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I am submitting herewith a thesis written by John William Laux entitled "Waterbird Responses to Drawdown of Two East Tennessee River Valley Reservoirs." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

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WATERBIRD RESPONSES TO DRAWDOWN OF TWO EAST TENNESSEE RIVER VALLEY RESERVOIRS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

John William Laux

August 2008

DEDICATION

I would like to dedicate this to my parents Ronald and Rosalind Laux and to all my other friends and family that provided me with their love and support along the way. Without their encouragement this would not have been possible.

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ABSTRACT

Waterbirds rely on stopover sites in the interior United States to meet the energetic demands associated with migration. Mudflats exposed during annual drawdowns of reservoirs in the Tennessee River Valley (TRV) provide stopover habitat for thousands of migratory waterbirds. Timing of drawdowns may significantly affect waterbird use of TRV mudflats. Thus, I quantified the impacts of drawdown date for Douglas (1 August) and Chickamauga (1 October) Reservoirs on mudflat acreage and characteristics, food availability, and waterbird use. I also quantified waterbird activities on TRV mudflats to determine their functional role to migratory waterbirds. From August 2005/06 – January 2006/07, I conducted waterbird surveys twice weekly at four mudflats each in Douglas and Chickamauga Reservoirs. I sampled mudflat acreage weekly; vegetation, seeds and aquatic invertebrates twice monthly; water depth and quality twice monthly; and soil moisture, compaction and temperature twice monthly. I documented 68 waterbird species using east TRV mudflats. Shorebirds were more abundant at Douglas Reservoir in August – September and at Chickamauga Reservoir from October – January. Total shorebird abundance was twice as great at Chickamauga Reservoir, and the community was composed of short-distance migrants. Shorebird richness was twice as great at Douglas Reservoir, and most species were longer-distance migrants of greater conservation concern. Waterfowl abundance and richness were greater at Chickamauga Reservoir, peaking November – December. Exposed mudflat acreage was greater at Douglas Reservoir from August – October; no mudflats were exposed in Chickamauga Reservoir during August – September either year. All vegetation parameters were greater on Douglas mudflats. Differences in seed biomass,

soil characteristics, and water depth and quality were not detected between reservoirs. Invertebrate analyses were not included in the thesis because they are ongoing. Shorebird abundance was positively associated with mudflat acreage and negatively associated with horizontal cover of vegetation and water depth. Primary waterbird activities included foraging, locomotion and resting. My results suggest that early and late drawdowns of TRV reservoirs benefit waterbirds. Thus, I recommend sequential drawdowns of reservoirs, such that new mudflats are continuously exposed from late July – November in the TRV. When possible, reservoir drawdown rate should be as slow as possible (e.g., $\leq$1 cm/day).

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CHAPTER I

INTRODUCTION

Wetland loss in the United States has been substantial (Dahl 1990, Mitsch and Gosselink 2000). Due to anthropogenic disturbance, approximately 53% and 60% of the wetlands have been lost in the United States and Tennessee, respectively (Dahl 1990). Fortunately, wetland regulations and conservation have slowed the rate of wetland loss (Mitsch and Gosselink 2000). Given that fewer wetlands exist now than historically, there is a need to intensively manage and conserve wetlands for resident and migratory wildlife, particularly wetland-dependent species (Tacha and Braun 1994, Baldassarre and Bolen 2006). Shorebirds require wetlands throughout the annual cycle (Helmers 1992). Several studies have documented substantial declines in shorebird populations (e.g., Howe et al. 1989, Morrison et al. 1994, Bart et al. 2007). Recently, Bart et al. (2007) reported that population trends declined in 22 of 30 shorebird species evaluated in the North Atlantic Region of the United States and Canada. This emphasizes the need for wetland managers to identify limiting factors of shorebird populations, and to provide quality habitat for these birds throughout the annual cycle (Brown et al. 2001).

Most shorebirds in North America breed in the arctic regions of Canada and Alaska, migrate south through the United States, and winter in the southern United States and Central and South America (Myers 1983, Myers et al. 1987). Southward migration begins in July and extends through November, with peak migration in mid-latitude United States (e.g., Tennessee) occurring from late July through mid-September (Smith et al. 1991, Helmers 1992, DeCecco and Cooper 1996). Spring migration begins in March and extends through May (Reid et al. 1983, Helmers 1992). Shorebirds depend on three

groups of habitats in the United States during migration, which correspond to existing migration pathways: Atlantic coast wetlands, interior wetlands, and Pacific coast wetlands (Myers et al. 1987). Wetland availability and quality during fall migration is considered one of the primary factors limiting shorebird populations (Morrison et al. 1994, Brown et al. 2001).

Shorebirds use wetlands in the conterminous United States during migration as stopover sites to meet energetic demands associated with long-distance flight (Skagen and Knopf 1993, 1994*a*). It is estimated that a 45-g shorebird must consume approximately 8 g of aquatic invertebrates per day to maintain body mass and accumulate sufficient fat reserves for migration (Loesch et al. 2000). Thus, the availability of aquatic invertebrates at migratory stopover sites is critical to shorebird survival (Myers 1983, Skagen and Knopf 1993).

Most shorebirds prefer shallowly flooded or recently dewatered wetlands with low vegetative cover for foraging (Baker 1979, Helmers 1992, Davis and Smith 1998*a*). Mudflats and associated shallowly flooded sites are ideal locations for shorebird stopovers (Skagen and Knopf 1993, 1994*b*). These wetlands can be classified as unconsolidated shore or unconsolidated bottom with a mud subclass (Cowardin et al. 1979). In the interior United States, these wetland types are often associated with riverine systems. Rivers also serve as corridors for migration, thus mudflats associated with riverine systems are important shorebird stopovers (Skagen and Knopf 1993, Farmer and Parent 1997).

During fall, mudflats exposed during reservoir drawdowns in the Tennessee River Valley (TRV) provide stopover and wintering habitat for thousands of shorebirds and

other waterbirds (T. Henry, Tennessee Valley Authority [TVA], unpublished data). The availability of these mudflats for shorebirds is dependent on reservoir drawdown date, which is controlled by TVA (Smith 2006). Recently, TVA shifted the drawdown schedules of several TRV reservoirs to accommodate late summer recreational demands (TVA 2004). Although Smith (2006) documented that this has resulted in less habitat available to migrating shorebirds in certain areas of the TRV, no study has quantified the influences of drawdown date on shorebird (or other waterbird) use. Moreover, habitat conditions resulting from differing drawdown dates (i.e., vegetation response, food resource availability, soil moisture and compaction) may affect the suitability of mudflats for waterbirds. Thus, the goal of my research was to determine the influences of drawdown date on: 1) waterbird use of mudflats, 2) temporal availability of mudflats, 3) vegetation response, 4) food resource availability, and 5) other possible proximate factors of waterbird habitat use. In Chapter II, I present data on these five objectives. I also quantified the activities of waterbirds using TRV mudflats to gain insight into the functional role these habitats provide to waterbirds. These data are presented in Chapter III. My study was conducted during two fall drawdowns (2005 and 2006), and results presented herein will be the basis for providing recommendations to TVA on future drawdown schedules that address waterbird needs.

CHAPTER II

INFLUENCES OF DRAWDOWN ON WATERBIRD USE OF MUDFLATS

Introduction

In the Tennessee River Valley (TRV), mudflats associated with the Tennessee River and its tributaries provide stopover habitat for thousands of shorebirds annually (T. Henry, Tennessee Valley Authority [TVA], unpublished data). The TRV is the fifth largest watershed in the nation, encompassing portions of seven southeastern states, with most of the acreage occurring in Tennessee (Miller et al. 1996; Figure 1[1]). Historically, few mudflats likely existed within the TRV because river channels were narrower, and the adjacent floodplain was hardwood bottomland (TVA 1942, 1949). Water levels within the Tennessee River fluctuated with seasonal precipitation patterns, with peak flows occurring in winter and spring, and decreasing through summer and fall. Over time, the risk of flooding increased as agriculture and human development moved into the TRV floodplain (Miller et al. 1996).

In 1933, the Tennessee Valley Authority, a federal agency, began construction of dams in the TRV to control the hydrology of the Tennessee River and its tributaries (Miller et al. 1996). Currently, TVA owns and operates a total of 49 dams within the TRV, each creating a reservoir upstream. Although the primary purpose of each reservoir is dependent upon its position within the watershed, TVA manages this reservoir system to provide flood control, generate electricity, and facilitate year-round navigation (Miller et al. 1996). Water recreation, such as fishing and boating, is an

[1]All tables and figures located in Appendix I.

additional and expanding use of TRV reservoirs (Cordell and Bergstrom 1993, Ungate 1996, Jakus et al. 2000). The creation of reservoirs inundated many of the historic floodplains along the Tennessee River and its tributaries. Throughout much of the TRV floodplain, hardwood bottomlands were cleared for agriculture prior to dam construction. For example, 84% of the 12,788 ha of land inundated following the completion of the Douglas Reservoir dam was previously cleared agricultural fields (TVA 1949). Standing timber remaining within the floodplain also was removed prior to completion of dam construction (TVA 1942, 1949). Agricultural fields and previously timbered sites became vast expanses of mudflats after flooding.

It has been estimated that over 12,000 ha of mudflats exist within the TRV watershed (T. Henry, TVA, unpublished data). The exposure of these mudflats is dependent on the timing and duration of seasonal drawdowns of reservoirs (Smith 2006), which are performed by TVA. Tennessee Valley Authority begins holding runoff in reservoirs from spring rains in early April, and reservoir levels typically reach full pool by May. Reservoirs drawdowns are initiated in late summer or fall and water levels are typically lowest during winter, which facilitates flood storage during increased precipitation in spring (Miller et al. 1996).

Historically, TVA initiated drawdowns of TRV reservoirs in June and July resulting in exposure of mudflats from July – September (Smith 2006), which coincided with peak shorebird migration in Tennessee (DeCecco and Cooper 1996, Short 1999). However, this drawdown schedule often conflicts with late summer recreational activities (Cordell and Bergstrom 1993, Jakus et al. 2000). As a result, TVA has received increased public pressure to accommodate these demands by delaying reservoir

drawdowns. Under the Lake Improvement Plan in 1991 and Reservoir Operations Study in 2004, TVA authorized delayed drawdown of 10 tributary reservoirs to 1 August (TVA 2004). Based on evaluations mandated under the Reservoir Operation Study, which this study is a part of, further delays may be expanded to include additional reservoirs if negative social, economic, and environmental impacts are not documented (TVA 2004).

Delayed drawdowns have resulted in fewer exposed mudflats in certain areas of the TRV for shorebirds during peak fall migration (Smith 2006). However, there have been no attempts to quantify shorebird (or other waterbird) use of TRV mudflats in response to drawdowns. Moreover, no studies exist comparing waterbird use among reservoirs with drawdown dates. Two reservoirs exist in east Tennessee (Douglas and Chickamauga) with different drawdown dates. The planned initiation of drawdowns for Douglas and Chickamauga Reservoirs is 1 August and 1 October, respectively. This provided an opportunity to compare waterbird use of mudflats between two reservoirs in relatively close proximity (i.e., 165-km separation) that are drawn down on different dates (i.e., 1 August vs. 1 October). This was the premise of my study.

In order to understand environmental mechanisms of waterbird responses, it is important to quantify the proximate and ultimate factors related to habitat selection and use (Haig et al. 1998, Oring et al. 2000, Brown et al. 2001). Proximate factors are cues that birds use to assess habitat suitability (e.g., vegetation and soil characteristics). In contrast, ultimate factors directly impact bird survival (e.g., food resource availability), and are often correlated with proximate factors. Shorebird use presumably could be influenced by water depth and quality, mudflat exposure, soil compaction and moisture (due to influences on prey availability), vegetation presence and food resource densities

(Pienkowski 1983*a*, Mouritsen and Jensen 1992, Skagen and Knopf 1994*b*, Davis and Smith 1998*a*, Collazo et al. 2002). Other waterbirds, such as Canada geese (*Branta canadensis*) and dabbling ducks (Tribe *Anatini*), may be attracted to mudflats to forage on vegetation shoots, seeds and invertebrates (Rundle and Fredrickson 1981, Gaston 1992). Drawdown date may affect aquatic invertebrate densities, seed germination and plant growth, and whether a plant reaches maturation and produces seed (Fredrickson and Taylor 1982, Fredrickson and Reid 1988*a*, Webb et al. 1988). In addition, drawdowns can provide foraging habitat for wading birds by concentrating prey into a reduced water volume (Kushlan 1976, Sprandel et al. 2002). Ideally, management of waterbirds should consider migration chronologies to ensure food resources are available at times when they are most needed by these birds (Fredrickson and Reid 1986, Reinecke et al. 1989, Brown et al. 2001).

To address these questions, I quantified the following response variables on mudflats in Douglas and Chickamauga Reservoirs:

- species-specific waterbird abundance,
- temporal mudflat availability,
- vegetation structure and biomass,
- moist-soil seed production,
- water depth and quality, and
- soil moisture, compaction and temperature.

Experimental units were eight mudflats; four with a 1 August drawdown (Douglas Reservoir) and four with a 1 October drawdown (Chickamauga Reservoir). Invertebrate

data are not included because analyses are ongoing. Invertebrate results will be provided in the peer-refereed publication.

Methods

Study Area

My study was conducted from 15 August 2005 – 13 January 2006 and from 31 July 2006 – 12 January 2007 at Douglas and Chickamauga Reservoirs located in the TRV of east Tennessee. Sampling at Douglas Reservoir (1 August drawdown) occurred adjacent to the Rankin Wildlife Management Area (WMA) near the confluence of the French Broad and Nolichucky Rivers (UTM zone 17, 299028 E, 3995062 N; Figure 2). Sampling at Chickamauga Reservoir (1 October drawdown) occurred in and adjacent to Hiwassee Wildlife Refuge, approximately 4.8 km west-northwest of Charleston, Tennessee (UTM zone 16, 696418 E, 3912292 N; Figure 3).

Douglas is considered a storage or tributary reservoir in the TRV and water levels fluctuate approximately 12.8 m (42 ft) each year. Chickamauga is a mainstem reservoir along the Tennessee River and water levels fluctuate approximately 2.3 m (7.5 ft) each year. I assumed that mudflats in Douglas and Chickamauga Reservoirs were similar, except for drawdown date, and that date of mudflat exposure was the primary mechanism driving waterbird use and other response variables. I also assumed that these reservoirs existed in the same migration flyway, which is reasonable considering they are separated by 161 km on approximately a north-south azimuth in east Tennessee. This distance represents <1% of the total migration distance for most shorebird species in the Western

Hemisphere (Morrison and Myers 1987, Myers et al. 1987). Thus, I assumed that both reservoirs were exposed to similar migratory waterbird communities during sampling.

