Shorebird Response to Post-Flood Drawdowns on Tennessee National Wildlife Refuge

Kira C. Newcomb[1,*], Adrian P. Monroe[1], J. Brian Davis[1], and Matthew J. Gray[2]

Abstract - Mudflats are important stopover sites for shorebirds during migration, but management plans typically do not provide mudflat habitat in the reservoirs of the Tennessee River Valley (TRV) during May–July. In May 2010, flooding delayed drawdowns on Tennessee National Wildlife Refuge and created wetlands for shorebirds from May–August. We studied wetland use and behavior of shorebirds during delayed drawdowns in 2010, and we compared shorebird abundance between years with delayed and typical drawdowns using International Shorebird Survey data. We found that shorebirds consistently used wetlands for foraging throughout summer during 2010. In addition, abundance of 43% of species tested was greater in years with delayed than typical drawdowns. Our results suggest extending availability of mudflats throughout summer in the TRV may provide important habitat for migrating shorebirds.

Introduction

Shorebirds (Charadriiformes) exploit diverse wetland and agricultural habitats throughout the Western Hemisphere during their annual cycle (Rundle and Fredrickson 1981, Skagen 2006, Skagen and Knopf 1993). Most of the 53 shorebird species that are regularly found in the US migrate thousands of kilometers between arctic and subarctic breeding grounds and non-breeding areas (Brown et al. 2001). For shorebirds like *Pluvialis dominica* (Müller) (American Golden-Plover) and *Calidris fuscicollis* (White-rumped Sandpiper), migration between Canadian Arctic breeding grounds and South American non-breeding areas may exceed 15,000 km (Skagen 2006; taxonomy throughout follows Chesser et al. [2013]). Long-distance migration is an energetically taxing activity for birds and can impact their survival (Lehnen and Krementz 2007, Skagen 2006). Thus, stopover wetlands along migration routes are critical resources for shorebirds, especially long-distance migrants, to replenish their energy reserves (Brown et al. 2001, Lehnen and Krementz 2013, Myers 1983, Skagen et al. 1999, Webb et al. 2010). Loss of stopover wetlands has been extensive (Brown et al. 2001, Skagen and Knopf 1993); therefore, maintaining remaining wetlands for migrating shorebirds is an important objective for resource managers (Laux 2008, Smith 2006, Twedt 2013, Wirwa 2009).

The Tennessee River Valley (TRV) is the fifth largest watershed in the US (Tennessee Valley Authority [TVA] 2004). The TVA manages water levels within 49 dam-created reservoirs throughout the TRV to facilitate navigation and

[1]Department of Wildlife, Fisheries, and Aquaculture, College of Forest Resources, Mississippi State University, Mississippi State, MS 39762. [2]Department of Forestry, Wildlife, and Fisheries, College of Agricultural Sciences and Natural Resources, University of Tennessee, Knoxville, TN 37996. *Corresponding author - knewcomb@cfr.msstate.edu.

recreation, create hydroelectric power, and control flooding (TVA 2004). Reservoirs are drawn down annually from July–October, exposing an estimated 12,000 ha of mudflats throughout the TRV (Laux 2008). The TRV's mudflats provide essential resources for migratory and resident waterbirds in fall and winter (Laux 2008, Wirwa 2009). Indeed, shorebird use of these mudflat sites may be as significant as use of similar habitats in the Mississippi Alluvial Valley (MAV; Minser et al. 2011, Wirwa 2009). However, few mudflats exist in TVA-controlled reservoirs from May–July because the agency maintains high water levels to support summer recreation activities (Wirwa 2009). Wetland managers could adjust strategies for water management on other public and private lands to provide mudflats for migrating shorebirds during these months (Brown et al. 2001, Minser et al. 2011, Natural Resources Conservation Service 2012, Scheiman 2007, Smith 2006, Taft et al. 2002, Twedt 2013, Twedt et al. 1998).

The Tennessee National Wildlife Refuge (TNWR) is located in the western TRV and encompasses a portion of the TVA-managed Kentucky Reservoir. The refuge was established in 1945 to provide habitat for migratory birds, specifically wintering waterfowl (TNWR 2010). Drawdowns are conducted within TNWR's managed impoundments from March–June to facilitate cooperative farming and enhance growth of desirable wetland vegetation for wintering waterfowl (Low and Bellrose 1944). In early May 2010, an extensive flood inundated the Duck River Unit (DRU) of TNWR with >3 m of water, which resulted in a second drawdown period (hereafter referred to as delayed drawdowns). In response to the Deepwater Horizon oil spill that affected coastal wetlands of the Gulf Coast (Corn and Copeland 2010), the US Fish and Wildlife Service received supplemental funding to extend drawdowns on DRU to provide mudflats for migrating shorebirds from May–August 2010. These unanticipated events provided an opportunity, similar to a natural experiment, for us to monitor migrating shorebirds during May–August, a period when mudflats typically are drying at DRU but not yet exposed in surrounding reservoirs of the TRV. Our objectives were to (1) quantify shorebird use and behavioral response to delayed drawdowns in DRU impoundments from May–August 2010, and (2) determine if delayed drawdowns had a positive effect on abundance and richness of shorebirds compared to typical drawdowns using International Shorebird Survey (ISS) data from 2000–2009 (S. Schmidt, Manomet Center for Conservation Sciences, Manomet, MA, unpubl. data).

