta^{18}O$ per mil (‰) VSMOW values (n=43) from resident nocturnal birds sampled during the spring and summer of 2007-2009. The regression line (y= 0.1963x + 7.353, r^2=0.87, P<.0001) represents all non-user birds for the 2007-2009 seasons. The dashed line represents the lower line of the 95% confidence interval; any birds falling to the right of the line were considered to be using the water developments.

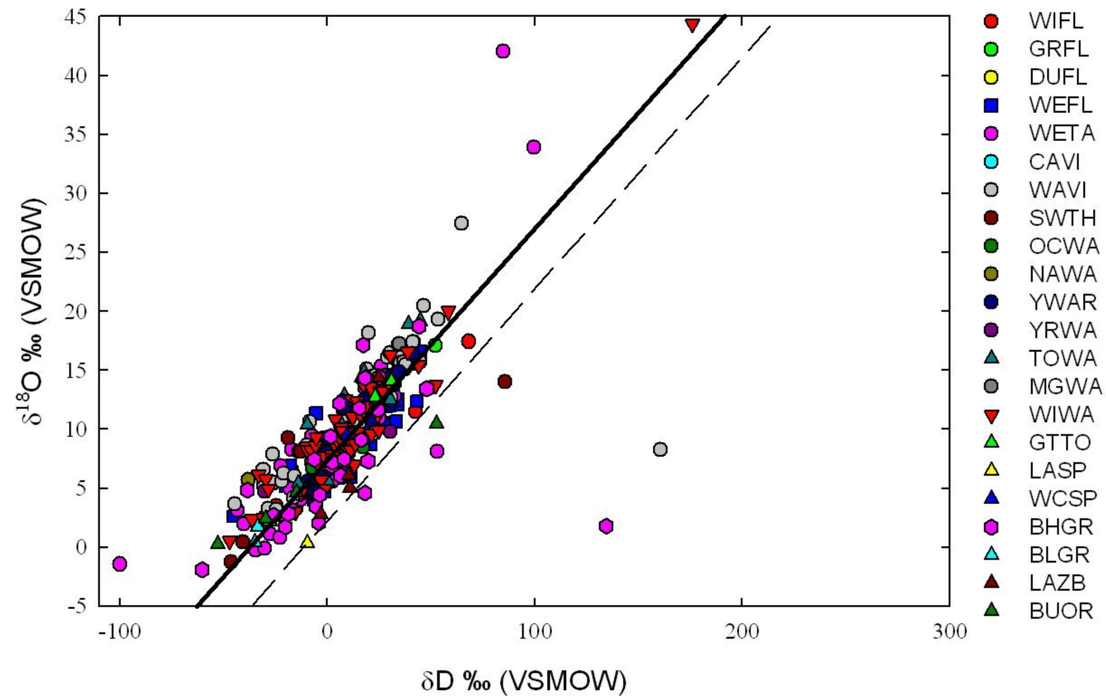

FIGURE 10. δD and δ^{18}O per mil (‰) VSMOW values from Neotropical migrants sampled during the spring and summer of 2007-2009. The regression line (y= 0.1963x + 7.353, r^2=0.87, P<.0001) represents all non-user birds for the 2007-2009 seasons. The dashed line represents the lower line of the 95% confidence interval; any birds falling to the right of the line were considered to be using the water developments.

TABLES

TABLE 1. Bird captures for which isotopic samples were obtained from blood. Birds were sampled at Tank 738 and New Water Well in 2007, at New Water Well and Scott's Well in 2008, and Scott's Well during 2009.