Waterbird Use of Mudflats

To determine the effect of drawdown date on waterbird use, all birds observed using mudflats and adjacent shallow water areas were recorded twice weekly per reservoir. Species-specific abundance was measured via scan sampling at four permanent viewing locations (one per mudflat) in each reservoir. A Swarovski® spotting scope (model ST-80) with 20 – 60X zoom was used to identify and count birds within an 180˚ semi-circle around each viewing location (Figure 4). For statistical analyses, each species was categorized into one of four waterbird guilds including: 1) shorebirds, 2) waterfowl, 3) "other waterbirds" (i.e., additional wetland-dependent species; Weller 1999), and 4) "other birds" (i.e., additional species not wetland-dependent; Appendix II). The mean acreage viewed at each mudflat was comparable between Douglas (23.0 ha, SE = 9.5) and Chickamauga Reservoirs (27.3 ha, SE = 9.4). All surveys occurred between sunrise and 5 hrs after sunrise, and the viewing order at each reservoir rotated systematically each week.

Mudflat Availability

The availability of mudflats can greatly influence habitat-use patterns of waterbirds (e.g., Rave and Baldassarre 1989, Skagen and Knopf 1994*b*, Collazo et al. 2002). In the TRV, the temporal availability of mudflats is dependent on reservoir drawdown date (Smith 2006). Thus, mudflat acreage was quantified weekly at each

reservoir by walking shorelines of mudflats using a Trimble GeoExplorer® XM unit. If possible, the entire perimeter of each mudflat was walked; otherwise, at least 50 m on each side of a permanent transect for vegetation sampling (discussed later) was traversed. Collected data were geo-corrected using Trimble Pathfinder® Office software and the Pellissippi State Continuously Operating Reference Station (CORS) located in Knoxville, TN. The temporal availability (acreage) of mudflats was then quantified using ESRI ArcGIS® 9.1. Panoramic digital photos also were taken weekly from permanent locations for image documentation of differences in mudflat exposure.

Initial mudflat exposure at Douglas Reservoir occurred on 3 August 2005 and 19 July 2006 at reservoir gage height = 302.1 m (991 ft) above mean sea level. In contrast, initial exposure of mudflats at Chickamauga Reservoir occurred on 1 October 2005 and 2 October 2006 at reservoir gage height = 207.6 m (681 ft). From 1 August – 15 January, drawdown rates at Douglas Reservoir averaged –7.2 and –6.5 cm per day in 2005 and 2006, respectively. At Chickamauga Reservoir, drawdown rates averaged –1.2 and –1.4 cm per day in 2005 and 2006, respectively, from 1 October – mid-January. Thus, drawdown date and rate were different between study reservoirs.

Exposed mudflats were 4.74 – 49.27 ha in Douglas Reservoir and 12.09 – 54.68 ha in Chickamauga Reservoir. At Douglas, a total of 91.93 ha of mudflats were exposed at reservoir gage height = 295.7 m (970 ft) on 4 October 2005 and 30 October 2006. Although water levels in Douglas Reservoir receded an additional 6.1 m (20 ft) both years, mudflat acreage did not increase, because all remaining water was restricted to the river channel. At Chickamauga Reservoir, a total of 109.28 ha of mudflats were exposed at reservoir gage height = 205.9 m (675.5 ft).

Vegetation Response

The establishment and structure of vegetation on mudflats following drawdowns can also influence waterbird-use patterns (Rundle and Fredrickson 1981, Helmers 1992, Davis and Smith 1998*a*). Plant germination, growth, and seed production are influenced by the timing and duration of mudflat exposure (Fredrickson and Taylor 1982, Webb et al. 1988, Amundsen 1994), which is dependent on reservoir drawdown date (Smith 2006). Thus, the vegetative response on mudflats may differ between the two study reservoirs and influence waterbird-use patterns. I sampled vegetation along a permanent transect established perpendicular to the contour gradient on each mudflat (Webb et al. 1988), extending from the upland to the edge of the water. Locations of 0.305-m (1-ft) contours along each transect were determined using coverages created from LIDAR data at Douglas Reservoir and using a surveying transit at Chickamauga Reservoir. The midpoint of each contour was marked permanently with rebar. As the water receded, additional midpoints were established (Figure 5).

Average vegetation height, richness, and percent horizontal and vertical cover were measured within 1-m^2 plots centered at contour midpoints every two weeks. Shorebirds prefer foraging in areas with low horizontal vegetative cover (Helmers 1992, Davis and Smith 1998*a*) and waterfowl also often land and forage in areas where vegetation is less dense (White and James 1978, Clark and Greenwood 1987, Smith et al. 2004). Thus, percent horizontal cover of plant life forms was visually estimated in each 0.25-m^2 quadrant ($n = 4$) of the 1-m^2 plot. Life forms included grasses, forbs, sedges, dead organic material and bare ground. Vertical structure of vegetation also may inhibit waterbird use (Clark and Greenwood 1987, Helmers 1992). For instance, shorebirds tend

to avoid areas with vegetation taller than half their height (Helmers 1992). Thus, plant height and the percent vertical cover were quantified within each 1-m^2 plot using a metric ruler and modified profile board, respectively (Nudds 1977). This profile board was designed to include two 0.5-m height strata, each containing thirty 25-cm^2 (5 x 5 cm) alternately colored boxes (Figure 6). Vertical structure was indexed by placing the board in the center of the 1-m^2 plot, kneeling exactly 2 m upslope, and counting the number of boxes that were >50% covered by vegetation in each stratum. Plant species occurring in each plot also were recorded.

To estimate available browse for Canada geese (Sedinger and Raveling 1986, Cadieux et al. 2005), vegetative biomass was clipped from 0.0625-m^2 (0.25 x 0.25 m) plots positioned 2 m from each 1-m^2 plot and parallel to the contour gradient (Figure 5). Because clipping is destructive, vegetation was clipped from a different 0.0625-m^2 plot every two weeks, with subsequent plots 2 m from the previously clipped plot. Vegetation was placed in bags, labeled and frozen at -5^{o}C until lab processing. In the lab, vegetation biomass samples were thawed, sorted by species, oven-dried at 50˚C for 24 hours, weighed to the nearest 0.01 g, and represented as dry biomass (g/m^2).

At the end of the growing season, all vegetation within 1-m^2 plots was clipped. To estimate seed production, seed heads from ≥30 plants per seed-producing species were randomly collected outside the 1-m^2 plot, placed separately in bags, labeled and frozen. In the lab, stem densities of seed-producing species within clipped 1-m^2 plots were tallied. Seed heads were threshed by hand, dried to a constant mass, and dry seed mass weighed to the nearest 0.0001 g (Laubhan and Fredrickson 1992, Gray et al. 1999*a*). Average dried seed mass per plant species was multiplied by its corresponding

stem density in each 1-m^2 plot for an estimate of aboveground seed production. Seed production was estimated to determine the extent that mudflat seed banks were being replenished.

Aquatic Invertebrate and Seed Density and Composition

To estimate available food for shorebirds and dabbling ducks, aquatic invertebrates and seeds in the water column and soil were collected via benthic core sampling (Swanson 1978, Murkin et al. 1996). Sampling occurred along a 20-m transect parallel to and 20 m from the vegetation transect, with its midpoint positioned at the water-interface (Figure 5). Previous studies have suggested that this zone is a common foraging location for waterbirds (Baldassarre and Fischer 1984, Taft and Haig 2005). Core samples 8.8 cm in diameter (Whittington 2005) were taken to a soil depth of 10 cm, which is assumed to be the maximum foraging depth of waterfowl (Stafford et al. 2006). At this water-interface transect, core samples were collected at the transect midpoint and every 2 m on land and in water, thus n=11 per transect. Core contents were placed in a Wildco® bucket with a 500-μm screen to remove water, put in plastic bags, labeled and frozen for lab processing.

Core samples were thawed and stained with Rose Bengal solution overnight to facilitate invertebrate sorting and detection (Rundle 1982, Sherfy et al. 2000). Lab procedures followed Gray et al. (1999*a*) and Manley et al. (2004), and invertebrates were identified to family or the lowest taxonomic grouping possible following Thorp and Covich (2001). All 11 core samples from each transect collected on Chickamauga mudflats in 2006 and on Douglas mudflats in 2005 and 2006 were sorted. However,

sorting time was underestimated, thus only five core samples were sorted per transect collected on Chickamauga mudflats in 2005 to reduce sorting duration. Invertebrates have been sorted from core samples and identified for density estimates but biomass estimates are ongoing. A subsample of invertebrates from each taxonomic grouping was retained, and will be oven-dried at 105˚C for 24 hours and weighed to the nearest 0.0001 g. The average biomass of each taxa will be multiplied by its corresponding density from core samples for an estimate of dry biomass (g/m^2; Gray et al. 1999*b*). Seeds in core samples were sorted into 3 categories: moist-soil seeds (e.g., *Echinochloa*, *Eragrostis*, *Polygonum*), hard-mast tree seeds (e.g., *Acer*, *Quercus*), and rough cockleburr (*Xanthium strumarium* L.). These categories represent waterfowl food resources from herbaceous and woody plants, respectively, and a moist-soil plant (i.e., rough cockleburr) that has low food value yet often dominates mudflats. Seeds of each category were oven-dried at 50˚C for 24 hours, weighed to the nearest 0.0001 g, and represented as dry biomass (g/m^2).

Soil Characteristics and Water Depth

The availability of food is affected by water depth because it provides species-specific limitations based on morphology, such as leg and bill length (Poysa 1983, Ntiamoa-Baidu et al. 1998, Taft et al. 2002). Similarly, substrate conditions and temperature can influence the distribution and overall availability of invertebrates to shorebirds (Goss-Custard et al. 1977; Pienkowski 1983*a*, 1983*b*; Weber and Haig 1996). Thus, I measured water depth and soil compaction, moisture and temperature at each core sampling site. I used DICKEY-john® soil compaction tester (DICKEY-john

Corporation, Auburn, Illinois) to measure mudflat compaction and an Aquaterr® TEMP-300 digital soil moisture and temperature meter (Ravalco, Inc., Costa Mesa, California) to measure mudflat moisture and temperature. Every two weeks a new transect was established at the new water-mudflat interface (i.e., referred to as "water-interface transect" in results) following the same sampling protocol. If the water receded <20 m (i.e., the length of the transect) between sampling periods, the new transect was established 10 m from and parallel to the previous transect (Figure 5). I also returned to the permanently marked midpoint of all previous transects (i.e., referred to as "previous transects" in results) and collected one core sample 1 m from the previously collected sample to estimate seed and aquatic invertebrates, and measured soil compaction, moisture and temperature. The goal of these samples was to document trends in food resource availability and soil characteristics as mudflats dried.

In 2006, I also measured water quality at each mudflat, because nutrient concentrations can influence aquatic invertebrate species composition and abundance (Reid 1985, Thorp and Covich 2001). During core sampling, water samples were collected at the midpoint of the inundated section of each water-interface transect and concentrations of ammonia-nitrogen (0.00 – 4.00 mg/L), nitrite (0.00 – 1.25 mg/L), and nitrate (0.0 – 60.0 mg/L) were quantified using a LaMotte® Smart2 colorimeter (LaMotte, Chestertown, Maryland). Ammonia-nitrogen readings were multiplied by 1.2 and represented as un-ionized ammonia (NH_3; LaMotte 2004).

Statistical Analyses

I quantified the following response variables: mean species-specific daily

abundance of waterbirds; mean daily waterbird richness and diversity; mean weekly mudflat acreage (ha); mean bi-monthly plant height (cm), plant richness, percent horizontal and vertical cover of vegetation, vegetative biomass (g/0.0625 m^2), seed biomass (g/608.21 cm^3), water depth (cm), water quality (mg/L), soil compaction (lbs./in^2), soil moisture (%), and soil temperature (˚C); and end-of-year vegetation biomass (g/m^2) and seed production (g/m^2). In addition to quantifying differences between reservoirs, I wanted to determine if monthly trends existed in the above response variables. Thus, waterbird abundance was averaged across days per mudflat per month for each observed species and four avian guilds: shorebirds, waterfowl, other waterbirds (i.e., wetland-dependent species other than shorebirds and waterfowl), and other birds (i.e., additional species not wetland-dependent). For each waterbird guild, differences in species composition at each reservoir were tested among months using a chi-square test of homogeneity (Zar 1999). All remaining variables, except end-of-year biomass and seed production, were sampled either two or four times per month, thus were averaged across weeks. Response variables were analyzed separately for each year. All vegetative parameters were tested between reservoirs in 2005 only, because no plants became established on mudflats in Chickamauga Reservoir in 2006. Seed production was not tested either year, because no seed was produced on Chickamauga mudflats.

For variables with monthly averages, I used a repeated measures analysis-of-variance (ANOVA) with Huynh-Feldt correction to test for differences between reservoirs and among months (Montgomery 2000). A Shapiro-Wilk W-test was used to test for normality, and a Wilcoxon nonparametric 2-sample test was used to quantify differences between reservoirs if normality was violated (Conover 1980). If an

interaction existed, analyses were separated by month for reservoir tests, and by reservoir for monthly tests (Montgomery 2000). For end-of-year biomass and seed production, I used a two-way ANOVA to test for differences between reservoirs and among plant species. All tests were performed at $\alpha = 0.10$ using the SAS® system (Littell et al. 1991, Freund and Littell 2000, Stokes et al. 2003).

I also was interested in identifying potentially important habitat variables that explained significant variation in shorebird and waterfowl abundance. I used canonical correspondence analysis (CCA) to determine the relationship between habitat variables that were uncorrelated with each other and shorebird community composition (ter Braak 1995). The response matrix (26×4) was mean daily abundance of the four most common species over two years at each mudflat. Mean daily abundance per mudflat was calculated for eight periods per year, which were consecutive 2-week intervals from August through November. Only the most common species were used, because CCA is sensitive to zeroes in the response matrix (ter Braak 1995). Similarly, December and January were not used because of few shorebirds using the mudflats during these months. I natural-log transformed all mean abundances, because CCA is sensitive to outliers and bimodally distributed data (ter Braak 1995). I used Program CANOCO (version 4.5) to perform CCA analyses (Leps and Smilauer 2003). A global Monte Carlo permutation test was used to determine if a significant relationship ($\alpha = 0.10$) existed between habitat variables and shorebird species composition (ter Braak 1995). Uncorrelated habitat variables in this analysis were percent horizontal cover of vegetation, vegetation biomass, water depth, percent exposure of mudflats, water temperature and reservoir gage height.

