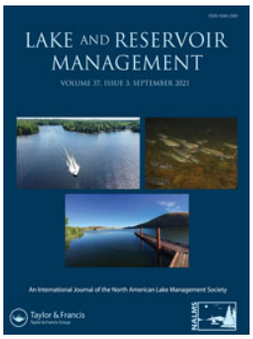

Lake and Reservoir Management

ISSN: 1040-2381 (Print) 2151-5530 (Online) Journal homepage: www.tandfonline.com/journals/ulrm20

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To cite this article: Rachel A. Vanausdall & Stephen J. Dinsmore (2021) Stopover ecology of the least sandpiper (*Calidris minutilla*) in Iowa: implications for reservoir management, Lake and Reservoir Management, 37:3, 300-312, DOI: 10.1080/10402381.2021.1920071

To link to this article: https://doi.org/10.1080/10402381.2021.1920071

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LAKE AND RESERVOIR MANAGEMENT
2021, VOL. 37, NO. 3, 300–312
https://doi.org/10.1080/10402381.2021.1920071

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Stopover ecology of the least sandpiper (*Calidris minutilla*) in Iowa: implications for reservoir management

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ABSTRACT

Vanausdall RA, Dinsmore SJ. 2021. Stopover ecology of the least sandpiper (*Calidris minutilla*) in Iowa: implications for reservoir management. Lake Reserv Manage. 37:300–312.

Multipurpose reservoirs can be used to manage habitat for shorebirds during migration, an energetically costly event that may influence demographics and population numbers. This is particularly true for shorebirds that migrate through the interior of the United States, which has lost much of its wetland habitat. Shorebirds use aquatic systems during stopover periods throughout migration to rest and refuel. Understanding the factors that influence the probability of a shorebird remaining at a stopover area can inform decisions regarding reservoir management. We examined the influence of habitat and environmental covariates and body condition on the daily local residency probability of migrant least sandpipers (*Calidris minutilla*) at Saylorville Lake, a reservoir in central Iowa. We monitored 189 least sandpipers in fall 2016, 2017, 2019, and 2020 using radiotelemetry. Using a nest survival model, our most competitive model included significant negative effects of water level (β = −8.35, 85% *CI* = −11.18, −5.52) and body condition (β = −4.91, 85% *CI* = −6.82, −3.01) on residency probability. We calculated a mean daily local residency probability of 0.78 (95% *CI* 0.56, 1.00) and used this value to calculate a minimum stopover duration of 3.96 d (95% *CI* = 3.45, 4.46). Our findings indicate that the timing of water level management at Saylorville Lake can impact the residency probability of the least sandpiper. Drawing down water levels just prior to fall migration and maintaining water levels at or below the conservation pool level (254.8 m) can provide habitat for this species and likely other shorebirds.

KEYWORDS

Least sandpiper; migration; stopover ecology; water management

Multipurpose dams and reservoirs provide several functions for humans and the environment, including flood control, water storage, irrigation, and recreation. While the primary purpose of dams and reservoirs was historically to control water resources for human use and protection, negative effects from dramatic landscape alterations require that the needs of rivers be taken into consideration, and this includes habitat and wildlife downstream from dams (Poff et al. 1997, King et al. 2003, Yin et al. 2011). As a result, reservoir management may include seasonally controlling river inflows to adjust water levels, managing thermal variability (Olden and Naiman 2010) and excess nutrient loads (Schindler 2006), and controlling increased rates of sedimentation (Morris 2014) to improve conditions for aquatic, riverine, and terrestrial species (Jager and Smith 2008). The degree of managing for wildlife depends on the impacted species and other social, environmental, or economic objectives. Understanding the effect of different management tools can help better inform the proper use and timing of reservoir operations that consider wildlife populations.

Birds are particularly affected by water resource management, including within reservoirs and along riparian areas along and downstream of reservoirs (Anteau et al. 2012, Quinlan and Green 2012, Anteau et al. 2014, Wagner et al. 2014). Areas flooded or with variable water levels as a result of dam operation can alter habitat used by birds (Desgranges et al. 2006, Anteau et al. 2012, Monfils et al. 2014). Flooding may reduce available foraging or nesting habitat for some species, while providing more of these resources for

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others (Isola et al. 2000, Anteau et al. 2014). In contrast, periods of low water can expose mudflats for shorebirds, and gradual reflooding can produce shallow emergent habitat for waterfowl (Colwell and Taft 2000, Isola et al. 2000, Taft et al. 2002). As a result, some reservoir operations include management objectives for birds (Anteau et al. 2012). A broad management approach to reservoirs for multiple benefits is the focus of programs such as the Sustainable Rivers Program (Warner et al. 2014, The Nature Conservancy 2020).