Field-site Description

The DRU (35°57'30"N, 87°57'00"W) of TNWR is located at the confluence of the Tennessee and Duck Rivers in western Tennessee and consists of 10,820 ha of seasonally flooded, moist-soil and forested wetlands; permanent open water; agricultural fields; and upland forests (TNWR 2010). Wetland managers at DRU typically draw down impoundments in which row crops (e.g., corn and soybeans) are grown in early March, and then mid-April for impoundments managed primarily for moist-soil plant production (TNWR 2010). Approximately 1564 ha of wetlands are exposed across 15 managed impoundments on DRU during annual drawdowns

in typical years. All impoundments are managed for production of moist-soil plants to some extent but also contain a complex of other habitat types (TWNR 2010).

Methods

2010 survey protocol

We monitored shorebird use in 9 managed impoundments (1753 ha total area; 63% exposed) on DRU from 24 May–28 August 2010 (Fig. 1); surveys were initiated as soon as roads were accessible from receding floodwaters. During our study, drawdowns began in 3 impoundments during May, 4 in June, and 1 each in July and August. Because summer drawdowns and subsequent exposure of mudflats occurred asynchronously among impoundments, the number of survey points needed to view as many mudflats as possible changed throughout summer. Thus, we established 2–6 survey points per impoundment as mudflats became available in locations where maximum mudflat area was visible and no overlap of area surveyed occurred with adjacent points (Fig. 1). Mudflats were associated with moist-soil wetlands, edges of permanent open water, and agricultural fields.
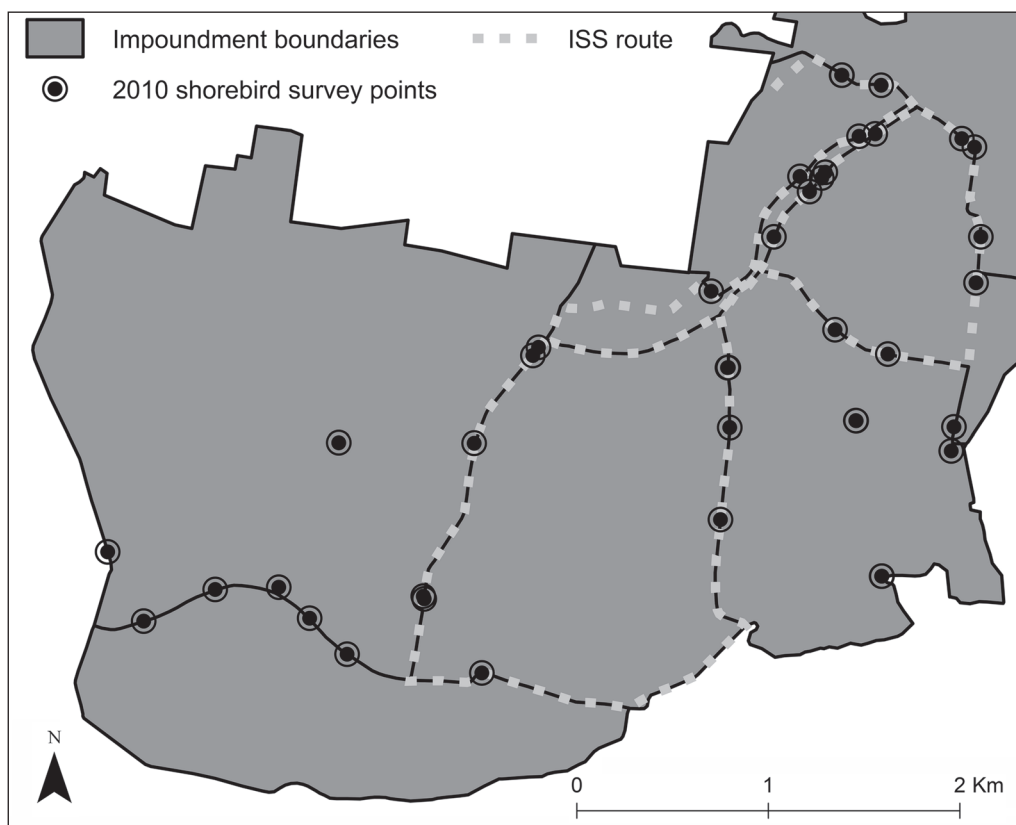

Figure 1. Survey points, May–August 2010, and International Shorebird Survey (ISS) route, 2000–2009, on the Duck River Unit of Tennessee National Wildlife Refuge. Surveyed impoundments are managed to produce moist-soil plants, but each contains a complex of moist-soil wetlands, open water, forested and scrub-shrub wetlands, and agricultural crops.

Previous studies have found effects of vegetation on detectability of shorebirds in moist-soil impoundments (e.g., Farmer and Durbian 2006, Lehnen and Krementz 2013). During drawdowns in the DRU's moist-soil impoundments, a mudflat zone occurs between the receding water's edge and newly germinating vegetation. Shorebirds concentrated in these mudflat zones and shallow open water with sparse or no vegetation. Therefore, reduced visibility from vegetation was not an issue, and we assumed that detectability for our surveys was near 1. In order to maximize visibility and thus detectability, we discontinued survey points when vegetation re-established on mudflats and most shorebirds no longer used these areas.