Lack of correlation was determined by examining a multivariate ordination before CCA analyses.

I also created a dimensionless species-habitat ordination to examine the relationship between shorebird species abundance and habitat variables (ter Braak 1995). This ordination was composed of triangles and arrows representing species abundance and habitat variables, respectively. The length and direction of each arrow corresponded to the eigenvalue and eigenvector, respectively, for the particular habitat variable. Metrics with larger eigenvalues (hence longer arrow lengths) were associated more strongly with shorebird abundance. Also, species that were more closely positioned to a habitat-variable arrow were more strongly correlated with it. To further illustrate the relationships among habitat variables and shorebird species abundance, I created an inferred ranking diagram. This diagram was created by extending the blunt end of each eigenvector through the origin of the biplot and drawing orthogonal lines from each species to the eigenvector. Species closer to the arrowhead and blunt end of the eigenvector were more positively and negatively correlated, respectively, with the habitat variable. Species positions along the inferred ranking also can be interpreted as positive and negative associations (ter Braak 1995).

I also constructed multiple linear regression models for predicting shorebird and waterfowl abundance using habitat variables. All measured variables were considered as possible predictors in addition to reservoir gage height (ft) and percent of total mudflat exposure. Similar to multivariate analyses, waterbird abundance and habitat variables were averaged for consecutive 2-week intervals. I took a hierarchical approach to modeling, creating separate models for vegetation, soil, and mudflat acreage variables.

Possible predictor variables for the vegetation model included plant height, richness, biomass, percent horizontal cover, and percent vertical cover. Possible soil model variables included water depth, seed biomass, and soil compaction, moisture, and temperature. Possible variables for the mudflat acreage model were acreage, percent exposure and gage height. Given that time of year can influence migratory waterbird abundance, I assigned sequential numbers to each consecutive sampling period, and included it as a possible variable in all models. I used stepwise selection (entry and stay $\alpha = 0.10$; Myers 1990) with mean shorebird and waterfowl abundance as the response variable. Analyses were performed separately for 2005 and 2006.

Lastly, I used simple linear regression to quantify the relationship between soil moisture and compaction (response variables) and number of weeks following mudflat exposure (explanatory variable). Data collected from the permanently marked midpoint of all previous transects was used in these analyses. Analyses were performed separately for reservoirs and years. Fitted line plots with 95% confidence intervals were constructed to graphically illustrate the relationship.

Results

Waterbird Abundance, Richness and Species Composition

A total of 38,981 birds, comprising 60 species, were observed using eight mudflats in Douglas and Chickamauga Reservoirs (Appendix II). Total abundance was 40% greater on Chickamauga than Douglas mudflats; however, total species richness (S = 41) was identical between the two reservoirs. The avian community observed using the

eight mudflats consisted of 20 shorebirds species, 16 waterfowl species, 16 other waterbird species, and 8 other bird species.

Shorebirds.—Shorebird composition differed among months at Douglas (χ^2_{68} = 966.0, $P < 0.001$) and Chickamauga Reservoirs (χ^2_{24} = 972.2, $P < 0.001$). The shorebird community was comprised primarily of killdeer (*Charadrius vociferus*), which constituted 62% and 77% of the two-year combined totals at Douglas and Chickamauga Reservoirs, respectively. Killdeer were commonly observed (51 – 98%) on Douglas mudflats from August – December (Figure 7). During August and September, least (*Calidris minutilla*) and pectoral sandpipers (*Calidris melanotos*) each comprised 11 – 18% of the total observed and least sandpipers also constituted 17% in October. Wilson's snipe (*Gallinago delicata*) comprised 30% of the December total, but only six individuals were observed. At Douglas Reservoir, no other species alone constituted >3% of the total observed during any month (Figure 7). At Chickamauga Reservoir, killdeer were common during October – January, comprising 47 – 85% of the total observed (Figure 8). Wilson's snipe (8 – 30%) and least sandpipers (5 – 20%) also were abundant on Chickamauga mudflats from October – January both years. No other shorebird species constituted >2% of the total observed at Chickamauga Reservoir during any month (Figure 8).

Total shorebird abundance was 2.2X greater on Chickamauga (n = 10,070) than Douglas mudflats (n = 4,620). In contrast, total shorebird species richness was 2.1X greater at Douglas than Chickamauga Reservoir (S = 19 and S = 9, respectively). Shorebird abundance and species richness at Douglas Reservoir in 2006 (n = 3,520; S = 16) was 321% and 33% greater than that observed in 2005 (n = 1,100; S = 12),

respectively. However, abundance at Chickamauga was 26% greater in 2005 (n = 5,609) than 2006 (n = 4,461) and species richness was similar between years (2005: S = 8, 2006: S = 7). During both years, the greatest monthly richness of shorebirds at Douglas and Chickamauga Reservoirs was observed in August – September and October – November, respectively, during the initial exposure of mudflats (Figures 7 and 8).

Mean daily abundance of shorebirds per mudflat was significantly greater at Douglas than Chickamauga Reservoir in August 2006 and September both years (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$; Table 1). Shorebirds were not observed at Chickamauga Reservoir during August or September either year because mudflats were flooded. However, shorebirds were 21 – 161X more abundant on Chickamauga than Douglas mudflats in November, December, and January both years (Wilcoxon $Z \geq 2.2$, $P \leq 0.03$; Table 1).

Mean richness of shorebird species per mudflat was greater at Douglas than Chickamauga Reservoir in August 2006 and September both years (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$; Table 1). In contrast, mean richness was 6 – 16X greater at Chickamauga than Douglas Reservoir during November, December, and January both years (Wilcoxon $Z \geq 2.2$, $P \leq 0.03$). Similarly, mean daily shorebird diversity per mudflat was significantly greater at Douglas Reservoir in August 2006 and September both years (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$). However, diversity was 14 – 24X greater at Chickamauga than Douglas mudflats in October 2005 and November, December, and January both years (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$; Table 1).

Mean abundance of killdeer and pectoral sandpipers was greater at Douglas than Chickamauga Reservoir in August 2006 and September both years (Wilcoxon $Z \geq 1.8$, P

$\leq$ 0.07; Tables 2 and 3). Least and semipalmated sandpipers (*Calidris pusilla*) were more abundant on Douglas than Chickamauga mudflats in September 2005 (Wilcoxon $Z = 1.8$, $P = 0.07$; Table 2). In 2006, mean abundance of least sandpipers and greater yellowlegs (*Tringa melanoleuca*) in August and September, respectively, and spotted sandpipers (*Actitis macularius*) during both months were significantly greater at Douglas than Chickamauga Reservoir (Wilcoxon $Z = 1.8$, $P = 0.07$; Table 3).

Killdeer and Wilson's snipe abundance was significantly greater at Chickamauga than Douglas Reservoir from November – January both years (Tables 2 and 3). Killdeer were 15 – 19X and 128 – 390X more abundant on Chickamauga mudflats during November and December, respectively (Wilcoxon $Z = 2.2$, $P = 0.03$; Tables 2 and 3). Wilson's snipe were 45X more abundant at Chickamauga than Douglas Reservoir in December 2005 (Wilcoxon $Z = 2.2$, $P = 0.03$). Wilson's snipe also were more abundant on Chickamauga than Douglas mudflats in October 2005 (Wilcoxon $Z = 1.8$, $P = 0.07$; Table 2). No other significant differences were detected between reservoirs (Wilcoxon $Z \leq 1.5$, $P \geq 0.12$; Tables 2 and 3).

Waterfowl.—Waterfowl composition differed among months at Douglas ($\chi^2_{25} = 2311.8$, $P < 0.001$) and Chickamauga Reservoirs ($\chi^2_{75} = 2494.6$, $P < 0.001$). The waterfowl community was comprised primarily of Canada geese, which constituted 57% and 40% of the two-year combined totals at Douglas and Chickamauga Reservoirs, respectively. Canada geese were abundant (40 – 99%) at Douglas Reservoir from October – January (Figure 9). Mallards (*Anas platyrhynchos*) were commonly observed on Douglas mudflats from August – October (53 – 78%). American green-winged teal (*A. crecca*) constituted 36% of the total observed in November but few individuals were

observed (n = 14). At Douglas Reservoir, no other species represented >14% of the total observed during any month (Figure 9). Canada geese comprised 26 – 100% of the total observed on Chickamauga mudflats from August – January (Figure 10). Hooded mergansers (*Lophodytes cucullatus*), gadwalls (*A. strepera*), and mallards each constituted 8 – 35% of the total observed during November – January. Wood ducks (*Aix sponsa*) comprised 35% of the August total on Chickamauga mudflats; however, only nine individuals were observed. At Chickamauga Reservoir, no other species constituted >9% of the total observed during any month (Figure 10).

At Chickamauga Reservoir, total waterfowl abundance (n = 5,287) and species richness (S = 16) was 2.3X and 2.7X greater, respectively, than that observed at Douglas Reservoir (n = 2,332; S = 6). At Douglas Reservoir, 2.3X more waterfowl were observed in 2006 (n = 1,628) than 2005 (n = 704); whereas waterfowl abundance at Chickamauga was 2.1X greater in 2005 (n = 3,562) than 2006 (n = 1,725). Total waterfowl species richness was similar among months at Douglas Reservoir (Figure 9); however, waterfowl richness on Chickamauga mudflats peaked in November of both years (Figure 10).

Mean waterfowl abundance per mudflat was 17X greater at Douglas than Chickamauga Reservoir in August 2006 (Wilcoxon Z = 1.9, P = 0.06; Table 4). Abundance was 11 – 21X greater on Chickamauga mudflats in November 2006 and December 2005 (Wilcoxon $Z \geq 1.9$, $P \leq 0.05$). Waterfowl richness was 8X greater on Douglas than Chickamauga mudflats in August 2006 (Wilcoxon Z = 2.2, P = 0.03). In contrast, waterfowl richness at Chickamauga Reservoir was 8 – 31X greater in November 2006, December 2005, and January both years (Wilcoxon $Z \geq 1.6$, $P \leq 0.10$). Similarly, mean diversity of waterfowl was significantly greater at Douglas than Chickamauga

Reservoir in August 2006 (Wilcoxon $Z = 2.3$, $P = 0.02$). Waterfowl diversity was significantly greater on Chickamauga than Douglas mudflats in January 2006 (Wilcoxon $Z = 2.3$, $P = 0.02$). No other differences were detected between reservoirs (Wilcoxon $Z \leq 1.5$, $P \geq 0.12$; Table 4).

Mean abundance of mallards was significantly greater at Douglas than Chickamauga Reservoir in August 2006 and September both years (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$; Tables 5 and 6). Wood ducks were more abundant on Chickamauga than Douglas mudflats in October 2006 and November 2005 (Wilcoxon $Z = 1.8$, $P = 0.07$; Tables 5 and 6). Abundance of hooded mergansers and gadwalls was significantly greater at Chickamauga Reservoir in December 2005 and January 2006 (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$; Table 5). Hooded mergansers also were more abundant on Chickamauga than Douglas mudflats in November 2006 and January 2007 (Wilcoxon $Z = 1.8$, $P = 0.07$; Table 6). Mallard abundance was 15 – 45X greater at Chickamauga Reservoir in December 2006 and January 2006 (Wilcoxon $Z \geq 2.1$, $P \leq 0.04$; Tables 5 and 6). Similarly, Canada geese were 5X more abundant on Chickamauga than Douglas mudflats in December 2005 (Wilcoxon $Z = 1.6$, $P = 0.10$; Table 5).

Other Waterbirds.—Composition of other waterbirds differed among months at Douglas ($\chi^2_{40} = 1050.2$, $P < 0.001$) and Chickamauga Reservoirs ($\chi^2_{45} = 2065.8$, $P < 0.001$). At Douglas Reservoir, the other waterbird community was comprised primarily of great egrets (*Ardea alba*) and great blue herons (*A. herodias*), which constituted 66% and 25% of the two-year combined total, respectively. Great blue herons were abundant on Douglas mudflats from August – January (15 – 67%), whereas great egrets were common (41 – 75%) only during August – October (Figure 11). Ring-billed gulls (*Larus*

delawarensis) comprised 33 – 63% of the total observed during November and December. At Douglas Reservoir, no other species constituted >6% of the total observed during any month (Figure 11). At Chickamauga Reservoir, sandhill cranes (*Grus canadensis*) constituted 41% of the two-year combined total, and were abundant (20 – 63%) from November – January (Figure 12). Great blue herons comprised 19 – 84% of the total observed from August – January and great egrets were abundant from August – October (16 – 27%). Ring-billed gulls constituted 33 – 36% of the total observed during November and December. At Chickamauga Reservoir, no other waterbird species comprised >10% of the total observed during any month (Figure 12).

Total abundance other waterbirds at Chickamauga Reservoir (n = 6,223) was 4.2X greater than that observed at Douglas Reservoir (n = 1,493). However, total richness of additional waterbird species was similar between reservoirs (Douglas: S = 11; Chickamauga: S = 10). In 2006, other waterbird abundance at Douglas (n = 1,118) and Chickamauga Reservoirs (n = 3,556) were 298% and 33% greater than that observed in 2005 (Douglas: n = 375; Chickamauga: n = 2,667), respectively. At Douglas Reservoir, total richness of other waterbirds was greatest during August and September, with peak richness occurring in September both years (Figure 11). In contrast, the greatest richness of other waterbirds at Chickamauga Reservoir was observed from October – December (Figure 12).

Mean daily abundance of other waterbirds was 8 – 11X greater on Douglas than Chickamauga mudflats in August 2006 and September 2005, respectively (Wilcoxon $Z \geq 1.7$, $P \leq 0.08$; Table 7). In contrast, other waterbirds were 6.7 – 1,827X more abundant at Chickamauga than Douglas Reservoir in October 2005 and November, December, and

January both years, respectively (Wilcoxon $Z \geq 1.9$, $P \leq 0.06$). Mean richness of other waterbirds was 3X greater at Douglas Reservoir in August 2006 (Wilcoxon $Z = 2.0$, $P = 0.04$). However, richness of other waterbirds at Chickamauga Reservoir was 5 – 54X greater in October 2005 and 6 – 54X greater in November and December both years (Wilcoxon $Z \geq 2.2$, $P \leq 0.03$). Similarly, other waterbird diversity was 6.8X greater on Douglas than Chickamauga mudflats in August 2006 (Wilcoxon $Z = 2.2$, $P = 0.03$). However, other waterbird diversity was significantly greater at Chickamauga Reservoir in October 2005 and November – December both years (Wilcoxon $Z \geq 2.2$, $P \leq 0.03$; Table 7).