In highly altered landscapes, reservoirs can provide critical habitat for waterbirds. Migrant shorebirds utilize human-modified aquatic habitats in interior North America (Skagen et al. 1999, Skagen et al. 2008, Albanese et al. 2012), a place that has lost much of its natural wetland resources and seen alterations to riverine habitats (Dahl 2014). Migration is energetically costly and migrant birds dramatically increase their lipid levels prior to departure and during migration (Odum and Connell 1956, Krapu et al. 2006). Along their migration routes, shorebirds acquire additional energy reserves by stopping at areas for a few days to several weeks to feed and rest (Krapu et al. 2006, Morrison 2006, Warnock 2010). The amount of energy reserves is often referred to as body condition (Peig and Green 2009). Several studies have found that birds in poor body condition remain at stopover areas for a longer period than birds in better condition (Turcotte et al. 2013, Murphy and Dinsmore 2014, Anderson et al. 2019) because birds may need to obtain a minimum lipid load in order to continue migration (Hedenström and Alerstam 1997). Shorebirds may alter where they choose to refuel in different years (Albanese et al. 2012, Steen et al. 2018), and reductions in stopover site quality may contribute to population declines (Myers 1983, Thomas et al. 2006) and lower survival and reproductive success (Baker et al. 2004). Reservoirs and other managed aquatic systems often attract migrants and have the potential to provide reliable resources, but understanding the influence of reservoir operations on shorebird migration ecology could improve managing quality habitat for several species.

To assess the impact of water management at a reservoir on a continental migrant shorebird, we examined the stopover ecology of the least sandpiper (*Calidris minutilla*), a common but declining shorebird in North America (Brown et al. 2001), at a multipurpose reservoir in Iowa. Specifically, our objectives were to determine the effect of body condition, habitat availability, and other factors on the daily local residency probability of radiomarked least sandpipers during their southward migration in the fall and to estimate their minimum stopover duration at this reservoir. We predicted that residency probability would be negatively affected by body condition and habitat availability, but that residency probability would also decline as the fall season progressed, which has been documented in other small sandpipers (Dunn et al. 1988, Farmer and Wiens 1999, Murphy and Dinsmore 2014). This may be due to declining prey abundance or avoiding freezing temperatures later in the season (Anderson et al. 2019).

Study site

Our study took place in Polk County, Iowa, at a portion of Saylorville Lake, a reservoir impounded along the Des Moines River and managed by the US Army Corps of Engineers (USACE), Rock Island District (Figure 1). The Des Moines River is in the Des Moines River Basin, which drains about 36,000 km^2. About 26 streams drain into Saylorville Lake, and the reservoir has a drainage area of about 15,000 km^2. The dam was authorized in 1958, and its primary purpose is flood risk management for areas south of the reservoir, including the city of Des Moines, which is about 2 miles south of the reservoir. Other authorized purposes include water supply, water quality, low flow augmentation, wildlife management, and recreation (USACE 2019). The lake is surrounded by residential properties, along with forest, wetlands, and recreational areas managed by Polk County Conservation and the Iowa Department of Natural Resources (DNR). Several species considered to be Species of Greatest Conservation Need by the Iowa DNR use this lake and surrounding areas, and the US Fish and Wildlife Service identified several migratory bird species