Initially, we visited each survey point 6 times per week within 5 h after sunrise, but we reduced surveys to 3 times per week once the length of time needed to survey all points in a day exceeded 5 h. Previous shorebird research did not detect differences in activity budgets of birds among diurnal time periods (i.e., morning, mid-day, and afternoon; De Leon and Smith 1999, Wirwa 2009); thus, we assumed morning surveys were representative of overall diurnal activity. We reversed the order in which points were surveyed each day to capture potential variability associated with birds' habitat use among impoundments during this period (Andrei et al. 2008). We minimized the possibility of bias from double-counting individuals among survey points by avoiding flushing birds during surveys and altering the order that points were surveyed each day. It is possible that some individuals were surveyed from multiple points, but we assumed that this was random or unrelated to our survey protocol and effect of month.

We used a spotting telescope (Swarovski® model STS-80) with 20–60X zoom to identify and count all shorebirds at each point, excluding birds flying overhead. After completing shorebird counts at a survey point, we used focal sampling to quantify shorebird behavior among impoundments (Davis and Smith 1998). Following the protocol of previous studies (Davis and Smith 1998, De Leon and Smith 1999, Wirwa 2009), we classified and recorded activities of individuals as locomotion, resting, foraging, alert, maintenance, or aggression. We chose individuals for focal sampling by randomly realigning the spotting scope and observing the individual at the center of the field of view. We followed one individual per species at each survey point for one continuous minute and dictated a description of its activities into a digital voice recorder (De Leon and Smith 1999, Fitzpatrick and Bouchez 1998, Laux 2008, Wirwa 2009).

2010 survey analyses

Shorebird abundance. The total number of survey points in each impoundment and surveys per point varied because we established sampling locations as mudflats became available. Therefore, we standardized abundance measurements of shorebirds by averaging the number of shorebirds counted during repeated visits to each survey point by month. This provided an overall mean number of shorebirds per survey for each point and month. We modeled mean total abundance and richness using linear mixed-effects models in R (v. 3.0.2; R Development Core Team

2013) and the *lme* function in package *nlme* (v. 3.1-115; Pinheiro et al. 2013). We included month as a fixed effect and survey point as a random effect. We also tested for month effects on abundance of species with sufficient detections (>5% of total individuals detected): *Charadrius vociferus* (Killdeer), *Calidris pusilla* (Semipalmated Sandpiper), *Calidris melanotos* (Pectoral Sandpiper), and *Calidris minutilla* (Least Sandpiper) (Table 1). We ensured that assumptions of normality were met by log- or square root-transforming the response. We used Tukey contrasts and Holm's method for posthoc multiple comparisons among months. We also restricted analyses to June–August because we only surveyed for one week in May and hence summarized May counts with descriptive statistics (mean ± SE). In all tests, we considered statistical significance at α = 0.05.

Behavioral observations. We followed the guidelines in Skagen and Knopf (1993) to categorize shorebirds by average migration distance—short, intermediate, and long—and compared monthly and overall behavioral activity data among the 3 groups. We used multivariate ANOVA (MANOVA) in R to examine activity budgets because our response variables (i.e., percent of one minute observed in each behavioral activity) were correlated and should be treated as a single multivariate response (Andrei et al. 2007, Crawley 2013, Davis and Smith 1998). We defined each focal individual as an experimental unit and included month and shorebird migration distance as independent variables. We examined data for outliers using Mahalanobis distance, square root- or arcsine-transformed the response, and used Pillai's trace as the test criterion. Following a significant MANOVA, we used univariate ANOVA and Tukey's HSD to determine differences in behavior among months and migration categories of birds (Davis and Smith 1998). We were primarily interested in foraging, maintenance, and resting, and how these behavioral activities related to habitat use, so we restricted posthoc analyses to these behaviors.

International Shorebird Survey analyses

Since 1974, volunteers have gathered ISS data during spring and fall migration. These data are used to monitor shorebird populations, map staging areas, and inform conservation planning in documents such as the US Shorebird Conservation Plan (Bart et al. 2007). The ISS protocol recommends surveys be conducted every 10 days between 15 March and 15 June for spring migration, and 15 July and 25 October for fall migration (Schmidt 2010). When feasible, biologists at DRU conduct 1–3 ISS surveys per month each year from a vehicle along an established route and according to the proposed schedule (Fig. 1; Schmidt 2010).

We analyzed ISS data collected at DRU to determine if shorebird use differed between years with typical and delayed drawdowns. Typical drawdowns begin in March and April, and delayed drawdowns, as occurred during our 2010 observations, begin later in spring and early summer because impounds are inundated again after significant flooding in the adjacent Kentucky Reservoir. As a result, delayed drawdowns begin weeks later after falling water levels allow pumping to resume; drawdown schedule and total availability of mudflats were similar to

typical drawdowns but occurred later in the season. Thus, we assumed that detectability was comparable between delayed and typical drawdowns, and differences in species abundance or richness were related to habitat availability and not detectability. We compared total monthly counts in May–August during years with typical ($n = 4$) and delayed drawdowns ($n = 4$) from 2000–2009, but we excluded 2004 and 2006 because no ISS surveys were conducted during those years. In addition, we excluded June surveys from our analyses because none were conducted during 3 of the years. We could not make statistical comparisons between our 2010 survey results and ISS data because of differences in survey methodology and extent of drawdowns. Because only limited inferences could be made with our 2010 data about the effects of delayed drawdowns on shorebird abundance, analysis of multi-year ISS data was important.