Abundance of great egrets was 20 – 69X greater at Douglas than Chickamauga Reservoir in August 2006 and September 2005 (Wilcoxon $Z = 2.2$, $P = 0.03$; Tables 8 and 9). Green herons (*Butorides virescens*) and double-crested cormorants (*Phalacrocorax auritus*) were significantly more abundant on Douglas than Chickamauga mudflats in August and September 2006, respectively (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$; Table 9). However, great blue herons were 21 – 425X more abundant at Chickamauga Reservoir from November – January both years (Wilcoxon $Z \geq 2.2$, $P \leq 0.03$; Tables 8 and 9). Sandhill cranes and pied-billed grebes (*Podilymbus podiceps*) were more abundant at Chickamauga than Douglas Reservoir in November 2005 and 2006, respectively (Wilcoxon $Z = 2.3$, $P = 0.02$). Ring-billed gull abundance was significantly greater at Chickamauga mudflats in November 2006, December both years, and January 2006 (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$; Tables 8 and 9).

Other Birds.—Composition of other birds differed among months at Douglas ($\chi^2_{20} = 6928.2$, $P < 0.001$) and Chickamauga Reservoirs ($\chi^2_{15} = 30.5$, $P = 0.01$). At Douglas

Reservoir, the other bird community was almost entirely comprised of tree swallows (*Tachycineta bicolor*), which constituted 93% (n = 7,250) of the two-year combined total. This species was observed on Douglas mudflats only during August and September, and comprised 99% of the total observed during these respective months. American crows (*Corvus brachyrhynchos*) comprised 95 – 100% of the other bird community from October – December but were less abundant (n = 515) compared to tree swallows. At Douglas Reservoir, no other species comprised >5% of the total observed during any month. American crows also were abundant at Chickamauga Reservoir (n = 1,104), where they comprised 96% of the two-year combined total. This species constituted 94 – 100% of the total observed on Chickamauga mudflats during October – January. At Chickamauga Reservoir, no other species comprised >6% of the total observed during any month.

Total abundance of other birds at Douglas Reservoir (n = 7,805) was 6.8X greater than that observed at Chickamauga Reservoir (n = 1,151) and total species richness was identical between reservoirs (S = 6). Other bird abundance observed in 2005 at Douglas (n = 4,076) and Chickamauga Reservoirs (n = 735) was 9% and 77% greater than that observed in 2006, respectively (Douglas: n = 3729, Chickamauga: n = 416). Total species richness of other birds on Douglas mudflats was greatest in September 2005 (S = 3) and August – September 2006 (S = 4).

Other bird abundance was significantly greater at Douglas than Chickamauga Reservoir in August 2006 and September 2005 (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$; Table 10). However, other birds were more abundant on Chickamauga than Douglas mudflats in November 2006 and December and January both years (Wilcoxon $Z \geq 1.6$, $P \leq 0.10$).

Similarly, other bird richness was significantly greater at Douglas Reservoir in August 2006 and September 2005 (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$). However, mean richness was significantly greater on Chickamauga than Douglas mudflats in November 2006 and December – January both years (Wilcoxon $Z \geq 1.6$, $P \leq 0.10$). No significant differences in diversity were detected between reservoirs (Wilcoxon $Z \leq 0.8$, $P \geq 0.11$; Table 10).

American crow abundance was greater on Douglas than Chickamauga mudflats in August 2006 (Wilcoxon $Z = 1.8$, $P = 0.07$; Table 11). In contrast, American crows were 3.1X more abundant at Chickamauga than Douglas Reservoir in December 2005 (Wilcoxon $Z = 1.6$, $P = 0.10$), and a similar trend existed in November – December 2006 and January both years (Wilcoxon $Z \geq 1.8$, $P \leq 0.07$). No other significant differences were detected between reservoirs (Wilcoxon $Z \leq 1.3$, $P \geq 0.19$; Table 11).

Acreage of Exposed Mudflats

Mean acreage exposed per mudflat was 17 – 69X greater at Douglas than Chickamauga Reservoir in August 2006 and September – October both years (Wilcoxon $Z \geq 2.2$, $P \leq 0.03$; Table 12). Due to the 1 October drawdown of Chickamauga Reservoir, no mudflats were exposed in this reservoir during August or September either year. No other significant differences in mudflat acreage were detected between reservoirs (Wilcoxon $Z \leq 1.6$, $P \geq 0.11$; Table 12).

Vegetation Response on Mudflats

Vegetation was present on mudflats at Douglas Reservoir from August – November both years. However, all vegetation plots on Chickamauga mudflats remained

flooded during August and September 2005 and from August – early November 2006. A total of 28 plant species were observed on mudflats in the east TRV, including 21 forbs, 3 grasses and 5 sedges (Appendix III). In 2005, all 28 species were observed on Douglas mudflats, whereas Chickamauga mudflats supported only three species. In 2006, 21 species were observed on Douglas mudflats, and no vegetation germinated on Chickamauga mudflats.

Vegetation Composition and Structure.—Mean plant species richness was 15.3X greater at Douglas than Chickamauga Reservoir in November 2005 (Wilcoxon $Z = 2.2$, $P = 0.03$; Table 13). Mean plant height was 99X greater on Douglas than Chickamauga mudflats in November 2005 (Wilcoxon $Z = 2.2$, $P = 0.03$). Percent vertical cover of vegetation on mudflats was significantly greater at Douglas than Chickamauga Reservoir in October and November 2005 (Wilcoxon $Z \geq 1.6$, $P \leq 0.10$; Table 13).

Mean percent horizontal cover of forbs and sedges in November 2005 were 55 – 64X greater at Douglas than Chickamauga Reservoir (Wilcoxon $Z = 2.2$, $P = 0.03$; Table 14). Coverage of grasses was significantly greater on Douglas than Chickamauga mudflats in October and November 2005 (Wilcoxon $Z \geq 1.6$, $P \leq 0.10$). Mean percent bareground was 6.7X greater at Chickamauga Reservoir in November 2005 (Wilcoxon $Z = 2.2$, $P = 0.03$; Table 14).

Vegetation Biomass.—Monthly biomass of forbs, sedges and grasses clipped from 0.0625-m^2 plots was 432 – 1055X greater on Douglas than Chickamauga mudflats in October and November 2005 (Wilcoxon $Z \geq 1.6$, $P \leq 0.10$; Table 15). At the end of the 2005 growing season, mean total biomass of vegetation clipped from 1-m^2 plots was 1615X greater at Douglas than Chickamauga Reservoir (Wilcoxon $Z = 2.2$, $P = 0.03$;

Table 16). Biomass of the following species was significantly greater on Douglas than Chickamauga mudflats in 2005: dodder sp. (*Cuscuta* sp.), Fernald's yellow cress (*Rorippa palustris* ssp. *fernaldiana*), green carpetweed (*Mollugo verticillata* L.), Japanese mazus (*Mazus pumilus* [Burm.f.] Steenis), marsh cudweed (*Gnaphalium uliginosum* L.), marsh seedbox (*Ludwigia palustris* [L.] Ell.), purple love grass (*Eragrostis spectabilis* [Pursh] Steud.), rough cockleburr, teal love grass (*Eragrostis hypnoides* [Lam.] B.S.P.), Vahl's fimbry (*Fimbristylis vahlii* [Lam.] Link), valley redstem (*Ammannia coccinea* Rottb.), whiteedge flatsedge (*Cyperus flavicomus* Michx.), and yellowseed false pimpernel (*Lindernia dubia* [L.] Pennell; Wilcoxon $Z \geq 1.8$, $P \leq 0.07$). None of these plant species were present on Chickamauga mudflats. Additionally, mean biomass of path rush (*Juncus tenuis* Willd.) and Pennsylvania bitter cress (*Cardamine pensylvanica* Muhl. ex Willd.) were 87 – 116X greater at Douglas than Chickamauga Reservoir in 2005, but significant differences were not detected (Wilcoxon $Z \leq 1.2$, $P \geq 0.25$). These plant species were the only two that produced measurable biomass on Chickamauga mudflats in 2005 (Table 16).

At Douglas Reservoir, mean total biomass per plot were nearly identical in 2005 and 2006 (Table 16). Rough cockleburr comprised 59% and 52% of the mean total biomass produced on Douglas mudflats in 2005 and 2006, respectively. During both years, marsh cudweed and teal love grass biomass contributed 9 – 18% and 7 – 13% to the mean total biomass at Douglas Reservoir, respectively. Pennsylvania bitter cress constituted 12% of the total biomass in 2005, and dodder sp. and Japanese mazus each comprised 7% of the total biomass in 2006. No other species comprised >3% of the total biomass produced on Douglas mudflats either year (Table 16).

Aboveground Seed Production.—A total of 12 species reached maturity and produced seed on mudflats in Douglas Reservoir in 2005 and 2006 (Table 17). On Douglas mudflats, moist-soil seed production estimates from aboveground inflorescences were 3.18 and 9.78 g/m^2 in 2005 and 2006, respectively. No seed production occurred on Chickamauga mudflats either year. Seed production on Douglas mudflats in 2005 was 3.1X greater than in 2006, but the 2005 estimate did not include seed production by dodder sp., which produced 6.70 g/m^2 in 2006 (i.e., 69% of the total seed yield). The 2005 seed yield estimate also did not include devil's beggar tick (*Bidens frondosa* L.), valley redstem, white panicle aster (*Aster lanceolatus* Willd.), or whitestar (*Ipomoea lacunosa* L.), which together contributed an additional 0.26 g/m^2 in 2006 (i.e., 2.6% of the total seed yield). These species were not included in 2005, because it was unknown that they produced seed at the time. Thus, total seed yield estimates on Douglas mudflats in 2005 are likely underestimated (Table 17).

Belowground Seed Biomass

Mean biomass of rough cockleburr seed retained from core samples was significantly greater in Douglas than in Chickamauga mudflats during November and December 2005 (Wilcoxon $Z = 1.9$, $P = 0.06$; Table 18). No other significant differences in seed biomass were detected between reservoirs during either year (Wilcoxon $Z \leq 1.6$, $P \geq 0.11$). However, moist-soil seed biomass in mudflats was greatest at Douglas Reservoir in August and September and at Chickamauga Reservoir in October and November both years (Table 18).

Soil Characteristics and Water Depth and Quality

Soil compaction, moisture and temperature.—Statistical differences in mean substrate compaction, moisture and temperature were not detected between reservoirs either year (Wilcoxon $Z \leq 1.6$, $P \geq 0.11$; Table 19). Despite not detecting significant differences, several general trends were apparent. During both years, mean compaction readings measured at water-interface transects from October – January were 8 – 250% greater on Chickamauga than Douglas mudflats (Wilcoxon $Z \leq 1.4$, $P \geq 0.15$). Moreover, excluding December 2006, soil compaction measured at previous transect midpoints was 14 – 260% greater at Chickamauga Reservoir from November – January (Wilcoxon $Z \leq 1.2$, $P \geq 0.22$). Although significant differences were not detected in substrate temperature between reservoirs (Wilcoxon $Z \leq 1.6$, $P \geq 0.11$), temperatures measured at water-interface transects on Chickamauga mudflats from October – January were 7 – 48% and 2 – 30% greater in 2005 and 2006, respectively (i.e., averaged 2.2˚C and 1.2˚C warmer, respectively), than those measured on Douglas mudflats (Table 19).

Number of weeks following mudflat exposure explained significant variation (13 – 28%) in soil compaction at Chickamauga Reservoir both years (Table 20). There was a moderate positive relationship between duration of exposure and soil compaction on Chickamauga mudflats (Figure 13). No relationship appeared to exist between exposure duration and soil compaction on Douglas mudflats (Table 20, Figure 14). Marginally significant variation ($P = 0.057 – 0.058$) in soil moisture was explained by duration of mudflat exposure at Douglas Reservoir (Table 20). There was a weak negative relationship between soil moisture and exposure duration on Douglas mudflats (Figure

14). No relationship appeared to exist between exposure duration and soil moisture on Chickamauga mudflats (Table 20, Figure 13).

Water Depth and Quality.—No significant differences in water depth at the mudflat-water interface were detected between reservoirs either year (Wilcoxon $Z = 0$, $P = 1.00$; Table 21). However, excluding November 2005, mean water depths measured from October – January both years were 48% – 490% greater at Douglas than Chickamauga Reservoir. Significant differences in water quality also were not detected between reservoirs in 2006 (Wilcoxon $Z \leq 1.6$, $P \geq 0.11$), but un-ionized ammonia (NH_3) concentrations measured from October – January were 2 – 4X greater on Douglas than Chickamauga mudflats (Table 21).

Habitat Models

Multivariate Models.—Canonical correspondence analysis revealed that 34% of the variation in shorebird community structure was explained by the habitat variables included in the analysis. Reservoir gage height and plant biomass in 0.0625-m^2 plots explained significant variation in shorebird abundance ($F \geq 3.06$, $P \leq 0.01$; Figure 15a). Mean water depth, percent exposure of mudflats, percent horizontal coverage of vegetation, and soil temperature also were retained in the final multivariate model; however, significant variation in abundance was not explained by any of these variables ($F \leq 0.57$, $P \geq 0.60$; Figure 15a). The orthogonal inferred rankings revealed that Wilson's snipe were negatively associated with reservoir gage height and plant biomass (Figure 15b). Killdeer had slight negative and positive associations with gage height and plant biomass, respectively. In contrast, least and pectoral sandpipers exhibited positive

and negative associations with gage height and plant biomass, respectively (Figure 15b). Abundance of these two species also was slightly positively related with soil temperature (Figure 15a).

Regression Models.—In 2005, approximately 63% of the variation in shorebird abundance was explained by mean horizontal cover of vegetation (Table 22). This variable had a strong negative relationship with shorebird abundance in 2005 (β_{ST} = –0.87) but was not retained in the 2006 vegetation model of shorebird abundance. No other variable alone explained greater than 26% of the variability in shorebird or waterfowl abundance and no other combination of variables explained greater than 47%. Of these lower performance models, the acreage model for shorebirds in 2005 explained 32% of the variation in abundance. Mean acreage of mudflats and gage height were positively and negatively related to abundance, respectively. In 2006, the vegetation model with period explained 23% of the variation in abundance, and as period increased (or months progressed from August to November), shorebird numbers decreased. The 2005 vegetation model for waterfowl explained 16% of the variation in abundance, with a negative correlation with percent horizontal cover. Similar to shorebirds, the 2006 vegetation model explained 39% of the variation in waterfowl abundance, with period negatively related to abundance. Mean vertical structure of vegetation also was retained in this model, and was negatively correlated with waterfowl abundance (Table 22).