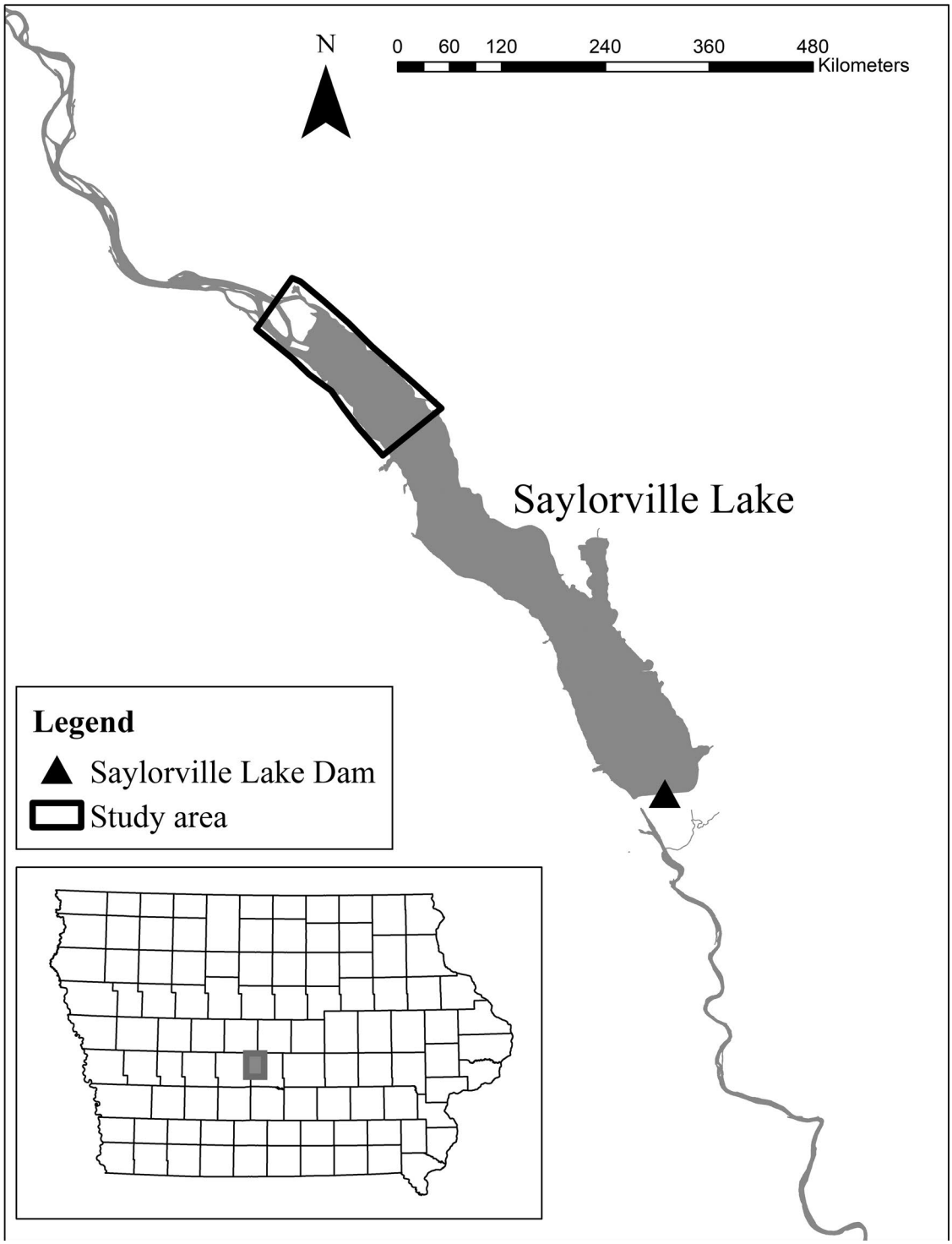

Figure 1. The location of the study area used to study the stopover ecology of least sandpipers in Polk County, Iowa, fall 2016, 2017, 2019, and 2020.

of conservation concern using this area (USACE 2019).

During most of the year, water levels are maintained at a conservation pool of 254.8 m (or 836 ft) for low flow augmentation purposes (USACE 2019). This may be increased to 256 m in the fall to provide waterfowl habitat (USACE 2019). At a conservation pool of 254.8 m, silt and sand deposits ("mudflats") are exposed and these are used by shorebirds and other waterbirds. The amount and location of these deposits vary annually due to sedimentation and water

flow, so the amount of habitat available for foraging birds varies from year to year. Available habitat occurs in the northern portion of the reservoir (Figure 1), which is where we monitored least sandpipers. In recent years, increased sedimentation has altered the storage capacity of the reservoir and increased precipitation has led to an increase in flooding events (USACE 2019). For example, approximately 6% of flood control storage was lost due to increased soil deposition between 1977 and 2014 (USACE 2019). These factors are likely to affect reservoir management and available wildlife habitat in the future.

Materials and methods

Sandpiper capture and handling

Least sandpipers migrate through central Iowa in fall from about mid July to mid September as they travel from their breeding grounds throughout northern Canada and Alaska to their wintering grounds in the southern United States, Central America, and parts of northern South America (Nebel and Cooper 2020). During this time in 2016, 2017, 2019, and 2020, least sandpipers were captured using mistnets along shorelines of the reservoir and exposed mudflats. Most captures occurred around sunrise to about 4 h after sunrise, but some captures occurred in late afternoon. Once a bird was caught we recorded mass (g), wing chord (mm), tarsus length (mm), and culmen length (mm) of the bird (Murphy and Dinsmore 2014). We sexed birds based on morphometric measurements described by Page (1974), but most birds were unknown sex based on this method. We identified individuals as adults or juveniles (i.e., born that year) using differences in feather wear and color (Nebel and Cooper 2020).