Delayed drawdowns and species abundance. We compared counts for 7 species at DRU: *Tringa melanoleuca* (Greater Yellowlegs), *T. flavipes* (Lesser Yellowlegs), *Charadrius semipalmatus* (Semipalmated Plover), *Actitis macularius* (Spotted Sandpiper), *T. solitaria* (Solitary Sandpiper), Least Sandpiper, and Pectoral Sandpiper (Table 1). We chose the aforementioned species because they were observed at least once during each year of available ISS data. We analyzed ISS data using zero-inflated generalized linear mixed-effects models with a negative binomial distribution using the *glmmADMB* function in the R package *glmmADMB* (v. 0.7.7; Fornier et al. 2012, Skaug et al. 2013). We used a zero-inflated model to address potential issues with overdispersion and biased parameter estimates associated with excessive zeros in the ISS data (30% of response data; Zuur et al. 2012). We created a binary covariate (delayed year) to indicate whether delayed drawdowns occurred between May and August of any given year. We treated delayed year and month as fixed effects, used a random intercept for year, and designated the log-transformed number of surveys per month as an offset to account for variation in survey effort (Zuur et al. 2012). We ran 2 models per species, including one model with month and delayed year as additive effects, and a second model with a delayed year × month interaction. Then we used a likelihood-ratio test to determine significance of the interaction term (Bolker et al. 2013, Zuur et al. 2009). Estimated overdispersion ($\hat{c}$) for all interpreted models was marginal (range = 0.69–1.25), except for Spotted Sandpiper ($\hat{c} = 1.72$).

Delayed drawdowns and species richness. In addition to examining the effect of delayed drawdowns on total monthly counts in the ISS data, we also tested for an effect of delayed drawdowns on species richness. We analyzed species richness using generalized linear mixed-effects models with a Poisson distribution using the *glmer* function in the R package *lme4* (v. 1.0-5; Bates et al. 2013). We treated delayed year and month as fixed effects, used a random intercept for year, and designated the log-transformed number of surveys per month as an offset. Similar to monthly count data, we compared the additive and interaction models with likelihood-ratio tests to determine significance of the interaction.

Results

2010 surveys

We observed 8862 individuals of 26 shorebird species at DRU during late May–August 2010 (Table 1). Killdeer comprised 68% of all shorebirds observed; 3 species of sandpiper (i.e., Least, Pectoral, and Semipalmated) comprised 19% of all individuals observed. Semipalmated Plover, Spotted Sandpiper, and White-rumped Sandpiper also were commonly observed during surveys. Although few in number (≤1%), we recorded several species of high conservation concern, including *Charadrius melodus* (Piping Plover), *Calidris subruficollis* (Buff-breasted Sandpiper), *Phalaropus tricolor* (Wilson's Phalarope), and *Arenaria interpres* (Ruddy Turnstone). Overall, total number of species detected was greatest in August ($n = 20$), followed by July ($n = 17$), May ($n = 11$), and June ($n = 8$).

Table 1. Shorebirds observed at Duck River Unit, Tennessee National Wildlife Refuge, May–August 2010. Number of observed individuals unadjusted for turnover rate. Migration group is based on the migration-distance index created by Skagen and Knopf (1993) and used by Wirwa (2009). Short = less than 3900 km, Intermediate = 6300–12,400 km, and Long = greater than 14,800 km.

Species	Code	n	% of total n	Migration group	Scientific name
American Avocet	AMAV	4	<1	Short	*Recurvirostra americana* Gmelin
Baird's Sandpiper[A]	BASA	12	<1	Long	*Calidris bairdii* (Coues)
Black-bellied Plover[B]	BBPL	16	<1	Intermediate	*Pluvialis squatarola* (L.)
Buff-breasted Sandpiper	BBSA	16	<1	Long	*Calidris subruficollis* (Vieillot)
Dunlin[B]	DUNL	2	<1	Intermediate	*Calidris alpina* (L.)
Greater Yellowlegs[A, B]	GRYE	37	<1	Intermediate	*Tringa melanoleuca* (Gmelin)
Killdeer[B]	KILL	6046	68	Short	*Charadrius vociferus* L.
Long-billed Dowitcher[B]	LBDO	12	<1	Intermediate	*Limnodromus scolopaceus* (Say)
Least Sandpiper[A, B]	LESA	565	6	Intermediate	*Calidris minutilla* (Vieillot)
Lesser Yellowlegs[A, B]	LEYE	85	<1	Intermediate	*Tringa flavipes* (Gmelin)
Marbled Godwit[B]	MAGO	3	<1	Short	*Limosa fedoa* (L.)
Pectoral Sandpiper[A, B]	PESA	607	7	Long	*Calidris melanotos* (Vieillot)
Piping Plover	PIPL	2	<1	Short	*Charadrius melodus* Ord
Red-necked Phalarope	RNPH	1	<1	Intermediate	*Phalaropus lobatus* (L.)
Ruddy Turnstone[B]	RUTU	15	<1	Intermediate	*Arenaria interpres* (L.)
Sanderling	SAND	1	<1	Intermediate	*Calidris alba* (Pallas)
Short-billed Dowitcher[B]	SBDO	10	<1	Intermediate	*Limnodromus griseus* (Gmelin)
Semipalmated Plover[A, B]	SEPL	264	3	Intermediate	*Charadrius semipalmatus* Bonaparte
Semipalmated Sandpiper[B]	SESA	513	6	Intermediate	*Calidris pusilla* (L.)
Solitary Sandpiper[B]	SOSA	183	2	Intermediate	*Tringa solitaria* Wilson
Spotted Sandpiper[A, B]	SPSA	232	3	Intermediate	*Actitis macularius* (L.)
Stilt Sandpiper[B]	STSA	26	<1	Long	*Calidris himantopus* (Bonaparte)
Western Sandpiper[B]	WESA	14	<1	Intermediate	*Calidris mauri* (Cabanis)
Willet[B]	WILL	2	<1	Short	*Tringa semipalmata* (Gmelin)
Wilson's Phalarope[B]	WIPH	3	<1	Intermediate	*Phalaropus tricolor* (Vieillot)
White-rumped Sandpiper[B]	WRSA	191	2	Long	*Calidris fuscicollis* (Vieillot)