Discussion

Waterbird Use and Migration Chronology

Shorebird abundance was greater at Douglas than Chickamauga Reservoir during

August 2006 and September both years, and a similar trend existed in August 2005. Given that the drawdown of Chickamauga Reservoir was not initiated until 1 October, differences in the temporal availability of mudflats likely explain these trends. Shorebirds rely on exposed and shallowly flooded mudflats to meet their energetic demands during migration (Skagen and Knopf 1993, 1994*b*), and several studies have documented a positive relationship between shorebird abundance and mudflat availability at interior stopovers (Taylor and Trost 1992, Skagen and Knopf 1994*b*, Davis and Smith 1998*a*). In the east TRV, the early (1 August) drawdown of Douglas Reservoir exposed 1 – 6 and 14 – 18 ha of habitat per mudflat during August and September, respectively. However, Chickamauga mudflats remained completely flooded during these respective months, and thus were functionally unavailable to shorebirds.

In contrast, shorebird abundance was greater on Chickamauga than Douglas mudflats from November – January, and a similar trend existed in October both years. Interestingly, exposed mudflat acreage was similar between reservoirs from November – January, and was 17 – 69X greater at Douglas Reservoir during October both years. These results suggest that mudflats in Douglas Reservoir may have become less suitable for shorebirds over time. Several factors (e.g., vegetation density, water depth, food availability, substrate characteristics) are known to influence the suitability of mudflats for shorebirds (Rundle and Fredrickson 1981, Pienkowski 1983*a*, Davis and Smith 1998*a*, Collazo et al. 2002). A discussion of how these factors may have influenced shorebird-use patterns in these reservoirs is provided in later sections.

In the east TRV, shorebirds were quickly attracted to newly exposed mudflats, regardless of drawdown date or the amount of acreage exposed. For example, 10 August

2006 marked the initial exposure of one mudflat in Douglas Reservoir. Although only 0.27 ha of habitat was exposed on this date, 55 killdeer, 4 least sandpipers, 29 pectoral sandpipers, 1 solitary sandpiper (*Tringa solitaria*) and 14 spotted sandpipers were documented during the survey. Previous studies have reported a similar rapid response by shorebirds to available habitat at other interior stopovers (Rundle and Fredrickson 1981, Skagen and Knopf 1994*b*). In Missouri, Rundle and Fredrickson (1981) documented shorebirds within 4 – 24 hrs of the initial exposure of mudflats. The immediate response of shorebirds following the exposure of mudflats in Douglas and Chickamauga Reservoirs suggests that shorebirds opportunistically take advantage of available habitat, and shorebird habitat may be limiting in the east TRV.

Shorebirds were observed both years on Douglas mudflats during my first sampling date (15 August 2005 and 31 July 2006). At this time, mudflats had been exposed for roughly two weeks both years. The use of mudflats by shorebirds at this time suggests that shorebirds will use east TRV mudflats if they are available mid- to late-July. Several studies conducted at similar latitudes to the TRV have documented considerable shorebird use during July (Brown 1978, Reid et al. 1983, Smith et al. 1991, Andrei et al. 2006). Smith et al. (1991) reported that 6 of the 19 shorebird species migrating through Arkansas reached their peak numbers in July. In the east TRV, Fowler (1983) reported 22 species arriving in July, including three that were not observed during my study (i.e., red knot [*Calidris canutus*], piping plover [*Charadrius melodus*], marbled godwit [*Limosa fedoa*]). Several fall migrants (e.g., lesser yellowlegs [*Tringa flavipes*] and least and semipalmated sandpipers) have even been observed as early as June in

Tennessee (DeCecco and Cooper 1996). These results collectively suggest that availability of mudflats in July would benefit migratory shorebirds in the east TRV.

Total shorebird abundance was two times greater at Chickamauga (n = 10,070) than Douglas Reservoir (n = 4,620). I hypothesize that suitable habitat was available for longer duration in Chickamauga Reservoir, which may have been a consequence of differences in drawdown rate. On average, Douglas Reservoir was drawn down over five times faster (–6.9 cm/day) than Chickamauga Reservoir (–1.3 cm/day). Slow drawdowns provide suitable habitat for longer duration than fast drawdowns, because newly exposed mudflats are available continuously (Rundle and Fredrickson 1981, Fredrickson and Taylor 1982, Hands et al. 1991). Drawdowns of both Douglas and Chickamauga Reservoirs were relatively faster than is recommended for shorebird management (i.e., –0.3 to –0.4 cm/day; Rundle and Fredrickson 1981). On average, 37 shorebirds per mudflat per day were observed from November – January at Chickamauga both years. In contrast, shorebird abundance on Douglas mudflats exceeded this level (65 shorebirds/mudflat) only in August 2006, and numbers were consistently low ($\leq$3 shorebirds/mudflat) from October – January both years.

Position in the TRV watershed also may have contributed to greater shorebird abundance at Chickamauga Reservoir. Chickamauga is located on the main channel of the Tennessee River, downstream of 39 other reservoirs (including Douglas) and past the confluences of six major rivers (i.e., Clinch, French Broad, Hiwassee, Holston, Little Tennessee and Ocoee Rivers. In contrast, Douglas Reservoir is the first dam on the French Broad River positioned north and east of Chickamauga Reservoir (Miller et al. 1996). Thus, it is possible that Chickamauga Reservoir is located in a more natural

migration corridor for shorebirds. Differences in vegetation cover and shorebird species composition between reservoirs also may have influenced abundance results (discussed later).

Total shorebird richness was twice as great at Douglas ($S = 19$) than Chickamauga Reservoir ($S = 9$). Eleven of the 20 shorebird species observed during my two-year study occurred only on Douglas mudflats, which were exposed during peak migration. At interior stopovers, shorebird richness is typically greatest during late summer and early fall compared to late fall and winter months (e.g., Smith et al. 1991, Davis and Smith 1998*a*, Twedt et al. 1998). In the Mississippi Alluvial Valley, Twedt et al. (1998) observed 22 species during August, and only 9 species from 15 November – 9 January. Similarly, Davis and Smith (1998*a*) documented 22 species using Texas playa lakes during a one-week interval in late August. In Tennessee and other mid-latitude states, peak fall migration occurs from late July – mid-September (Smith et al. 1991, Helmers 1992, DeCecco and Cooper 1996). Thus, Douglas Reservoir may have supported a greater number of shorebird species than Chickamauga Reservoir because the later drawdown of Chickamauga did not provide habitat during peak migration.

Chickamauga mudflats supported a shorebird community primarily composed of killdeer (77%) and other relatively short-distance migrants (e.g., Wilson's snipe and least sandpipers) known to winter in Tennessee (DeCecco and Cooper 1996). These three species constituted >99% of the total abundance observed at Chickamauga Reservoir over the two years. Killdeer and least sandpipers also were relatively abundant on Douglas mudflats, comprising 62% and 13% of the total, respectively. However, most shorebird species observed on Douglas mudflats were longer-distance migrants.

According to Skagen and Knopf (1993), 16 of the 19 species that I observed on Douglas mudflats migrate ≥6,300 km from their breeding grounds to wintering areas, and four species (American golden-plovers [*Pluvialis dominica*] and buff-breasted [*Tryngites subruficollis*], pectoral and stilt sandpipers [*Calidris himantopus*]) travel approximately 14,800 – 16,800 km one way (Table 23). In comparison, killdeer and Wilson's snipe migrate 3,400 – 3,900 km (Skagen and Knopf 1993; Table 23). Due to flying greater distances, many of the earlier migrants have higher energetic demands and are considered more of a conservation concern (Skagen 2006). For example, of the 11 shorebird species I documented only on Douglas mudflats, six are considered species of high concern, and this included two species (buff-breasted and solitary sandpipers) with estimated population sizes of less than 21,000 individuals (Brown et al. 2001).

Late (1 October) drawdowns can be beneficial to shorebirds, especially for later migrants and species that overwinter. Wilson's snipe migrate later than most shorebird species, and take advantage of mudflats exposed in November and December (e.g., Reid et al. 1983). Although I observed a few snipe during August and September (n = 8), considerable numbers began arriving in mid-October and peaked in November both years. McCloskey and Thompson (2000) reported similar dates of peak snipe abundance at wintering areas along the Gulf Coast of Texas. Wilson's snipe were the second most common shorebird species observed during my study (n = 1,523), with 99% of individuals occurring on Chickamauga mudflats. I also documented a modest number of dunlin (*Calidris alpina*) at Chickamauga Reservoir (n = 37) that arrived later in the fall (4 – 10 November) and departed by the end of November both years. On 27 December 2006, I documented two American avocets (*Recurvirostra americana*) using

Chickamauga mudflats, which are considered rare sightings in the east TRV. These individuals probably were juveniles, which typically migrate later than adults (O'Brien et al. 2006).

Little is known about shorebird populations that winter in the southeastern United States (Ciuzo et al. 2005). During my study, killdeer, Wilson's snipe and least sandpipers wintered on Chickamauga mudflats. Most notable were wintering populations of killdeer, which increased through fall and winter, peaking in January (56 – 66 individuals per mudflat per day). Killdeer also were the primary shorebird species (77%) observed wintering in flooded agricultural habitats in Arkansas and Mississippi (Twedt et al. 1998). Although considered a relatively common shorebird species throughout North America, killdeer are a conservation concern because of declining population trends (Sanzenbacher and Haig 2001, Bart et al. 2007). Killdeer populations in the North Atlantic Region of the United States and Canada declined 5% per year from 1974 – 1998 (Bart et al. 2007).

Sandhill cranes were common on Chickamauga mudflats, and began arriving on 10 – 18 November. These mudflats combined with the high abundance of agricultural foods produced on nearby Hiwassee Wildlife Refuge, have provided staging habitat for the eastern population of migratory greater sandhill cranes since at least 1963 (Lovvorn and Kirkpatrick 1981). Peak usage of Chickamauga mudflats by cranes occurred during December (69% of 2,532 individuals). On 12 December 2006, I observed 691 sandhill cranes roosting on one 16-ha mudflat. Some cranes were present on mudflats in mid-January when sampling ended, suggesting that some individuals likely wintered in the east TRV.

Most migrant waterfowl species typically arrive at mid-latitude United States in October – November (Minser 1968, Reid et al. 1989, Benedict and Hepp 2000). Of the 16 waterfowl species that I documented, 12 were first observed in October or later. Thus, most waterfowl arrived during the initial exposure of mudflats in Chickamauga Reservoir, but after two of the four mudflats in Douglas Reservoir were completely exposed. Similar to shorebirds, waterfowl can quickly locate suitable habitat as it becomes available (Fredrickson and Drobney 1979, Poysa 1983), and often use shallow water adjacent to mudflats (Short 1999, Johnson and Rohwer 2000, Ciuzo et al. 2005). Not surprising due to temporal differences in mudflat exposure, Chickamauga Reservoir supported over two times more waterfowl species ($S = 16$) than Douglas mudflats ($S = 6$), and greater abundance from October – January both years (excluding January 2007).

Among the 10 waterfowl species observed only on Chickamauga mudflats, hooded mergansers ($n = 1{,}102$) and gadwalls ($n = 947$) were the most abundant. These species were the third and fourth most abundant waterfowl species observed during my study. Interestingly, I did not find any previous literature documenting their use of mudflats during any portion of the annual cycle, thus my results appear to be novel. In the southeastern United States, hooded mergansers and gadwalls are most commonly associated with forested wetlands and habitats with aquatic vegetation, respectively (Dugger et al. 1994, Benedict and Hepp 2000). In the east TRV, both species were commonly observed at Chickamauga Reservoir from late October – January, indicating that mudflats also may serve as wintering habitat for these species. Excluding American black ducks (*Anas rubripes*, $n = 120$) and northern shovelers (*Anas clypeata*, $n = 177$), most remaining species occurring only at Chickamauga Reservoir were observed

infrequently ($n \leq 16$ individuals). Of conservation importance, nine lesser scaup (*Aythya affinis*) were observed on Chickamauga mudflats on 17 November 2006. Lesser scaup are a species of concern, as populations have been declining since the 1970s and currently remain below the population recovery goals of the North American Waterfowl Management Plan (Austin et al. 2000, Afton and Anderson 2001). Although this species was uncommon in the east TRV, its occurrence indicates that some individuals migrate through the region.

During August and September, waterfowl abundance was greater on Douglas than Chickamauga mudflats. Thus, waterfowl also benefited from the early exposure of mudflats in Douglas Reservoir. Blue-winged teal (*Anas discors*) were the earliest migrants documented, arriving as early as 31 August 2006. Nearly all blue-winged teal (96%) occurred on Douglas mudflats in September, although only 55 individuals were observed throughout my study. In other areas, early fall drawdowns have attracted greater numbers of teal (e.g., Rundle and Fredrickson 1981, Short 1999). In southeastern Missouri, one 14.5-ha moist-soil unit drawn down on 30 October supported over 3,000 use-days by blue-winged teal (Rundle 1980). Eastern portions of Missouri lie in a major waterfowl migration corridor (i.e., Mississippi flyway) compared to the east TRV, which likely contributed to the lower number of blue-winged teal observed in Douglas Reservoir. On the other hand, blue-winged teal frequently use mudflats in the west TRV. Drew Wirwa (University of Tennessee, unpublished data) documented 8,654 blue-winged teal using nine west TRV mudflats in fall 2006 and 2007. In general, this held true for other waterfowl species as well. In the same study (D. Wirwa, University of

Tennessee, unpublished data), west TRV mudflats supported considerably more waterfowl (n = 107,851) than did east TRV mudflats (n = 7,619).

Trends in waterfowl abundance at Douglas Reservoir were largely driven by species with resident populations at least partially in Tennessee. Most notable were Canada geese and mallards, which comprised 57% and 37% of the total number of waterfowl observed on Douglas mudflats, respectively. These species also constituted 40% (Canada geese) and 9% (mallards) of the total observed at Chickamauga Reservoir, and overall were the most abundant species that I recorded. At Douglas Reservoir, 61% (n = 529) of the mallards were observed during August. The first migrant mallards usually do not arrive in west Tennessee until mid-September, and sizeable populations do not occur until mid-October (Reid et al. 1989). Thus, it is likely that the individuals observed on Douglas mudflats during August and possibly September were residents or produced in the region. Minser (1968) documented mallard broods during June – July on the Holston River, located approximately 85 km from my study sites in Douglas Reservoir. In contrast, mallards were absent at Chickamauga Reservoir until October both years, and most individuals (98%) were observed from November – January, which suggests these birds may have been migrants.