Birds- Summer and year-round resident species	***# Samples 2007/2008/2009 (total)***	***# Enriched 2007/2008/2009 (total)***
Gambel's Quail, *Callipepla gambelii*	0/7/44 (51)	0/5/37 (42)
White-winged Dove, *Zenaida asiatica*	17/14/2 (33)	16/12/2 (30)
Mourning Dove, *Zenaida macroura*	66/22/24 (112)	58/17/14 (89)
Common Ground Dove, *Columbina passerina*	0/3/0 (3)	0/1/0 (1)
Western Screech-Owl, *Megascops kennicottii*	5/4/12 (21)	1/2/8 (11)
Elf Owl, *Micrathene whitneyi*	6/0/1 (7)	0/0/0
Lesser Nighthawk, *Chordeiles minor*	0/3/1 (4)	0/2/0 (2)
Common Poorwill, *Phalenoptilus nuttallii*	7/13/10 (30)	3/7/7 (17)
Gila Woodpecker, *Melanerpes uropygialis*	7/14/12 (33)	1/1/5 (7)
Ladder-backed Woodpecker, *Picoides scalaris*	2/7/3 (12)	0/0/0
Gilded Flicker, *Colaptes chrysoides*	5/3/2 (10)	0/0/0
Say's Phoebe, *Sayornis saya*	0/2/0 (2)	0/0/0
Ash-throated Flycatcher, *Myiarchus cinerascens*	35/47/33 (115)	2/0/0 (2)
Brown-crested Flycatcher, *Myiarchus tyrannulus*	11/9/7 (27)	1/0/1 (2)
Loggerhead Shrike, *Lanius ludovicianus*	1/9/6 (16)	0/0/0
Verdin, *Auriparus flaviceps*	6/64/55 (125)	0/0/1 (1)
Cactus Wren, *Campylorhynchus brunneicapillus*	4/10/17 (31)	0/0/2 (2)
Black-tailed Gnatcatcher, *Polioptila melanura*	7/13/17 (37)	0/0/1 (1)
Northern Mockingbird, *Mimus polyglottos*	1/7/10 (18)	0/6/3 (9)
Curve-billed Thrasher, *Toxotoma curviroste*	2/0/5 (7)	0/0/0
Crissal Thrasher, *Toxotoma crissale*	8/15/16 (39)	0/0/0
Phainopepla, *Phainopepla nitens*	1/9/30 (40)	0/0/13 (13)
Lucy's Warbler, *Vermivora luciae*	0/12/4 (16)	0/0/0
Black-throated Sparrow, *Amphispiza bilineata*	10/27/25 (62)	0/0/0
Brown-headed Cowbird, *Molothrus ater*	3/1/2 (6)	0/0/0
Hooded Oriole, *Icterus cucullatus*	1/1/0 (2)	0/0/0
Scott's Oriole, *Icterus parisorum*	0/0/2 (2)	0/0/1 (1)
House Finch, *Carpodacus mexicanus*	9/58/131 (198)	7/38/47 (92)
Lesser Goldfinch, *Carduelis psaltria*	0/1/8 (9)	0/1/7 (8)

TABLE 1 Continued

Neotropical Migrants	***# Samples 2007/2008/2009 (total)***	***# Enriched 2007/2008/2009 (total)***
Willow Flycatcher, *Empidonax traillii*	0/8/1 (9)	0/1/0 (1)
Gray Flycatcher, *Empidonax wrightii*	0/4/0 (4)	0/0/0
Dusky Flycatcher, *Empidonax oberholseri*	0/0/2 (2)	0/0/0
Western Flycatcher, *Empidonax difficilis*	2/22/26 (50)	0/0/0
Unknown Flycatcher, *Empidonax spp.*	1/0/0 (1)	0/0/0
Western Tanager, *Piranga ludovicana*	28/20/7 (55)	0/1/0 (1)
Bell's Vireo, *Vireo bellii*	0/1/0 (1)	0/0/0
Cassin's Vireo, *Vireo cassinii*	0/2/0 (2)	0/0/0
Warbling Vireo, *Vireo gilvus*	14/37/9 (60)	0/1/0 (1)
Swainson's Thrush, *Catharus ustulatus*	1/8/1 (10)	0/1/0 (1)
Hermit Thrush, *Catharus guttatus*	0/1/0 (1)	0/0/0
Orange-crowned Warbler, *Vermivora celata*	1/2/2 (5)	0/0/0
Nashville Warbler, *Vermivora ruficapilla*	0/1/4 (5)	0/0/0
Yellow Warbler, *Dendroica petechia*	0/16/8 (24)	0/0/0
Yellow-rumped Warbler, *Dendroica coronata*	0/3/2 (5)	0/1/0 (1)
Townsend's Warbler, *Dendroica townsendii*	1/7/5 (13)	0/0/0
Hermit Warbler, *Dendroica occidentalis*	0/1/0 (1)	0/0/0
MacGillivray's Warbler, *Oporornis tolmiei*	0/2/2 (4)	0/0/0
Wilson's Warbler, *Wilsonia pusilla*	1/33/31 (65)	0/0/0
Green-tailed Towhee, *Pipilo cholrurus*	0/2/2 (4)	0/0/0
Lark Sparrow, *Chondestes grammacus*	0/0/1 (1)	0/0/1 (1)
White-crowned Sparrow, *Zonatrichia leucophrys*	0/4/0 (4)	0/0/0
Rose-breasted Grosbeak, *Pheucticus ludovicianus*	0/0/1 (1)	0/0/0
Black-headed Grosbeak, *Pheucticus melanocephalus*	8/11/7 (26)	0/1/0 (1)
Blue Grosbeak, *Passerina caerulea*	0/2/0 (2)	0/0/0
Lazuli Bunting, *Passerina amoena*	1/2/1 (4)	0/1/0 (1)
Bullock's Oriole, *Icterus bullockii*	2/2/0 (4)	1/0/0 (1)