[A]Species selected for analysis of International Shorebird Survey (ISS) data
[B]Species observed on ISS surveys during years with delayed drawdowns (2002, 2003, 2008, 2009).

Shorebird abundance. We observed 428 individuals during May surveys, with a mean ± SE = 21.7 ± 10.5 birds per survey (range = 2.5–65.0). Semipalmated Sandpiper (57%) and Semipalmated Plover (24%) were most common, whereas Solitary Sandpiper, Ruddy Turnstone, Killdeer, and *Pluvialis squatarola* (Black-bellied Plover) each comprised <5% of individuals.

In general, we did not find an effect of month on shorebird abundance or species richness during June–August 2010. We observed 8434 shorebirds with mean relative abundance of 19.0 ± 3.9 (range = 0–201) and mean richness of 1.42 ± 0.2 (range = 0–9.5). Total shorebird abundance ($F_{2, 35} = 1.72$, $P = 0.19$) and species richness ($F_{2, 35} = 0.28$, $P = 0.76$) per survey did not vary by month. Mean relative abundance of Killdeer ($F_{2, 35} = 3.20$, $P = 0.053$), Semipalmated Sandpiper ($F_{2, 35} = 1.37$, $P = 0.27$), and Pectoral Sandpiper ($F_{2, 35} = 2.26$, $P = 0.12$) did not vary by month (Table 2). However, we found an effect of month for Least Sandpiper ($F_{2, 35} = 3.83$, $P = 0.031$). Abundances were similar in July and August ($P = 0.75$) but greater during these months than in June ($P = 0.038$ for both tests). Among species comprising <5% of individuals in our sample during June–August, we detected White-rumped Sandpiper—a long-

Table 2. Mean relative abundance per survey (± SE) for migrating shorebirds on the Duck River Unit, Tennessee National Wildlife Refuge, May–August 2010. Different letter superscripts indicate a significant difference ($P < 0.05$) among months when tested for 4 species, each comprising >5% of individuals detected in June–August. Species codes are defined in Table 1. Abundance was not formally compared in May because only the last week was surveyed.

Species	May	June	July	August
AMAV	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.02
BASA	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.10 ± 0.07
BBPL	0.62 ± 0.47	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.02
BBSA	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.08 ± 0.05
DUNL	0.10 ± 0.06	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
GRYE	0.00 ± 0.00	0.01 ± 0.01	0.06 ± 0.03	0.14 ± 0.08
KILL	1.31 ± 0.52	10.53 ± 3.31[A]	17.46 ± 5.39[A]	10.26 ± 3.25[A]
LBDO	0.00 ± 0.00	0.00 ± 0.00	0.06 ± 0.04	0.02 ± 0.01
LESA	0.38 ± 0.33	<0.01 ± <0.01[A]	2.27 ± 1.36[B]	2.94 ± 1.88[B]
LEYE	0.00 ± 0.00	0.00 ± 0.00	0.81 ± 0.52	0.17 ± 0.12
MAGO	0.00 ± 0.00	0.00 ± 0.00	<0.01 ± <0.01	0.00 ± 0.00
PESA	0.10 ± 0.10	0.00 ± 0.00[A]	2.17 ± 1.04[A]	2.01 ± 0.86[A]
PIPL	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.03	0.00 ± 0.00
RNPH	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	<0.01 ± <0.01
RUTU	0.71 ± 0.50	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
SAND	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	<0.01 ± <0.01
SBDO	0.00 ± 0.00	0.00 ± 0.00	0.14 ± 0.14	0.03 ± 0.02
SEPL	5.21 ± 2.47	0.11 ± 0.06	0.30 ± 0.24	0.67 ± 0.33
SESA	11.83 ± 6.72	0.31 ± 0.16[A]	0.26 ± 0.22[A]	1.16 ± 1.00[A]
SOSA	1.02 ± 0.70	<0.01 ± <0.01	1.02 ± 0.58	0.27 ± 0.07
SPSA	0.00 ± 0.00	<0.01 ± <0.01	0.47 ± 0.18	0.72 ± 0.20
STSA	0.00 ± 0.00	0.00 ± 0.00	0.06 ± 0.04	0.08 ± 0.06
WESA	0.14 ± 0.14	0.00 ± 0.00	0.02 ± 0.02	0.13 ± 0.12
WILL	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.07	0.00 ± 0.00
WIPH	0.00 ± 0.00	0.00 ± 0.00	<0.01 ± <0.01	<0.01 ± <0.01
WRSA	0.29 ± 0.29	0.42 ± 0.18	0.00 ± 0.00	0.00 ± 0.00

distance migrant—only in June, whereas *Calidris bairdii* (Baird's Sandpiper), Buff-breasted Sandpiper, and *Calidris himantopus* (Stilt Sandpiper) (Table 2) Baird's Sandpiper, Buff-breasted Sandpiper, and *Calidris himantopus* (Stilt Sandpiper) were observed only in July and/or August. We detected intermediate-distance migrants—Greater Yellowlegs, Solitary Sandpiper, Semipalmated Plover, and Spotted Sandpiper—in all 3 months, although they tended to be more common in July and August. In addition, *Limnodromus scolopaceus* (Long-billed Dowitcher), Lesser Yellowlegs, *Limnodromus griseus* (Short-billed Dowitcher), and *Calidris mauri* (Western Sandpiper) were only detected in July and August.