To track individual birds throughout the stopover period, we attached VHF radiotransmitters (Advanced Telemetry Systems, model A2426, Isanti, MN) to each bird. We used methods described by Warnock and Warnock (1993), which involved clipping the posterior ends of a few dorsal feathers and gluing the radiotransmitter on the interscapular region using cyanoacrylate glue (Loctite). Past studies show that this method of attachment has little to no effect on the behavior and survival of shorebirds (Mong and Sandercock 2007, Cohen et al. 2009). The radiotransmitters were expected to have a retention rate of about 40 d and to detach after that time (Mong and Sandercock 2007). However, least sandpipers never stayed in the study area for more than 2 weeks, so the retention rate of the transmitter was not a concern. The radiotransmitters weighed 0.65 g, and we ensured that the weight of the radiotransmitter was less than or equal to 3% of the weight of the bird, which was about 9g for a least sandpiper. The Iowa State University Institutional Animal Care and Use Committee approved this study (Protocol 7-16-8315-Q).

Monitoring

After processing and release, sandpipers were monitored at the reservoir until they departed the study area. We used a handheld Yagi antenna and receiver (ATS, model R4000) to detect the presence of individual birds every 1 to 3 d after initial release. The radiotransmitters had a maximum detection distance of about 1 km. We tested this prior to the 2016 study season to ensure that we could detect birds at different locations throughout the study area. We used the same locations during each visit to detect birds, and we attempted to get a visual sighting of the bird if possible. We assumed a bird left the study area once it was not detected after 2 consecutive checks with no detections.

Statistical analysis

We used the nest survival model in Program MARK (White and Burnham 1999) to estimate the daily local survival probability (φ) and minimum stopover duration of least sandpipers (Dinsmore et al. 2002). The nest survival model is generally used for estimating the daily survival probability of nests, but it can also be used with telemetry data for individuals marked at different times throughout a study period (Dinsmore et al. 2002, Murphy and Dinsmore 2014). Rather than checking nests that survive or not, the observer checks for the presence or absence of individual

birds. Thus, survival probability from one day to the next becomes the probability of a bird remaining in the study area, and the probability of departure is 1 minus that probability. Because we did not assume that the date of capture was the same as the day of arrival for most birds, we calculated the minimum stopover duration, which was calculated using the daily survival probability (Brownie et al. 1985, Kaiser 1995):

$$\frac{-1}{\ln(\varphi)} \quad (1)$$

For the remainder of this article, we refer to the daily probability of a sandpiper remaining in the study area as the daily local residency probability. We did not have any known fatalities during the study period, but we did have 2 instances where the transmitter detached from the bird and was recovered. We removed these 2 individuals from further analysis.

Estimating body condition

We were interested in the impact of body condition on the effect of daily local residency probability, but there are several techniques for estimating body condition in birds (Jakob et al. 1996). Body mass has been used as a proxy for body condition in avian studies, but this measurement may not be appropriate, as it does not consider the structure of individual birds. As such, we examined 4 other methods for determining body condition and its influence on daily local residency probability. For all calculations we assessed relationships between body mass and the 3 linear features measured: wing chord, tarsus length, and culmen length. These methods are intended to condition estimates of body mass on some measure of body structure. The first and simplest technique, which we refer to as the RATIO index, is to divide body mass by the length of a linear feature of the body, such as the wing chord or culmen (Jakob et al. 1996, Choi et al. 2009). However, the relationship between body mass, which is volumetric, and a linear feature is not linear, so another technique is to assume an isometric relationship between body mass and a linear feature (Cone 1989). This second method, which we refer to as the CUBED RATIO index, divides the linear feature by the measurement of the linear feature raised to a power of 3. This is multiplied by 10,000 to avoid errors with small numbers (Winker et al. 1992). Third, a more recent method is to use the residual of body mass regressed by the linear feature (Peig and Green 2009). Termed the scaled mass (SM) index, a standard major axis (SMA) regression is fitted between body mass and the linear feature, and the following equation is used to estimate SM:

$$M_i\left[\frac{L_0}{L_i}\right]^{b_{sma}} \quad (2)$$

where M_i is the body mass of individual i, L_i is the measurement (mm) of the linear feature, L_0 is the arithmetic mean of that linear feature, and b_{sma} is the slope of the SMA regression between body mass and the linear feature (Peig and Green 2009). While this method also attempts to account for body structure, it assumes that the relationship between body mass and body structure is not perfectly cubic (Peig and Green 2009). Finally, we used a principal components analysis (PCA) on the 3 morphological features to account for differences in body size (Legendre and Legendre 2012). This method has been used extensively in studies on body condition in waterfowl (Alisauskas and Ankney 1987, Alisauskas 2002, Ballard et al. 2006). We used residuals from a linear regression between the loadings from the first principal component, which generally explains most of the variation in body size, as the independent variable and body mass as the dependent variable (Alisauskas 2002). Indeed, the first principal component explained 55% of the variation. We termed this body condition method the PCA index.