During the mid-1970s, the Tennessee Wildlife Resources Agency (TWRA) released giant Canada geese (*Branta canadensis maxima*) into the east TRV to establish a resident population, and they are now present in every TRV reservoir (White and Fronczak 2007). Three additional populations of Canada geese occur in Tennessee during migration including the Mississippi Valley, Southern James Bay, and Eastern Prairie populations. Yet, giant Canada geese comprised $\geq$93% of the state harvest from

2002 – 2005 (White and Fronczak 2007). Thus, it is likely that the majority of geese I documented on east TRV mudflats were residents. My results indicate that waterfowl, like shorebirds, use newly exposed mudflats, and resident populations may especially benefit from early drawdowns of east TRV reservoirs.

Wading birds are frequently attracted to drawdowns of moist-soil impoundments and reservoirs (Rundle 1980, Short 1999, Sprandel et al. 2002, Ciuzo et al. 2005). Most wading birds were observed at Douglas Reservoir during August and September (87%) and at Chickamauga from October – January (95%), indicating that the majority of use occurred when water levels were receding. Similarly, Breininger and Smith (1990) found greater wading bird densities in coastal impoundments that were undergoing drawdowns.

Great blue herons and great egrets were the most common wading birds observed in the east TRV, comprising >98% of the total observed at both reservoirs. Great blue herons were observed at both reservoirs during almost every month, suggesting that some individuals may be year-round residents. This species was more abundant on Douglas mudflats in August – September and more abundant on Chickamauga mudflats from November – January both years. However, overall abundance of great blue herons was over four times greater on Chickamauga (n = 1,674) than Douglas mudflats (n = 372), suggesting that migrants likely arrived and wintered in the east TRV.

Great egrets were the most abundant wading bird species at Douglas Reservoir, comprising 70% of the total wading birds. Similarly, this species comprised 48% of the wading bird community observed in west Tennessee moist-soil wetlands drawn down in late summer and early fall (Short 1999). Peak usage of Douglas mudflats by great egrets occurred in August and September (93% of individuals), and feeding congregations of

great egrets during these months were substantial (J. Laux, personal observation). On 14 September 2006, one Douglas 37-ha mudflat attracted 142 great egrets. Overall more great egrets were observed at Douglas (*n* = 988) compared to Chickamauga Reservoir (*n* = 86), indicating the importance of early fall drawdowns to this species. Breeding populations of great egrets were nearly extirpated from the TRV during the mid-1900s (Pullin 1987). However, through recovery efforts made by TVA and the TWRA (Pullin 1987), egret populations have increased and the availability of TRV mudflats early in the fall may be important for population sustenance.

Several other waterbird species were observed only on Douglas mudflats, including American white pelicans (*Pelecanus erythrorhynchos*, n = 7), black-crowned night herons (*Nycticorax nycticorax*, n = 1), little blue herons (*Egretta caerulea*, n = 16), and three tern species (*n* = 5). On 4 September 2006, one Forster's tern (*Sterna forsteri*), one Caspian tern (*Hydroprogne caspia*), and two black terns (*Chlidonias niger*) were observed on a Douglas mudflat. In addition, I observed four white ibis (*Eudocimus albus*) and one federally-endangered wood stork (*Mycteria americana*) in early August at Douglas Reservoir using non-study mudflats. Green herons were more abundant on Douglas (*n* = 32) than Chickamauga mudflats (*n* = 1), with the vast majority (88%) occurring in August. These results collectively illustrate the importance of early drawdowns to wading and other waterbird bird species in the TRV.

Mechanisms Influencing Habitat Suitability and Waterbird Use

Vegetation Response.—Average plant height and percent horizontal and vertical coverage were greater on Douglas than Chickamauga mudflats during October –

November both years. Previous studies suggest that most shorebird species do not prefer foraging areas with abundant vegetation (Baker 1979, Helmers 1992, Davis and Smith 1998*a*). Helmers (1992) reported that areas with vegetation greater than half the height of a shorebird are avoided. Davis and Smith (1998*a*) found that average horizontal cover of vegetation in playa lakes used by shorebirds was 9.1% compared to 40.1% in playas not used. As a result, vegetation establishment on mudflats following drawdowns is considered one of the primary factors limiting shorebird use at interior stopovers (Rundle and Fredrickson 1981, Skagen and Knopf 1994*b*, Davis and Smith 1998*a*). Once Chickamauga mudflats became exposed in October, they remained mostly bare ($\geq$98%) throughout the end of the growing season. In contrast, the average horizontal coverage ($\geq$61%) and height (16 cm) of vegetation on Douglas mudflats in October exceeded levels preferred by shorebirds (e.g., Helmers 1992). The difference in vegetation cover may have contributed to the observed trends in monthly abundance, as shorebird use was greater on Chickamauga than Douglas mudflats from October – January.

Monthly trends in shorebird abundance on Douglas mudflats suggest that their suitability for shorebirds declined after September. Of the 4,620 shorebirds observed on Douglas mudflats over the two years, 85% occurred during August and September. Migration chronology could have contributed to this trend in bird use (previous section), but probably not entirely, because shorebirds used un-vegetated mudflats in Chickamauga Reservoir from October – January. Rundle and Fredrickson (1981) reported that shorebird use declined rapidly within one month post-mudflat exposure following the establishment of vegetation in a Missouri moist-soil impoundment. During August and September, vegetative coverage on Douglas mudflats (18 – 43%) was lower

compared to October and November (61 – 85%). In addition to increasing vegetative cover, temporal changes in soil moisture and compaction and food density following the exposure of Douglas mudflats may have contributed to the declining use by shorebirds after September (discussed later). Douglas mudflats appear to be most suitable for shorebirds during August and September.

The vegetative response on Douglas mudflats also may have influenced habitat use patterns of other waterbirds such as waterfowl. Most waterfowl species tend to forage in wetlands with low emergent vegetation coverage (White and James 1978, Smith et al. 2004). Fourteen waterfowl species studied by White and James (1978) in coastal Texas, which included nine I documented on east TRV mudflats, foraged in habitats with $\leq$50% emergent cover. Although increasing vegetative cover and height on Douglas mudflats may have impacted waterfowl use, the primary factor likely reducing the suitability of Douglas mudflats to waterfowl was the lack of shallowly flooded habitat (discussed later).

The extent that plants respond following drawdowns is largely dependent upon the timing and duration of mudflat exposure (Harris and Marshall 1963, Fredrickson and Taylor 1982, Webb et al. 1988, Merendino et al. 1990), which likely contributed to vegetation differences between Douglas and Chickamauga Reservoirs. The higher elevations of mudflats (ca. 1 – 6 ha per mudflat) in Douglas Reservoir were exposed from late July through the end of the growing season or 94 – 109 days. Lower elevations of Douglas mudflats were exposed by late September or approximately 35 days during the growing season (i.e., 29 March – 4 November in Cocke County, Tennessee; Natural Resources Conservation Service [NRCS] 2001). In contrast, initial mudflat exposure in

Chickamauga Reservoir occurred in early October both years, but most of the acreage remained flooded during this month (i.e., only 0.3 – 1.4 ha exposed per mudflat). Thus, most mudflats in Chickamauga Reservoir were exposed for <10 days during the growing season (i.e., 31 March – 9 November in Bradley County, Tennessee; NRCS 2001).

Amundsen (1994) documented moist-soil plants germinating on mudflats in Watts Bar Reservoir within two weeks of exposure following an early October drawdown. Similarly, plants germinated on Chickamauga mudflats 21 days post-exposure. However, on Douglas mudflats that were exposed early August, plants germinated within seven days, and had 86% coverage within 21 days post-exposure. Previous studies have reported mudflats exposed earlier in the year and for a longer duration typically produce denser stands of vegetation (Harris and Marshall 1963, Fredrickson and Taylor 1982, Merendino et al. 1990). Merendino et al. (1990) reported that shoot densities on mudflats exposed for 105 and 75 days during the growing season ($\geq$1,377 shoots/m^2) were considerably greater than on those exposed for 45 days (863 shoots/m^2) and 15 days (92 shoots/m^2).

Douglas mudflats also supported a greater number of plant species (S = 21 – 28) than Chickamauga mudflats (S = 0 – 3). Webb et al. (1988) documented a similar trend in species richness when comparing plant communities on mudflats exposed following 15 June (S = 31), 1 July (S = 19 – 32), and 1 October (S = 1) drawdowns of several TRV mainstem reservoirs. Interestingly, when Chickamauga Reservoir was drawn down on 1 July in 1980, its mudflats supported 19 plant species (Webb et al. 1988). Indeed, mudflats exposed for a longer duration of the growing season allow more time for a greater number of plant species to germinate.

Seeds of most moist-soil plants require exposure to light and high temperature fluctuations to break dormancy (Salisbury 1970, Galinato and Van der Valk 1986, Baskin et al. 1993*a*). Baskin et al. (1993*a*, 1993*b*, 2004) conducted several studies on the germination requirements of moist-soil seeds collected from mudflats in Lake Barkley, which is located in the west TRV. Baskin et al. (1993*a*) found high germination rates (91%) in seeds of three moist-soil plant species when exposed to ambient temperatures exceeding 25˚C and 15˚C for daily high and low temperatures, respectively. Using monthly climatic data, they concluded that these species would only germinate on Lake Barkley mudflats from May – September (Baskin et al. 1993*a*). I documented two of these species in the east TRV (i.e., Vahl's fimbry and whiteedge flatsedge), and both germinated on Douglas mudflats in August, but they were not found on Chickamauga mudflats either year. Average soil temperatures on Douglas mudflats in August and September (21.0 – 26.7˚C) were considerably greater than those on Chickamauga mudflats during November (11.6 – 11.8˚C), when the majority of mudflats became exposed there. Thus, even though some mudflats in Chickamauga Reservoir were exposed during the last weeks of the growing season, it is unlikely that environmental conditions reached levels to stimulate seed germination.

In the TRV, Webb et al. (1988) documented a positive relationship between vegetation biomass and duration of mudflat exposure, and concluded that delaying reservoir drawdowns from late summer into fall leads to a reduction in vegetative biomass produced on mudflats. My results support this conclusion, as average biomass production on Douglas mudflats (162 – 165 g/m^2) was greater than that produced on Chickamauga mudflats (0 – 0.1 g/m^2). Webb et al. (1988) also hypothesized that

delaying reservoir drawdowns would reduce plant density, height, and species diversity. In my study, all vegetative parameters quantified (i.e., plant biomass, height, richness, horizontal and vertical cover) were greater on Douglas than Chickamauga mudflats at the end of the 2005 and 2006 growing seasons. Thus, my results support conclusions made by Webb et al. (1988) that delaying drawdowns of TRV reservoirs later into the fall will negatively affect the plant community on TRV mudflats.

Plant responses on TRV mudflats also may have been influenced by the rate of drawdown, because Douglas Reservoir was drawn down faster (–6.9 cm/day) than Chickamauga Reservoir (–1.3 cm/day). Fredrickson and Taylor (1982) suggested that gradual drawdowns encourage establishment of a more diverse plant community with a higher proportion of seed-producing species than fast drawdowns. Inasmuch as plant richness and number of seed-producing species were greater on Douglas than Chickamauga mudflats, my results appear to contradict Fredrickson and Taylor (1982). However, the influence of drawdown rate was likely confounded by the timing of mudflat exposure (i.e., early versus late).

According to Fredrickson (1991), the drawdowns of Douglas and Chickamauga Reservoirs would be classified as slow, because they occurred over 2 – 3 months. A fast drawdown in a moist-soil impoundment lasts 1 – 3 days (Fredrickson 1991). However, considering the magnitude of the drawdowns of Douglas (12.8 m) and Chickamauga Reservoirs (2.3 m) compared to a typical moist-soil impoundment (e.g., 0.3 – 0.5 m; Gray et al. 1999*b*), drawdowns of these reservoirs are probably characteristic of a fast drawdown. Rundle and Fredrickson (1981) recommended that water levels should be

lowered 2 – 3 cm/wk (i.e., 0.3 – 0.4 cm/day), which is 4 – 20X slower than what currently occurs in Douglas and Chickamauga Reservoirs.

Due to the relatively fast drawdown of Douglas Reservoir, large expanses of mudflats often became exposed in a short period of time. In early September 2005, water levels in Douglas Reservoir dropped 1.4 m during a 7-day period, and exposed approximately 52 ha of mudflats (i.e., 57% of the total acreage in one week). The resulting vegetative community on Douglas mudflats was dominated by rough cockleburr, which produced 85 – 98 g/m^2 of biomass each year (i.e., 52 – 59% of the total biomass). The establishment of a monotypic plant community often results following fast drawdowns, which produce uniformly dry conditions over large expanses of mudflats (Fredrickson and Taylor 1982). It is important to note that only a weak negative relationship existed between soil moisture and post-exposure duration (discussed later). In addition, mean soil moisture remained above 90% at both reservoirs. Thus, it appears that east TRV mudflats remain moist following drawdowns, perhaps due to frequent rains or close proximity to the water table. It is also possible that the sensitivity of the equipment I used failed to document significant moisture trends.

Rough cockleburr is considered a nuisance species in moist-soil wetlands, because it provides little value to wildlife and its broad leaves can shade out more desirable seed-producing species (Kelley 1986, Reid et al. 1989, Bowyer et al. 2005). Bowyer et al. (2005) reported that sampling plots dominated by cockleburr produced 19 – 21X less seed per ha than plots without cocklebur in an actively managed moist-soil impoundment. Inasmuch as cockleburr is not water-tolerant, it can be controlled by reflooding (Fredrickson and Taylor 1982, Reid et al. 1989). Although reflooding may not

be an option in TRV reservoirs due to competing water demands (e.g., flood control and hydropower generation), slowing the rate of drawdown might prolong saturation of the substrate, and facilitate the germination of more desirable plant species.

Aboveground and Belowground Seed Biomass.—On Douglas mudflats, moist-soil seed production estimated from aboveground inflorescences averaged 31.8 and 97.8 kg/ha in 2005 and 2006, respectively. The difference in seed yield between years likely was a consequence of not including five seed producing species in the 2005 estimate (see pp. 30 – 31). In support, excluding these species from the 2006 estimate reduced the seed yield to 28.2 kg/ha, which is similar to the 2005 estimate. Thus, the 2006 estimate of approximately 98 kg/ha of seed on Douglas mudflats is likely the most representative estimate. In contrast, seed production did not occur on Chickamauga mudflats either year.