Behavioral observations. We recorded 684 focal observations of shorebirds from June–August 2010, seven of which we excluded as outliers based on Mahalanobis distance. Our multivariate analysis indicated that effects of month, migration group, and month x group interaction on shorebird activities were all significant (Table 3). Therefore, we analyzed foraging, maintenance, and resting separately.

We found monthly significant differences in time spent foraging for intermediate- but not short- or long-distance migrants. Univariate analysis of foraging also indicated a month x group interaction ($F_{4, 668} = 5.16$, $P < 0.001$), so we analyzed month for each migration group separately. Percentage of time foraging did not vary significantly by month for short- or long-distance migrants (Table 4). However, month was significant for intermediate-distance migrants, where foraging frequency was greatest in July, least in June, and intermediate in August (Table 5).

Table 3. Multivariate analysis of variance test statistics for shorebird behavior by month (June–August) and migration-distance class (group) at Duck River Unit, Tennessee National Wildlife Refuge, 2010. For *F* values, df = 2, 668 for month and group; df = 4, 668 for month x group.

Factor	Pillai's trace	*F*	*P*
Month	0.175	10.63	<0.001
Group	0.307	20.08	<0.001
Month × group	0.064	1.82	0.009

Table 4. Analysis of variance test statistics for differences in shorebird behavior (by migration-distance class or pooled) among months (June–August) at Duck River Unit, Tennessee National Wildlife Refuge, 2010. Month x group interaction was not supported for maintenance ($F_{4, 668} = 1.30$, $P = 0.27$). Our sample of long-distance individuals performing resting behavior was too small to adequately test their response to month.

Behavior	Group	*F*	df	*P*
Foraging	Short	1.88	2, 323	0.15
	Intermediate	13.42	2, 284	<0.001
	Long	0.682	2, 61	0.51
	Pooled	63.23	2, 674	<0.001
Maintenance	Pooled	24.25	2, 674	<0.001
Resting	Short	29.67	2, 323	<0.001
	Intermediate	5.34	2, 284	0.005
	Long	-	-	-
	Pooled	48.22	2, 674	<0.001

Table 5. Diurnal activity budgets (mean % of time spent during 1-minute observations, ± SE) among months for short- ($n = 175$), intermediate- ($n = 232$), and long-distance ($n = 270$), migrating shorebirds on the Duck River Unit, Tennessee National Wildlife Refuge, June–August 2010 (classifications defined in Table 1). Different letter superscripts indicate significant difference ($P < 0.05$) among months within distance groups (when tested) for foraging and resting. Only foraging, maintenance, and resting behaviors were submitted to additional univariate tests. However, effects of month or month x group interactions were not supported for maintenance, so posthoc tests were not performed among months within distance groups. Additionally, our small sample of long-distance migrants resting prevented us from effectively testing for differences among months for this group.

Behavior	Short			Intermediate			Long		
	June	July	August	June	July	August	June	July	August
Alert	9.0 ± 1.3	5.4 ± 1.3	2.7 ± 1.0	9.3 ± 3.3	1.0 ± 0.4	1.6 ± 0.6	5.0 ± 2.4	3.1 ± 0.6	1.5 ± 0.7
Antagonistic	1.3 ± 0.4	0.8 ± 0.3	0.3 ± 0.3	0.0	0.3 ± 0.3	0.5 ± 0.3	0.6 ± 0.6	0.0	0.0
Foraging	38.4 ± 3.0[A]	36.0 ± 3.1[A]	27.7 ± 3.2[A]	38.9 ± 7.9[C]	73.6 ± 2.7[A]	59.7 ± 3.2[B]	75.8 ± 8.4[A]	74.7 ± 7.6[A]	65.9 ± 7.0[A]
Locomotion	13.8 ± 1.7	7.7 ± 1.0	12.8 ± 2.0	15.1 ± 4.7	12.5 ± 1.6	14.0 ± 1.7	4.3 ± 1.9	4.5 ± 1.3	13.1 ± 4.0
Maintenance	26.1 ± 3.3	25.8 ± 3.5	21.3 ± 4.1	22.2 ± 7.9	5.7 ± 1.8	7.6 ± 1.9	14.2 ± 8.8	15.8 ± 7.3	17.3 ± 6.8
Resting	11.4 ± 1.7[C]	24.3 ± 2.3[B]	35.1 ± 3.0[A]	13.9 ± 6.1[AB]	6.9 ± 2.5[B]	16.6 ± 2.5[A]	0.0	1.9 ± 0.8	2.3 ± 1.2

When we pooled observations among months, there was significant variation among distance classes (Table 4), and we observed similar percentages of time spent foraging among intermediate- and long-distance migrants ($P = 0.59$), whereas both groups spent more time foraging than short-distance migrants ($P < 0.001$ for each; Table 5).