Habitat and environmental covariates

In addition to body condition, we examined the effect of habitat availability on daily local residency probability. Shorebirds rely on mudflats to forage for invertebrates (Skagen and Oman 1996). While the area of mudflats exposed in Saylorville

Lake can vary annually, it is generally negatively correlated with the reservoir water level. Below 254.8 m (i.e., the conservation pool level), extensive mudflats are exposed and available to foraging shorebirds. Thus, we used water levels recorded by the USACE for each season of sandpiper monitoring (USACE n.d.). Specifically, we used the deviation (m) from the conservation pool level as a covariate in models for daily local residency probability.

Additionally, covariates such as time of season and wind speed and direction have shown variable effects on migrating shorebirds. As the season progresses, newly arriving birds are expected to spend less time at the stopover site so they can optimize time at their breeding or wintering grounds (Hedenström and Alerstam 1997) and, in the case of fall migration, avoid inclement weather conditions. Several studies have shown a negative relationship between time of season and residency probability (Dunn et al. 1988, Lyons and Haig 1995, Farmer and Wiens 1999). Wind characteristics can also influence migration patterns in birds. Specifically, strong tailwinds may encourage birds to depart regardless of body condition (Åkesson and Hedenström 2000, Obernuefemann et al. 2013), as tailwinds can save energy reserves (Butler et al. 1997). Thus, we examined the influence of daily average tailwind speed (m/s) and direction (in degrees). We used wind data from the Des Moines International Airport weather station, acquired through the National Oceanic and Atmospheric Administration (NOAA 2020).

Model selection

We used Akaike's information criterion adjusted for small sample sizes (AIC_c) to select the most competitive models that explain variation in daily local residency probability (Burnham and Anderson 2002). We analyzed 2 sets of models. First, we identified the body condition index that best represented body condition of least sandpipers. We compared models with main effects of year and each of the body condition indices. This included a model with only mass and 4 sets each for the RATIO, CUBED RATIO, SM, and PCA indices for each linear measurement, which resulted in a set of 11 models. We used the index from the top model in the next step. Similarly, we compared a linear and quadratic effect of time and used the best supported model in the subsequent steps, and we used the same method for a linear and quadratic effect of tailwind direction. Second, we modeled the most competitive body condition index with all combinations of the remaining covariates. We excluded models from the set of the most competitive models if the top model was only a subset of those (Burnham and Anderson 2002, Devries et al. 2008, Arnold 2010). To account for any interyear variation not explained by covariates, we included year in all models. We also did not find an effect of age on daily local residency probability, so we combined all individuals. We made inferences from the most competitive models and determined covariates to have significant coefficients if their 85% confidence intervals did not overlap zero (Arnold 2010). We used the top model to calculate residency probability and stopover duration, along with their 95% confidence intervals.

Results

We captured a total of 189 least sandpipers over the 4 years (Table 1). Body measurements for adults and juveniles varied slightly (Table 2). Tailwind speed showed little variation within and between years, while tailwind direction was more

Table 1. The number of adult and juvenile least sandpipers caught each year, the dates of capture, and the mean tailwind speed and direction (±SE) at Saylorville Lake in Polk County, Iowa, fall 2016, 2017, 2019, and 2020.

	2016	2017	2019	2020
Adults captured	28	45	39	38
Juveniles captured	9	0	22	8
Total captured	37	45	61	46
Dates of capture	Jul 14–Sep 13	Jul 9–Aug 21	Jul 20–Sep 15	Jul 23–Sep 15
Tailwind speed (km/h)	13.32 (1.85)	12.27 (1.72)	12.93 (1.65)	13.11 (1.30)
Tailwind direction (°)	169.86 (41.41)	183.91 (41.82)	194.06 (39.31)	186.35 (35.68)

Table 2. Mean (±SE) values for morphometrics of least sandpipers monitored at Saylorville Lake in Polk County, Iowa, fall 2016, 2017, 2019, and 2020.