My seed yield estimates on TRV reservoir mudflats were small compared to production in moist-soil wetlands (Fredrickson and Taylor 1982, Gray et al. 1999*b*, Bowyer et al. 2005). In Mississippi, aboveground seed yield in managed moist-soil wetlands was as high as 1,210 kg/ha and was between 172 - 212 kg/ha in unmanaged wetlands (Gray et al. 1999*b*). Most moist-soil impoundments are managed exclusively for wildlife, allowing managers to initiate drawdowns earlier in the growing season, which maximizes seed production (Fredrickson and Taylor 1982). In contrast, TRV reservoir drawdown dates are predetermined based on their position in the watershed, and always occur during the latter half of the growing season (Miller et al. 1996).

Seed production may have been less on TRV mudflats compared to other moist-soil habitats, because TRV mudflats were exposed for a shorter duration of the growing

season. Ahn et al. (2006) reported most moist-soil plants require 70 days during the growing season to germinate, reach maturity and produce seed. Given the short duration of mudflat exposure in Chickamauga Reservoir (<10 days), it is not surprising that seed production did not occur. At Douglas Reservoir, only the mudflats at higher elevations were exposed for >70 days during the growing season. Indeed, the high elevation contours on Douglas mudflats were the locations of seed production. Moist-soil seed production also may have been inhibited on Douglas mudflats due to interspecific competition with rough cockleburr (Bowyer et al. 2005). Thus, even though Douglas mudflats were exposed relatively earlier than Chickamauga mudflats, moist-soil seed production still was limited, and lower than previously reported estimates in wetlands of the Southeast.

Inasmuch as TRV reservoir drawdowns are initiated during the fall and mudflats are not reflooded until April (Miller et al. 1996), seeds produced on mudflats are not available to most waterbirds during the fall and winter following production. Although it did not occur during my study, occasionally fall or winter rains result in reflooding of TRV mudflats. In Kentucky Reservoir, reflooding of mudflats occurred in fall 2007, and waterfowl responded quickly, foraging among the newly-flooded moist-soil vegetation (D. Wirwa, University of Tennessee, unpublished data). Inaccessibility to moist-soil seeds during the year of production does not imply that these food resources cannot be utilized during the subsequent year. Although moist-soil seeds differ in their dispersal abilities (Goodson et al. 2001), it is likely that many seeds produced on TRV mudflats become incorporated into the seed bank, and thus would be available to waterbirds during the drawdown of the following year.

Amundsen (1994) suggested that delaying TRV reservoir drawdowns may attenuate the seed bank. Given that seed production did not occur on Chickamauga mudflats during my study, one would predict that moist-soil seed biomass in core samples would be greater at Douglas Reservoir. Although statistical differences in belowground seed biomass were not detected between reservoirs, the overall average biomass in Douglas mudflats over the two years (56.5 kg/ha) was two times greater than in Chickamauga mudflats (26.8 kg/ha). Thus, my results provide some evidence that delaying reservoir drawdowns to 1 October reduces the amount of seed available within the substrate.

Belowground seed biomass on TRV mudflats was considerably less than that previously reported in moist-soil wetlands (Naylor 2002, Kross et al. 2008). Naylor (2002) collected core samples from wetlands in the Central Valley of California, and estimated 200 – 586 kg/ha of available seed. Belowground seed biomass estimates in Mississippi Alluvial Valley moist-soil wetlands averaged 496 kg/ha (Kross et al. 2008). Low aboveground seed production on TRV mudflats probably contributed to low biomass in the substrate, and lower belowground seed biomass compared to previous studies.

The relatively low availability of moist-soil seed biomass on TRV mudflats likely had the greatest influence on granivorous waterbirds, such as waterfowl. The seed biomass estimate from core samples on Chickamauga mudflats was well below the 50 kg/ha optimal foraging threshold when waterfowl abandon a habitat to forage elsewhere (Reinecke et al. 1989, Rutka 2004). Even at Douglas Reservoir, moist-soil biomass was only slightly above this threshold value. Most waterfowl species are very opportunistic

and will shift their foraging strategies to exploit locally abundant food resources (Fredrickson and Drobney 1979, Poysa 1983). Thus, it is possible that waterfowl were foraging in other habitats adjacent to TRV mudflats that supported greater food densities. The distribution of waterfowl foraging habitats in the east TRV is currently unknown. Another possibility is that waterfowl were acquiring other foods items on mudflats, such as aquatic invertebrates. Given that invertebrate analyses for my study are ongoing, I cannot make conclusions on their availability. In chapter III, I discuss waterbird activities, and indeed, foraging constituted on average 41% of waterfowl activity budgets. Ideally, future studies should compare the food habits of waterfowl on TRV mudflats with available food resources in core samples collected adjacent to foraging birds.

Water Depth.—Water depth was not quantified at Chickamauga Reservoir during August or September; however, it was considerably deeper than that measured at Douglas Reservoir (2 – 20 cm) because all mudflats remained entirely flooded. Previous studies have reported that the influence of water depth on waterbird use is species-specific due to morphological differences (Baker 1979, Poysa 1983, Ntiamoa-Baidu et al. 1998). Inasmuch as drawdowns provide a diversity of suitable foraging depths, waterbird richness is typically greater in wetlands undergoing drawdowns compared to those that are permanently flooded (Sprandel et al. 2002, Taft et al. 2002). Taft et al. (2002) reported that waterbird richness was 18 – 50% greater in moist-soil wetlands that were drawn down compared to those that remained flooded. Sprandel et al. (2002) reported similar findings at Lake Talquin, Florida, where waterbird richness observed during its drawdown was 23% greater than when it was at full pool. Similarly, I documented 6 – 9X greater richness at Douglas (S = 24 – 35) than Chickamauga Reservoir (S = 4) during

August and September. In fact, only Canada geese, great blue herons, great egrets, and wood ducks were observed at Chickamauga Reservoir during these respective months.

Across all months and years, water depths at Douglas and Chickamauga Reservoirs averaged 20.1 and 13.2 cm, respectively. These depths likely placed greater limitations on shorebirds than on the other waterbird guilds. Some of the larger wading birds (e.g., great blue herons and great egrets) can efficiently forage at depths up to 50 – 60 cm, but most shorebirds are restricted to wetlands ≤18 cm deep (Fredrickson and Reid 1986, Helmers 1992). In addition, several studies suggest that the majority of shorebird species prefer water depths ≤5 cm (Rundle and Fredrickson 1981, Weber and Haig 1996, Davis and Smith 1998*a*). Thus, my results suggest that average water depth along 10-m transects perpendicular to the water-mudflat interface in Douglas and Chickamauga Reservoirs typically exceeded those preferred by shorebirds. During drawdowns, the gradual topography associated with most wetlands provides mudflats and shallowly flooded habitat (e.g., Weber and Haig 1996, Davis and Smith 1998*a*, Collazo et al. 2002, Taft et al. 2002). Davis and Smith (1998*a*) reported that shallowly flooded (0 – 16 cm) mudflats comprised approximately 39% of the area of playa lakes used by shorebirds in Texas. However, because of the rapid transition in depth on TRV mudflats, exposed mudflats probably constitute the majority of suitable shorebird habitat within east TRV reservoirs. The rapid depth transition associated with east TRV mudflats is due to the steep gradient of the underlying floodplain, which is characteristic of east TRV topography (TVA 1942, 1949).

Waterfowl use of Douglas mudflats may have been impacted by water depth during October – January. During these months, average water depth associated with

mudflats was typically 25 – 30 cm deep, which is deeper than those preferred by foraging dabbling ducks (i.e., 5 – 25 cm; Fredrickson and Reid 1988*b*). In contrast, Chickamauga mudflats provided shallower water (5 – 18 cm), and supported greater numbers of waterfowl. Excluding January 2007, waterfowl abundance was greater on Chickamauga than Douglas mudflats from October – January both years.

Soil Characteristics and Water Quality.—Differences were not detected between reservoirs in soil moisture, temperature, compaction, or water quality variables. Thus, it is unlikely that these variables directly contributed to the differences in waterbird use between reservoirs. However, all four of these variables are known to influence invertebrate composition and density, and ultimately their availability to waterbirds (Goss-Custard et al. 1977; Pienkowski 1983*a*, 1983*b*; Reid 1985; Mouritsen and Jensen 1992). Future analyses of invertebrate data will relate abundance to soil and water quality parameters.

My regression models indicated that soil moisture on Douglas mudflats declined slightly with post-exposure duration but this relationship did not exist at Chickamauga Reservoir either year. This trend is likely due to the difference in the magnitude of the drawdown between Douglas (12.8 m) and Chickamauga (2.3 m) Reservoirs, resulting in Douglas mudflats drying slightly more than Chickamauga mudflats. Declining soil moisture can reduce invertebrate activity and decrease detection by foraging birds (Pienkowski 1983*a*, *b*), which could have impacted waterbird use.

Typically, a substrate becomes more compact with greater post-exposure duration (Pienkowski 1983*a*), but no relationship existed at Douglas Reservoir and there was only a weak relationship at Chickamauga Reservoir. Increased compaction is known to inhibit

the ability of shorebirds to penetrate the substrate with their bills, which likely decreases foraging efficacy for invertebrate prey (Mouritsen and Jensen 1992). Soil compaction following a drawdown is a consequence of reduced soil moisture. Given that mean soil moisture remained over 90% on Douglas and Chickamauga mudflats, it is not surprising that a strong relationship between mudflat compaction and post-exposure duration was not found. Thus, on east TRV mudflats, it appears that soil characteristics are not an important mechanism influencing shorebird use, although their effects on invertebrate availability remain to be determined. As alluded earlier, sensitivity of my soil moisture and compaction sampling equipment may have influenced these results.

Conclusions and Management Recommendations

Mudflats in the east TRV provide important habitat for over 60 species of migrating and wintering waterbirds. I documented 22 shorebird and 18 waterfowl species using east TRV mudflats. In addition, 19 species of other waterbirds were observed during my study. Combining my data with Fowler (1983) and D. Wirwa (University of Tennessee, unpublished data), 32 species of shorebirds have been observed using mudflats in the TRV, which represents 64% of the species breeding in North America. Of the shorebird species that I documented, 73% are listed as species of moderate or high concern, because their populations are declining. I also documented use of east TRV mudflats by a federally-endangered species – the wood stork. Collectively, these results highlight the importance of east TRV mudflats to a diverse waterbird community.

For shorebirds, species richness on east TRV mudflats ($S = 22$) was comparable to other interior migratory stopover sites: Mississippi Alluvial Valley ($S = 29$), Quivira National Wildlife Refuge in central Kansas ($S = 29$), and playa ($S = 20 – 22$) and saline ($S = 28$) lakes in Texas (Skagen and Knopf 1994*b*, Davis and Smith 1998*a*, Short 1999, Andrei et al. 2006). It is important to note that the 32 species documented in the TRV exceeds all aforementioned regions. Relative shorebird abundance on east TRV mudflats also is comparable to that reported at other interior stopovers. Average yearly abundance on my eight mudflats (201 ha total) was 7,345 shorebirds. Hands et al. (1991) documented 6,432 shorebirds at Ted Shanks National Wildlife Refuge in northeastern Missouri, and their data were collected during one spring and two fall migration periods. It is estimated that approximately 12,000 ha of mudflats exist during drawdown in the TRV (T. Henry, TVA, unpublished data). Using the average density of shorebirds per ha of mudflat from my study (36.5 birds/ha), reservoir mudflats in the TRV could be used by nearly 450,000 shorebirds per year, which may be underestimated because shorebird densities are higher in the west TRV (44.7 birds/ha; D. Wirwa, University of Tennessee, unpublished data). Loesch et al. (2000) estimated that the Mississippi Alluvial Valley supports approximately 500,000 shorebirds annually. Thus, results from my study suggest that mudflats in the TRV may be as important to the continental shorebird population as those in the Mississippi Alluvial Valley.

My results suggest that early and late drawdowns of TRV reservoirs benefit migratory shorebirds at different times of the year. The 1 August drawdown of Douglas Reservoir provided mudflats for a greater number of shorebird species. Several rare species also were recorded including buff-breasted and solitary sandpipers. Most (83%)

of the shorebird species documented using Douglas Reservoir can be classified as intermediate- or long-distance migrants. In contrast, Chickamauga Reservoir provided habitat for more common species that migrate later and shorter distances (e.g., killdeer, least sandpiper and Wilson's snipe). Some of these species used Chickamauga mudflats through winter.

I quantified a variety of habitat factors that potentially could have influenced the suitability of mudflats (e.g., water depth and quality; invertebrate and seed availability; vegetation composition and structure; soil moisture, temperature and compaction). Although these factors may have had interactive and indirect effects on shorebird and other waterbird use, my monthly comparisons between reservoirs and regression models collectively suggest that increasing vegetative coverage was the primary mechanism influencing the suitability of mudflats for waterbirds. As a result, east TRV mudflats exposed in August and September likely provide very little suitable habitat for shorebird species that migrate later in fall or winter in the TRV.

An ideal reservoir drawdown schedule should include a combination of early and late drawdowns in close regional proximity. Smith (2006) suggested that nine reservoirs contain the majority of mudflat acreage in the TRV: Cherokee, Chickamauga, Douglas, Hiwassee, Nottely, Watauga, Kentucky, Pickwick and Wheeler. The first six reservoirs listed are located in the east TRV and the last three in the west TRV. Of these, three reservoirs (Chickamauga, Pickwick and Wheeler) have planned drawdown initiation dates on 1 October; the others occur in July or August. Kentucky Reservoir provides mudflat habitat annually for thousands of migratory shorebirds (D. Wirwa, University of Tennessee, unpublished data). Thus, I recommend that its current 5 July drawdown is

maintained, because Kentucky Reservoir represents the only west TRV reservoir with an early drawdown. If feasible, TVA might consider initiating an earlier drawdown of Wheeler or Pickwick Reservoir also. Scheduling of drawdowns in the east TRV could be more innovative given the greater number of reservoirs. In the east TRV, reservoir drawdowns could be staggered to provide a continuum of newly-exposed mudflats for migratory waterbirds. For example, the following drawdown schedule would meet the needs of various waterbirds throughout fall migration and winter, while ensuring that the majority of habitat is available during late July to mid-September, when peak shorebird migration occurs: Watauga (15 July), Douglas (1 August), Nottely (15 August), Hiwassee (15 September), Chickamauga (1 October), and Cherokee (1 October). Certainly, feasibility of this or other possible drawdown schedules will depend on engineering constraints and consideration of other reservoir uses. An additional benefit to a staggered drawdown is it can accommodate late-summer recreational demands at certain reservoirs. For example, Cherokee Reservoir has 950,000 visitor-days each year (Murray et al. 1998), and the local economy probably would benefit significantly from a later drawdown. I recommend that the strategic planning of TRV reservoir drawdowns be an interactive process, where engineers, biologists, and other stakeholders discuss possible management scenarios.