Unlike foraging, short-distance migrants spent the most time on maintenance. We did not find an effect of month ($F_{2,668} = 1.07$, $P = 0.34$) or a month x group interaction for maintenance ($F_{4,668} = 1.30$, $P = 0.27$). However, pooling observations among months indicated that time spent on maintenance varied among migrant groups (Table 4). Intermediate- and long-distance migrants spent comparable time on maintenance ($P = 0.22$), but short-distance migrants spent more time than intermediate ($P < 0.001$) and long-distance migrants ($P = 0.041$; Table 5).

We also found a month x group interaction ($F_{4, 668} = 4.54$, $P = 0.001$) for resting, and time spent resting varied significantly among months for short- and intermediate-distance migrants (Table 4). For short-distance migrants, resting increased from June–August (Table 5). However, for intermediate-distance migrants, time spent resting was least in July, intermediate in June, and greatest in August. Despite an apparent trend of increased time spent resting from June–August for long-distance migrants, the low frequency of individuals observed resting within this group precluded us from rigorously testing for a month effect on the frequency of this behavior (Tables 4, 5). Resting varied among months when pooled across distance classes (Table 4), with more time spent resting in June than July ($P < 0.001$) and August ($P < 0.001$), and more resting in July than August ($P = 0.002$).

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Species richness. We did not detect differences in species richness between ISS surveys conducted during typical and delayed drawdowns. The interaction model was not supported over the additive model for explaining variation in species richness ($L = 0.31$, df = 2, $P = 0.86$), and effect of delayed year on species richness was equivocal ($\beta = 0.25$, SE = 0.15, $P = 0.084$).

Monthly abundance. We detected a positive response of abundance to delayed drawdowns for Least Sandpiper, Greater Yellowlegs, Pectoral Sandpiper, and Spotted Sandpiper, but not for Solitary Sandpiper, Lesser Yellowlegs, or Semipalmated Sandpiper. The interaction model was better supported than the additive model for explaining differences in total monthly counts only of Least Sandpiper ($L = 7.37$, df = 2, $P = 0.025$). For this species, there was no overall effect of delayed year on monthly counts ($\beta = 0.26$, SE = 0.89, $P = 0.77$), although there was a significant positive interaction with delayed year during August ($\beta = 2.44$, SE = 1.12, $P = 0.029$) but not July ($\beta = -0.28$, SE = 1.11, $P = 0.80$). Thus, abundance of Least Sandpiper generally decreased from May through August, except in August during delayed years due to the positive interaction. There was a positive effect of delayed year overall for Greater Yellowlegs ($\beta = 1.35$, SE = 0.66, $P = 0.039$), Pectoral ($\beta = 1.99$, SE = 0.47, $P < 0.001$), and Spotted ($\beta = 1.04$, SE = 0.37, $P = 0.005$) Sandpipers. There was no effect of delayed year on monthly counts for Solitary Sandpiper

(β = 0.58, SE = 0.45, P = 0.19), Lesser Yellowlegs (β = 0.43, SE = 0.69, P = 0.53), or Semipalmated Plover (β = -0.94, SE = 0.75, P = 0.21).

Discussion

Mudflats associated with river systems are important sites for migratory water-birds (Minser et al. 2011, Smith 2006, Taylor et al. 1993). During our study, we observed 50% of the shorebird species that breed in North America (Morrison et al. 2006). Moreover, species richness at DRU in 2010 was comparable to that of other studies on migrating shorebirds in the TRV, the MAV, and other interior stopover areas (Andrei et al. 2006, 2009; Davis and Smith 1998; Laux 2008; Lehnen and Krementz 2013; Ranalli and Ritchison 2012; Short 1999; Twedt et al. 1998; Wirwa 2009). However, under typical schemes for water management, mudflat availability in these systems may not coincide with the onset of fall migration of shorebirds (i.e., end of June–August). We found that shorebirds foraged in wetlands consistently throughout summer 2010—a year with delayed drawdowns—and intermediate- and long-distance migrants spent more time on foraging than short-distance migrants. In addition, ISS data indicated that 4 out of 7 species' abundances responded positively to delayed drawdowns. Thus, we believe our results support the need for greater provisioning of habitat for migrating shorebirds throughout summer in the TRV.

Species richness and total abundance did not differ statistically among months in our 2010 surveys, which may reflect the consistent availability of mudflats and thus presence of shorebirds in our study area during delayed drawdowns. Differences in migration phenology among species and migration periods (i.e., spring vs. fall) also could have led to these findings. For example, greater abundance of Least Sandpiper in July and August versus June may have resulted from peak migration earlier in spring and later in fall, while Killdeer, Semipalmated Sandpiper, and Pectoral Sandpiper may persist in relatively high numbers at migration stopover-areas through the end of spring migration and onset of fall migration. At DRU, northbound shorebirds were observed into the first 2 weeks of June, followed by approximately 2 weeks of only resident waterbirds; southbound shorebirds may arrive as early as the last week of June (Nebel and Cooper 2008, Parmelee 1992). Killdeer regularly nest at DRU during the summer, so their presence throughout the summer was expected.