TABLE 2. Seasonal values for water developments enriched in deuterium from 2007 to 2009. δD values are presented in ‰ referenced to VSMOW. Water value range represents days when birds were actively trapped.

Water development	***2007***	***2008***	***2009***
Tank 738	409-462 ‰		
New Water Well	304-553 ‰	241-823 ‰	
Scott's Well		295-834 ‰	282-659 ‰

TABLE 3. δD and δ ^{18}O values in per mil (‰) VSMOW for plant and Arthropod samples collected near Tank 738, New Water Well and Scott's Well during spring and summer of 2007-2009. Data shown are for all years. Arthropods were collected during 2008 and 2009.

	δD‰ VSMOW	**δ^{18}O‰ VSMOW**
	PLANTS	
Acacia constricta		
Stem	-63.0±7.1(11)	-3.6±4.5 (11)
Leaf	-7.3±9.8(4)	16.8±3.6 (4)
Acacia greggii		
Stem	-59.8±13.2 (20)	-1.2±11.8 (20)
Leaf	3.9±21.3 (19)	24.6±11.8 (19)
Carnegiea gigantea		
Stem	-33.1±24.7 (16)	1.9±6.3 (16)
Fruit	61.7 ± 15.3 (54)	35.5 ± 3.4 (54)
Cercidium Microphyllum		
Stem	-52.5±18.7 (19)	1.2±8.8 (19)
Leaf	15.2±7.5 (6)	25.4±5.6 (6)
Condalia globosa		
Stem	-39.9±390. (15)	1.6±11.4 (15)
Leaf	13.7±31.6 (9)	24.3±14.4 (9)
Fruit	4.7±18.3 (20)	15.5±4.8 (20)
Justicia californica		
Stem	-21.2±2.7 (2)	21.6±6.4 (2)
Leaf	52.3±9.8 (2)	55.1±2.1 (2)
Lycium		
Fruit	27.9±21.8 (24)	29.4±11.8 (24)
Olneya testota		
Stem	-59.5±9.5 (21)	-1.9±7.1 (21)
Leaf	11.6±23.8 (16)	27.4±13.4 (16)

TABLE 3 Continued

	δD‰ VSMOW	$\delta^{18}O$‰ VSMOW
PLANTS		
Phoradendron californicum		
Fruit	82.1±42.9 (13)	54.2±17.5 (13)
Prosopis velutina		
Leaf	-7.8±9.5 (19)	16.5±4.9 (19)
Stem	-58.6±10.6 (16)	-1.4±6.4 (16)
ARTHROPODS		
Arachnida	-55.0±0 (1)	-2.0±0 (1)
Coleoptera	-46.8±26.5 (42)	-2.1±5.3 (42)
Hymenoptera	3.89±29.1 (10)	4.4±5.7 (10)
Hymiptera	8.0±20.3 (5)	7.0±3.9 (5)
Lepidoptera	40.6±27.9 (3)	20.9±3.1 (3)
Mantodea	2.0±0 (1)	5.0±0 (1)
Odonata	-40±0 (1)	1±0 (1)
Orthoptera	10.0±40.5 (11)	12.2±13.2 (11)
Phasmatodea	-7.0±0 (1)	9.0±0 (1)

TABLE 4.Number of bird captures for each year and the isotopic samples obtained from blood samples. Table below represents the most common bird species using water developments for each year and their body water percentage (mean ± SD (range, number)).