Age	Mass (g)	Wing chord (mm)	Culmen (mm)	Tarsus (mm)
Adult	28.12 (0.34)	85.94 (0.26)	18.75 (0.09)	19.28 (0.07)
Juvenile	25.15 (0.71)	86.69 (0.41)	18.44 (0.17)	19.17 (0.09)
Total	27.51 (0.08)	86.10 (0.23)	18.69 (0.08)	19.26 (0.06)

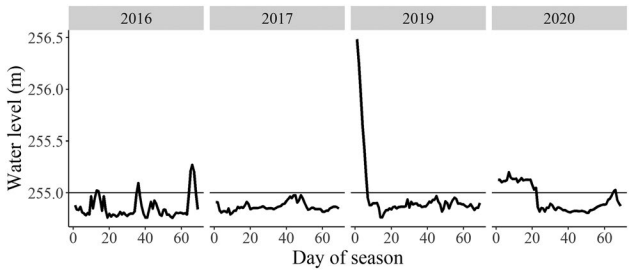

Figure 2. Water level (elevation) fluctuations at Saylorville Lake, Polk County, Iowa, fall 2016, 2017, 2019, and 2020, where least sandpipers were monitored. Day of season is relative to the earliest (Jul 9) and latest dates (Sep 15) of the study across all 4 years.

variable within years (Table 1). Habitat conditions at Saylorville Lake were variable across the 4 years. Water level was especially variable in 2016, with levels peaking at 255.3 m toward the end of the season (Figure 2). The following 2 years showed similar patterns, with short oscillations just above the conservation pool for most of the season, but water levels were nearly 1.5 m higher at the start of the season in 2019 compared to all other years. In 2020, water levels were also relatively high compared to 2016 and 2017 but declined as the season progressed.

The body condition model with the strongest support included the CUBED RATIO index with wing chord (AIC_c = 466.32), but models including the RATIO index with wing chord (AIC_c = 466.57), SM index with wing chord (AIC_c = 466.95), PCA index (AIC_c = 467.86), and a model including mass alone (AIC_c = 467.87) were also competitive. The top model had 25.75% of the weight, and all 5 models had a total of 91.08% of the weight. We used the top model for subsequent analyses. For the residency probability model set, linear effects of time and wind direction had better support than the models with quadratic effects. The final model set included only one competitive model, as more competitive models with a ΔAICc < 2 were more complex versions of the top model. The final

Table 3. Beta coefficients (β) and 85% confidence intervals (CI) for variables in the top model examining residency probability for least sandpipers at Saylorville Lake in Polk County, Iowa, fall 2016, 2017, 2019, and 2020.

Covariate	β	85% CI
Intercept (2016)	4.21	(3.28, 5.15)
2017	0.01	(−0.38, 0.40)
2019	−0.38	(−0.34, 0.43)
2020	−0.37	(−0.80, 0.06)
Water level (m)	−8.35	(−11.18, −5.52)
Body condition (g/mm^3)	−4.91	(−6.82, −3.01)

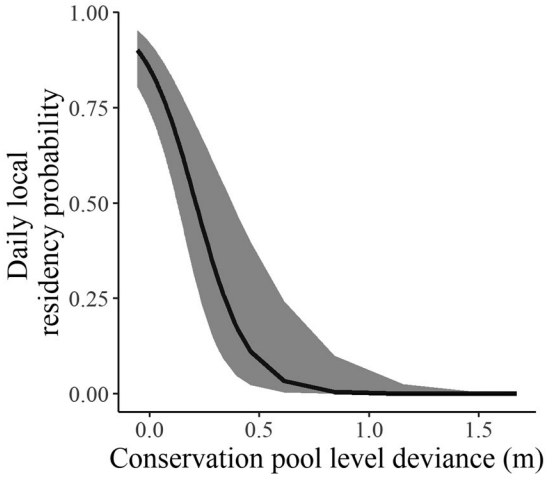

Figure 3. The effect of water level deviance from the conservation pool level (254.8 m) on the daily local residency probability of least sandpipers during migration at Saylorville Lake in Polk County, Iowa, fall 2016, 2017, 2019, and 2020. Deviance is presented as meters from the conservation pool.

model (AIC_c = 448.74) included effects of water level and body condition (Table 3) and had 55.48% of the weight. Both water level (Figure 3) and body condition (Figure 4) had negative effects on daily local residency probability. Using the top model, mean residency probability was 0.78 (95% CI = 0.56, 1.00) and stopover duration was 3.96 d (95% CI = 3.45, 4.46).

Discussion

Our study illustrates the dynamic nature of a managed waterbody in this region and how water level fluctuations can influence the stopover ecology of a common migrant in North America. We emphasize that even an increase of 0.30 m (or 1 ft) in reservoir water levels reduces the residency probability of the least sandpiper. Furthermore, our findings support other research showing a link between residency probability and