Results from our analyses of ISS data indicated an increase in overall monthly counts during years with delayed drawdowns for intermediate- and long-distance migrants such as Pectoral Sandpiper, Spotted Sandpiper, and Greater Yellowlegs, as well as Least Sandpiper in August. Though we did not detect a difference between species richness in years with and without delayed drawdowns, some shorebird species were observed only during delayed years, including American Golden-Plover, Baird's Sandpiper, *Himantopus mexicanus* (Müller) (Black-necked Stilt), *Limosa fedoa* (Marbled Godwit), *Bartramia longicauda* (Bechstein) (Upland Sandpiper), White-rumped Sandpiper, and *T. semipalmata* (Willet). Conversely, no shorebird species were observed only during typical years. These findings suggest delayed

drawdowns may have some positive influence on species richness and abundance, and management that mimics these flood events by implementing drawdowns through summer may provide important stopover habitat for shorebirds when most mudflats in the Kentucky Reservoir and elsewhere in the TRV still are inundated. Additionally, shorebirds that initially use habitats opportunistically may develop site fidelity pending somewhat predictable wetland availability (Skagen and Knopf 1994). In contrast to habitat along coastal migration routes, interior habitat for shorebirds is highly variable; thus, consistent availability in managed moist-soil areas may mitigate losses of other shorebird habitats (e.g., aquaculture ponds) within this region (Lehnen and Krementz 2013).

Migration is an energetically taxing activity, and fat reserves are essential fuel for survival during migration and at stopover locations (Skagen 2006). Years with increased precipitation can create favorable environmental conditions at stopover locations, which in turn can increase the amount of fat reserves accumulated by shorebirds (Davis et al. 2005, Farmer and Wiens 1999, Krapu et al. 2006, Skagen 2006). This response could be attributed to increased area of mudflats and shallowly flooded (<5 cm) wetlands and an increased abundance of invertebrates which may be available during drawdowns (Lehnen and Krementz 2013, Roshier et al. 2002, Skagen and Knopf 1994). Foraging was the predominant activity observed during delayed drawdowns on DRU in summer 2010. Furthermore, intermediate- and long-distance migrants, such as Semipalmated and Pectoral Sandpipers, spent more time foraging than short-distance migrants, such as Killdeer, in all months. However, intermediate-distance migrants spent the greatest amount of time foraging in July, and short- and long-distance migrants foraged consistently during all months. These results are likely due to differences in energetic requirements for migration, as well as a reflection of different foraging strategies.

The practice of moist-soil management in wetland impoundments to satisfy the needs of wetland-dependent birds and other wildlife is common on many state and federal wetland areas (Colwell and Taft 2000, Fredrickson and Taylor 1982, Loesch et al. 2000, Low and Bellrose 1944, Taft et al. 2002, TNWR 2010). These deliberate management practices provide stopover habitat for migrating shorebirds in spring and fall (Colwell and Taft 2000, Fredrickson and Taylor 1982, Loesch et al. 2000, Taft et al. 2002). The delayed drawdowns in 2010 were made possible in large part by supplemental funding after the Deepwater Horizon oil spill; thus, it may not be economically feasible to conduct drawdowns to that extent under normal budget constraints. However, we observed a positive response by shorebirds during other years with delayed drawdowns. Because monthly abundances were generally greater with delayed drawdowns and some species were only observed during those years, we recommend using water management to mimic flood pulses in July and August on sites designated as mudflats for migrating shorebirds.

Specifically, and where feasible in the TRV, resource managers might consider draining at least one impoundment beginning in early July to benefit fall-migrating shorebirds. Drawdowns should incrementally expose mudflats by decreasing water

levels at a rate of approximately 2–3 cm per week (Fredrickson and Taylor 1982, Hands et al. 1991, Laux 2008, Rundle and Fredrickson 1981). This management strategy is beneficial because it 1) provides shorebirds with foraging opportunities in impoundment mudflats; 2) benefits locally breeding rails, shorebirds, and wading birds; and 3) provides ideal substrates for germination of moist-soil plants (Fredrickson and Taylor 1982, Kross et al. 2008, Laux 2008, Wirwa 2009). If all contours in an impoundment were exposed by early August, sufficient time would remain during the growing season for some desirable moist-soil plants to mature (i.e., 60 days), which in turn would provide important habitat for migrating and wintering waterfowl when re-flooded in fall (Fredrickson and Taylor 1982). Moreover, this strategy could help mitigate effects of delayed exposure of mudflats in reservoirs throughout the TRV, like Kentucky Reservoir, where mudflats are not exposed until mid-August (Wirwa 2009).

Finally, we observed more shorebird species in 2010 ($n = 26$) than were observed on ISS surveys ($n = 9$–21), and the 5 species unique to our observations in 2010 included 2 of conservation concern, Piping Plover and Buff-breasted Sandpiper (Table 1). During our intensive surveys in 2010, we observed several species (i.e., Buff-breasted Sandpiper, Marbled Godwit, Piping Plover, *Calidris alba* [Sanderling], Willet, and Wilson's Phalarope) ≤10 days before their departure from DRU. Because we only collected data for a single year, we cannot unequivocally conclude whether these specific observations resulted from delayed drawdowns, inter-year variability, or survey design. However, it is possible that some of these species were missed on traditional ISS surveys due to differences in survey sites and frequency; thus, use of current methods may result in underestimates of the relative importance of some areas to intermediate- and long-distance migrants. Resource managers could consider conducting ISS surveys in this region more frequently than the every-10 day interval prescribed by ISS protocol. However, we advocate additional study and cost-benefit analyses to determine feasibility of increased number of surveys relative to desired outcomes prior to implementing any changes in protocol.

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