	2007	***2008***	***2009***
Capture total	427	785	732
Isotopic samples	274	566	591
Total number of birds using enriched source	90	99	150
Number of species captured	33	49	44
Species % use of water development	***2007***	***2008***	***2009***
Gamble's Quail	N/A	33.0 ± 14.8 (36, n=5)	45.0 ± 16.0 (68, n=37)
White-winged Dove	68.5 ± 27.3 (84, n=16)	59.8 ± 22.6 (64, n=12)	47.7 ± 43.3 (69, n=2)
Mourning Dove	71.9 ± 24.7 (91, n=58)	50.3 ± 25.1 (79, n=17)	48.8 ± 21.3 (63, n=14)
Western Screech Owl	15.0 ± 0 (0, n=1)	13.1 ± 0.3 (0, n=2)	18.0 ± 9.0 (23, n=8)
Common Poorwill	19.6 ± 7.2 (15, n=3)	24.5 ± 8.6 (23, n=7)	30.4 ± 15.0 (41, n=8)
Phainopepla	N/A	N/A	46.4 ± 13.2 (40, n=13)
House Finch	52.0 ± 30.3 (89, n=7)	35.4 ± 15.8 (52, n=38)	43.6 ± 23.2 (88, n=47)

TABLE 5. Water development use by resident and migrant birds in 2007-2009. Data shown are the estimated percentages of body water derived from the water development for each species using the enriched water source, the total number of each species sampled (including the number using the water development), and the distance that individual birds had to travel to use the enriched water resources.

Species	**% Body water pool (mean ± SD (range))**	**# Sampled (# using water development)**	**Min. Distance Traveled (m)**
RESIDENT BIRDS			
Gambel's Quail, *Callipepla gambelii*	43.6 ± 16.2 (8-76)	54 (42)	1, 303, 360
White-winged Dove, *Zenaida* asiatica	63.6 ± 26.4 (13-100)	33 (30)	2
Mourning Dove, *Zenaida macroura*	64.2 ± 26.3 (9-100)	102 (89)	833, 960
Common Ground Dove, *Columbina passerina*	10 ± 0 (0)	3 (1)	13
Western Screech-Owl, *Megascops kennicottii*	16.8 ± 7.8 (9-32)	21 (11)	1,2
Lesser Nighthawk, *Chordeiles minor*	25.1 ± 16.5 (14-37)	4 (2)	1,13
Common Poorwill, *Phalenoptilus nuttallii*	26.1 ± 11.7 (8-47)	30 (17)	1,2
Gila Woodpecker, *Melanerpes uropygialis*	35.4 ± 15.3 (14-57)	33 (7)	1, 488, 180
Ash-throated Flycatcher, *Myiarchus cinerascens*	50.7 ± 55.2 (12-90)	115 (2)	22, no net #
Brown-crested Flycatcher, *Myiarchus tyrannulus*	14.7 ± 0.8 (14-15)	26 (2)	1,704
Verdin, *Auriparus flaviceps*	47 ± 0 (0)	130 (1)	141
Cactus Wren, *Campylorhynchus brunneicapillus*	22.5 ± 17.7 (10-35)	31 (2)	53,356
Black-tailed Gnatcatcher, *Polioptila melanura*	17 ± 0 (0)	37 (1)	141
Northern Mockingbird, *Mimus polyglottos*	58.8 ± 21.8 (17-86)	18 (9)	30, 30, 51, 232, 354
Phainopepla, *Phainopepla nitens*	46.4 ± 13.2 (22-63)	40 (13)	1,51,149

TABLE 5 Continued

Species	% Body water pool (mean ± SD (range))	# Sampled (# using water development)	Min. Distance Traveled (m)
Scott's Oriole, *Icterus parisorum*	18 ± 0 (0)	2 (1)	1
House Finch, *Carpodacus mexicanus*	40.9 ± 21.5 (8-100)	197 (92)	1, 30, 289
Lesser Goldfinch, *Carduelis psaltria*	35.8 ± 14.4 (22-64)	9 (8)	1,2
NEOTROPICAL MIGRANTS			
Willow Flycatcher, *Empidonax traillii*	8 ± 0 (0)	9(1)	61
Western Tanager, *Piranga ludovicana*	16 ± 0 (0)	55(1)	57
Warbling Vireo, *Vireo gilvus*	46 ± 0 (0)	60(1)	68
Yellow-rumped Warbler, *Dendroica coronata*	8 ± 0 (0)	23(1)	1
Lark Sparrow, *Chondestes grammacus*	8 ± 0 (0)	1(1)	113
Black-headed Grosbeak, *Pheucticus melanocephalus*	20 ± 0 (0)	26(1)	1
Lazuli Bunting, *Passerina amoena*	8 ± 0 (0)	4(1)	1
Bullock's Oriole, *Icterus bullockii*	9 ± 0 (0)	4(1)	194