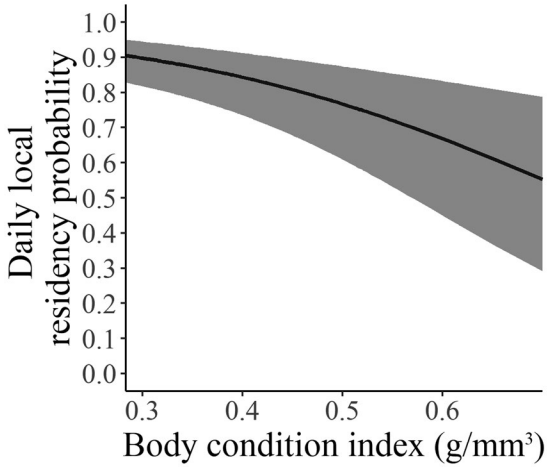

Figure 4. The effect of body condition on the daily local residency probability of least sandpipers during migration at Saylorville Lake in Polk County, Iowa, fall 2016, 2017, 2019, and 2020.

body condition. Both factors are important to consider when monitoring long-distance migrants, as conditions at nonbreeding areas can negatively influence survival and fecundity (Baker et al. 2004). In the interior United States, quality shorebird habitat is highly variable and can determine the spatial distribution (Skagen and Knopf 1994, Niemuth et al. 2006, Albanese and Davis 2013) and influence demographics of migratory species (Baker et al. 2004). The US Shorebird Conservation Plan identifies the importance of preserving diverse and abundant habitat for shorebirds during the migration period along the northern plains and prairie potholes of the United States (Brown et al. 2001). Managed aquatic systems, including multipurpose reservoirs, have the potential to provide habitat for migrating shorebirds and to influence stopover ecology (Wagner et al. 2014).

We found that an increase of 0.30 m (1 ft) in the water level of Saylorville Lake resulted in a nearly 60% decline in daily local residency probability of least sandpipers. While others have calculated the residency probability of migrating shorebirds (Cohen et al. 2009, Obernuefemann et al. 2013), few studies have directly related residency probability of shorebirds to habitat conditions. There is evidence that water level affects the abundance, occupancy, and habitat selection of migrant shorebirds in both natural and managed systems (Colwell and Taft 2000, Taft et al. 2002, Niemuth et al. 2006, Vanausdall and Dinsmore 2019). Not only is this due to the phenological limitations of foraging shorebirds, particularly *Calidrid* sandpipers like the least sandpiper, but it is also because of forage availability at certain depths. Shorebirds prefer to forage in water depths less than 10 cm; they generally forage on macroinvertebrates that live in benthos and moist substrates (Isola et al. 2000, Eldridge et al. 2009, Smith et al. 2012). Studies that have examined shorebird use at wetlands under different drawdown conditions found that shorebird abundance or density decreased with increases of water levels greater than 25 cm, particularly for small sandpipers that may forage in water levels as low as 5 cm (Weber and Haig 1996, Safran et al. 1997, Colwell and Taft 2000, Isola et al. 2000). In terms of reservoir management, the nesting success of breeding shorebirds may be related to water levels (Anteau et al. 2012). Furthermore, others have found a positive relationship between prey abundance and length of stay at a stopover site (Farmer and Wiens 1999), and habitat connectivity may also influence the movement rate or patterns of staging shorebirds (Farmer and Parent 1997), which may affect body condition. Preferred prey items exist in particular soil substrates and at certain water levels and soil moistures, and some studies suggest that prey availability can be a good predictor of shorebird occupancy or abundance in a region (Farmer and Wiens 1999, Gillespie and Fontaine 2017). While we did not measure prey abundance, it is likely that low water levels indicate conditions appropriate for prey items and foraging shorebirds and thus influence residency probability.

Although we did not examine the quality of foraging habitat for least sandpipers, understanding that body condition negatively influenced the residency probability of least sandpipers at Saylorville Lake indicates that it is important to provide adequate foraging habitat during migration. The body condition of birds during the nonbreeding period can potentially have cross-seasonal effects on survival and reproduction (Baker et al. 2004). Indeed, our finding agrees with some research in other parts of the continent for shorebirds (Dunn et al. 1988,

Turcotte et al. 2013, Murphy and Dinsmore 2014) and other birds (Cohen et al. 2014), while it contradicts results from other studies (Skagen and Knopf 1994, Lyons and Haig 1995, Dinsmore and Collazo 2003, Lehnen and Krementz 2007). Some research found this relationship only with juveniles or for adults later in the season (Anderson et al. 2019), or, in some cases, time of season was more influential than body condition (Lyons and Haig 1995). While we did not find an effect of time of season, our findings may indicate that least sandpipers prioritize obtaining enough fuel while at Saylorville Lake in order to migrate, instead of getting to their destination as quickly as possible (Hedenström and Alerstam 1997, Anderson et al. 2019).

Other studies have found that different covariates are more important than body condition on the residency probability of shorebirds (Lyons and Haig 1995, Farmer and Wiens 1999, Lehnen and Krementz 2007). This could be due to several factors, including the stopover area, time of season, or choice of body condition index. For example, environmental conditions, such as wind speed and the presence of tailwinds, were important in predicting residency probability (Butler et al. 1997, Obernuefemann et al. 2013) or migration speed (Duijns et al. 2019). We did not find tailwind speed or direction to be influential predictors of departure in our study system. This could be due to the strong influence of water level alone, which seemed to explain much of the variation in daily local residency probability. At areas with less water level fluctuation or along different parts of the migration route, wind speed and other environmental covariates may be more important for this species. The lack of importance for tailwind speed may also indicate high quality habitat, as marginal habitat may be overlooked in high wind conditions (Obernuefemann et al. 2013).

Our estimate of 3.96 d for stopover duration for the least sandpiper during fall migration is similar to estimates in other natural and managed systems, but this value should be viewed conservatively. Specifically, Lehnen and Krementz (2007) estimated 4.10 d and 6.50 d for adult least sandpipers in fall in Arkansas and Mississippi, respectively, while Farmer and Durbian (2006) estimated 3.60 d in fall and 9.70 d in spring in Missouri. Both of those studies occurred on wildlife management areas managed for shorebirds and other waterbirds. Similarly, Butler and Kaiser (1995) found a 5 d stopover length for southbound migrating least sandpipers at unmanaged marshes along the West Coast. Additionally, our estimate of residency probability (0.78) was relatively high, indicating that least sandpipers are likely to remain at Saylorville Lake for several days during fall migration. This value is nearly identical to least sandpiper residency probability along the West Coast in one study (Butler and Kaiser 1995), which estimated a residency probability of 0.80, and within the range of estimates (0.40–0.80) for other *Calidrid* sandpipers (Cohen et al. 2009, Obernuefemann et al. 2013). Although we did not conduct weekly counts of migrating least sandpipers, these values can be useful for estimating population size of migrating shorebirds (Cohen et al. 2009) and should be considered for future studies. However, we also acknowledge that our estimate of stopover duration did not consider the fact that capture date likely did not correspond to the date of arrival for most individuals. This can result in negatively biased estimates of stopover duration (Cohen et al. 2009), so our estimate of stopover duration should be considered as a minimum stopover duration.

Given the length of time least sandpipers are expected to remain at Saylorville Lake and the effect of body condition on residency probability during migration, this reservoir appears to serve an important role in the migration of least sandpipers. Furthermore, although we did not conduct a formal count of least sandpipers during the duration of the study, it is possible that several thousand least sandpipers use Saylorville Lake each fall (Dinsmore S, pers. obs.), so it will be important to account for the stopover ecology of this species when managing water levels. Similar to Saylorville Lake, other reservoirs may have a primary function, including flood risk management, to meet human needs, and these objectives can coincide with wildlife habitat management (Sprandel et al. 2002, Anteau et al. 2012). Lowering water levels to or below conservation pool between July and September not only creates habitat for migrating shorebirds but also increases

the storage capacity of the reservoir, which accommodates runoff in spring. However, another objective is to provide habitat for migrating waterfowl in fall, and this involves gradually increasing the pool level from the conservation pool to 256 m between September and November to flood vegetation and provide shallow water for foraging (USACE 2019). Delaying the raising of the pool level and maintaining levels at or near the conservation pool until mid to late September would still likely allow for both adequate shorebird habitat and some waterfowl habitat prior to the waterfowl hunting season. Thus, we recommend that water levels be maintained at the conservation pool of 254.8 m or lower during the late summer and early fall. One option is to consider staggered drawdowns (1–2 cm per week) during this period to continually expose new mudflats that are used by migratory shorebirds. While there are environmental and climatic conditions and other reservoir management objectives that may prevent this from occurring, understanding the importance of water level in the migration of this species further justifies the choice of conservation pool level for wildlife management in this system. Furthermore, while body condition was an important predictor for daily local residency probability of least sandpipers, future research should examine the quality and abundance of prey items available to shorebirds and how they influence body condition. This can help inform management decisions by providing estimates of carrying capacity of least sandpipers and other shorebirds at Saylorville Lake.

Acknowledgements

We thank D. Weidt, P. Petersen-Keys, and the Polk County Conservation for logistical assistance. We thank J. Mize, J. W. Moore, K. T. Murphy, T. M. Harms, J. M. H. Ford, C. Lundy, and J. Dupuie for help with capturing and monitoring least sandpipers.

Funding

This research was funded by a grant from the Iowa Science Foundation and a grant from the US Fish and Wildlife Service Migratory Bird Joint Ventures (# F17AP00794). This research was partially supported by the Iowa Agricultural Experiment Station with funding from the Hatch Act (Accession Number 1006691) through the USDA National Institute of Food and Agriculture.

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