Due to the multiple uses of the TRV reservoir system, all positive and negative effects of early and late drawdowns should be discussed. Economic benefits of delayed (later) drawdowns have been reported (Cordell and Bergstrom 1993, Murray et al. 1998, Jakus et al. 2000). Cordell and Bergstrom (1993) also reported that delaying drawdown of four east TRV reservoirs by 1 – 3 months could result in $12 – 16 million lost each

year due to a corresponding reduction in systemwide hydropower generation. Other negative impacts of delayed drawdowns include increased risk of flood damage and reduced interstate navigation in reservoirs downstream (Jakus et al. 2000). I encourage that changes to the existing TRV drawdown schedules consider all possible economic losses and gains, while integrating considerations for providing fish and wildlife habitat.

An ancillary observation that I made during my study was the potential impact of drawdown rate on mudflat suitability and waterbird use. Chickamauga Reservoir was drawn down at a slower rate than Douglas Reservoir. Slow drawdowns prolong the availability of suitable habitat for shorebirds and other waterbirds (Rundle and Fredrickson 1981, Hands et al. 1991). Chickamauga Reservoir supported greater numbers of shorebirds, and appeared to provide suitable habitat for longer duration than Douglas Reservoir. Additional research is needed quantifying the impact of reservoir drawdown rate on waterbird abundance, which could be done by comparing two reservoirs drawn down on the same date but at different rates. Slowing the rate of drawdown also may provide natural control of nuisance plants (e.g., rough cockleburr), and promote establishment of a more diverse wetland plant community. Further, slow drawdowns may provide additional opportunities for water recreationists because water levels would be maintained later in the summer and fall. Thus, I recommend TRV reservoirs be drawn down as slowly as possible (i.e., preferably $\leq$ 1 cm/day) to maximize the availability of suitable habitat for migratory waterbirds, with possible additional benefits on the plant community and water recreation.

The Tennessee River Valley is managed as a comprehensive multiple-use system. Uses include flood control, hydropower production, year-round navigation, economic

growth, water supply, and recreation (Miller et al. 1996). In this chapter, I demonstrated that TRV mudflats are used by a diverse waterbird assemblage from August – January. In Chapter III, I provide evidence that TRV mudflats function as critical migratory stopover and wintering sites for shorebirds and waterfowl. Given the importance of these mudflats to migratory shorebirds in North America, I recommend in Chapter III that TRV mudflats be added to the Western Hemisphere Shorebird Reserve Network as a "Landscape Site of Regional Importance." I also recommend that management of TRV reservoirs take into consideration mudflat availability for shorebirds and other waterbirds. Providing habitat for resident and migratory waterbirds should be added to the decision-making process of TRV reservoir management.

CHAPTER III

WATERBIRD ACTIVITIES ON MUDFLATS

Introduction

Quantifying the activities of waterbirds can provide insight into the functionality and importance of their wetland habitats (Fredrickson and Drobney 1979, Davis and Smith 1998*b*, Baldassarre and Bolen 2006). In the Tennessee River Valley (TRV), reservoir drawdowns initiated during late summer and fall expose over 12,000 ha of mudflats, which are used by thousands of waterbirds each year (Chapter II; T. Henry, Tennessee Valley Authority [TVA], unpublished data). In the interior United States, mudflats and adjacent shallowly flooded areas provide critical stopover habitat for migrating shorebirds (Myers 1983, Skagen and Knopf 1994*a*, Davis and Smith 1998*a*).

Documentation of shorebird behavior at interior stopover sites is limited (Davis and Smith 1998*b*), and most research has been conducted in the Southern Great Plains (Davis and Smith 1998*b*, Kostecke and Smith 2003, Andrei et al. 2007) and Prairie Pothole Regions (Wishart and Sealy 1980, DeLeon and Smith 1999). The expanse, timing, and duration of mudflat exposure in depressional wetlands differs from other interior mudflat wetlands (Mitsch and Gosselink 2000, Smith 2006), especially those associated with river systems where water levels are regulated, such as the TRV. Only one study (Elliot-Smith 2003) has quantified shorebird activities on mudflats exposed during reservoir drawdowns. This study was conducted in Rend Lake, Illinois (Elliot-Smith 2003), and activity patterns documented there may differ from those on TRV mudflats because reservoir drawdowns in the TRV are faster and greater in magnitude. On average, water levels in Rend Lake fluctuated 0.7 m (2.3 ft) and were drawn down at

a rate of –4.0 cm/wk (i.e., –0.6 cm/day; Elliot-Smith 2003). Water levels in Douglas and Chickamauga Reservoirs in the east TRV fluctuate 12.8 m (42.0 ft) and 2.3 m (7.5 ft), respectively, and receded on average –6.9 and –1.3 cm/day during my study. Shorebird use of mudflats in the TRV has been documented (Chapter II, Fowler 1983, Knight 1985); however to date, no information exists on shorebird activities on TRV mudflats.

Shorebirds rely on interior mudflats to meet energetic demands associated with long-distance migration (Skagen and Knopf 1994*b*, Davis and Smith 1998*a*). Using an energetics model, Loesch et al. (2000) reported that an average-sized shorebird must consume 8 g of invertebrates per day to meet the physiological demands of migration. Not surprising, feeding has been reported as the most common activity of shorebirds using interior mudflats (Wishart and Sealy 1980, Davis and Smith 1998*b*, DeLeon and Smith 1999, Elliot-Smith 2003, Kostecke and Smith 2003, Andrei et al. 2007). However, several studies have documented species-specific differences in time-activity budgets among coexisting species at stopover sites (Davis and Smith 1998*b*, DeLeon and Smith 1999, Elliot-Smith 2003, Andrei et al. 2007). Small-bodied, longer-distance migrants tend to spend more time feeding and less time resting than large-bodied, shorter-distance migrants (Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). It is hypothesized that species-specific differences are influenced by total migratory distance, metabolic rates, thermoregulatory costs and diet (Davis and Smith 1998*b*, DeLeon and Smith 1999). Conclusions from these studies are geographically limited though, because nearly all comparisons between short- and long-distance migrants were based exclusively on the American avocet (*Recurvirostra americana*), which served as the short-distance migrant. This species is rarely observed east of the Mississippi River Valley during

migration (e.g., Fowler 1983, DeCecco and Cooper 1996). More research is needed comparing activity budgets between short- and long-distance migrants in other regions of North America.

Additionally, previously studied stopover habitats in the Great Plains (Wishart and Sealy 1980, Davis and Smith 1998*b*, DeLeon and Smith 1999, Kostecke and Smith 2003, Andrei et al. 2007) differ from those in the TRV in terms of habitat connectivity due to differences in wetland coverage on the respective landscapes. Mudflats in the TRV cover approximately 0.1% of the TRV landscape (T. Henry, TVA, unpublished data). In comparison, mudflats and shallowly flooded wetlands cover around 2% and 6 – 12% of the Southern Great Plains and Prairie Pothole Region landscapes, respectively (Haukos and Smith 1994, Beeri and Phillips 2007). Lower abundance of suitable foraging sites in the TRV may force shorebirds to migrate farther distances between stopovers, causing them to spend more time feeding than in other regions. Thus, information on shorebird activities in the TRV will be useful in making qualitative comparisons with other regions (e.g., Great Plains), where most of the interior stopover research has been conducted. Further, this information will provide insight into the importance of mudflats associated with large river systems to migrating shorebirds.

Shallowly flooded mudflats also provide habitat for migrating and wintering waterfowl, yet few studies have quantified waterfowl behavior within these habitats (e.g., Quinlan and Baldassarre 1984, Rave and Baldassarre 1989, White 1994, Johnson and Rohwer 2000). Previous studies suggest that mudflats primarily serve as foraging and resting habitat for waterfowl (Quinlan and Baldassarre 1984, Rave and Baldassarre 1989, White 1994). The mudflat-water interface is a common foraging location of waterfowl,

likely due to ideal foraging depths and high densities of invertebrates and seeds (Rave and Baldassarre 1989, Gaston 1992, Johnson and Rohwer 2000). Mean water depths used by foraging American green-winged teal (*Anas crecca*) and mallards (*A. platyrhynchos*) on tidal mudflats (3.5 and 4.6 cm, respectively; Johnson and Rohwer 2000) were shallower than those typically utilized in emergent wetlands (5.1 – 25.4 cm, Fredrickson and Reid 1988*b*). Waterfowl also infrequently tipped-up (<7% of the time) when foraging on mudflats, providing further evidence that waterfowl acquire food items in shallower water (Johnson and Rohwer 2000).

Most behavioral studies conducted on mudflats have focused on American green-winged teal (Quinlan and Baldassarre 1984, Rave and Baldassarre 1989, Johnson and Rohwer 2000); however, TRV mudflats are used by at least 22 waterfowl species (Chapter II; D. Wirwa, University of Tennessee, unpublished data). Moreover, nearly all previous studies have been conducted on mudflats in tidal or depressional wetlands (Quinlan and Baldassarre 1984, Rave and Baldassarre 1989, Johnson and Rohwer 2000). To my knowledge, only one study (White 1994) has quantified the behavior of waterfowl using riverine mudflats. Although this study was conducted in the west TRV, it focused exclusively on the activities of American black ducks (*A. rubripes*; White 1994). Documentation of waterfowl behavior on interior mudflats is needed to determine how different species utilize these habitats.

The availability of mudflats in the TRV is controlled mainly by the Tennessee Valley Authority via reservoir drawdowns (Smith 2006), which are performed to provide flood control, generate electricity and cool nuclear reactors (Miller et al. 1996). However, it is believed that the current drawdown schedules do not promote waterfowl

use, because mudflats are exposed in the fall and usually not reflooded until spring unless fall or winter precipitation results in reservoir levels rising (Wiebe 1946, Steenis 1950, White 1994). Several studies in the TRV have indicated that mudflat exposure late in the growing season potentially inhibits seed production by moist-soil plants, because insufficient time exists for plants to germinate and mature (Chapter II, Webb et al. 1988, Amundsen 1994). In addition, moist-soil seed that is produced on TRV mudflats is functionally unavailable to waterfowl because these foods are rarely reflooded during fall or winter (Wiebe 1946, Steenis 1950). Hence, it is has been suggested that TRV mudflats are of little value to migrating and wintering waterfowl (Wiebe 1946, Morse and Steenis 1948, Steenis 1950, White 1994). Although mudflats may not reflood for use by waterfowl, shallow water associated with them may provide important foraging habitat. For example, over half of the waterfowl observed during 2005-06 winter surveys at Tennessee National Wildlife Refuge were using mudflats and adjacent shallow water in Kentucky Reservoir (R. Wheat, U.S. Fish and Wildlife Service, unpublished data). Quantifying the activities of waterfowl using these habitats will be useful in determining their functionality and relative importance to migrating and wintering waterfowl and in making reservoir management decisions.

Drawdowns of reservoirs also attract a variety of other waterbird species because food resources often become trapped or concentrated into a smaller water volume (Kushlan 1976, Swanson and Meyer 1977, Sprandel et al. 2002). The availability of food is typically driven by water depth due to species-specific differences in morphology and foraging tactics (Poysa 1983, Ntiamoa-Baidu et al. 1998, Taft et al. 2002). Thus, the availability of preferred water depths likely influences the activity patterns exhibited by

waterbirds using different habitats (e.g., Ntiamoa-Baidu et al. 1998). The functionality of TRV mudflats to different waterbird species is likely driven by the interaction between water levels and mudflat topography (Fredrickson and Taylor 1982, Johnson and Rohwer 2000, Taft et al. 2002). These relationships and how they interact with habitat-use patterns of waterbirds in the TRV remain largely unknown.

The goal of this research was to determine the relative importance and functional role that mudflats in the Tennessee River Valley provide to waterbirds. Specifically, my objectives were to: (1) quantify species-specific differences in waterbird activities on mudflats in the TRV, (2) determine if activity budgets differed between short- and long-distance migrant shorebirds, and (3) qualitatively compare these results to previous studies conducted in other reservoirs, wetland systems, and regions.

Methods

Species-specific activities were quantified at eight mudflats in Douglas and Chickamauga Reservoirs (n = 4 per reservoir) from 15 August 2005 – 13 January 2006 and from 31 July 2006 – 12 January 2007. All surveys were conducted between sunrise and 5 hrs after sunrise. I used scan and focal sampling to document the activities of waterbirds using TRV mudflats (Altmann 1974). Scan sampling was conducted on a randomly selected subsample of individuals ($n \leq 5$) for up to four distinct flocks using each mudflat. Distinct flocks were groups of waterbirds with $\geq$5 individuals that were spatially disjunct ($\geq$50 m) from other individuals. Random individuals were scan sampled by aligning the spotting scope at the approximate midpoint of each flock (Jorde et al. 1984, Quinlan and Baldassarre 1984, Rave and Baldassarre 1989), and recording

the instantaneous activity of the first five birds observed regardless of species. Focal sampling was performed on two randomly selected individuals per species per mudflat. If possible, individuals were randomly selected from a different flock than those used for scan sampling. Individuals were randomly selected by aligning the spotting scope at the approximate midpoint of the flock, and recording activities for the first two individuals per species that were encountered. Individuals were observed for one continuous minute, and the duration of their activities was recorded.

Waterbird activities recorded included feeding, preening, inactive, alert, sleeping, antagonistic behavior, courtship, walking, stretching, flying, swimming, tipping, and diving. Activities were combined into general categories post-hoc to simplify analyses and facilitate interpretation and comparisons to other studies. Combined activity categories included feeding, locomotion (flying, swimming and walking), maintenance (preening and stretching), resting (inactive and sleeping), alert, antagonistic and courtship (waterfowl only), which is standard based on previous waterbird activity budget studies (e.g., Paulus 1988, DuBowy 1996, Davis and Smith 1998*b*). I further categorized foraging for ducks as dabbling, diving and tipping, because these activities more accurately describe food-acquisition tactics, which often differ among species (Nudds and Bowlby 1984, Johnson and Rohwer 2000). This categorization was done only for one-minute focal samples.

To test hypotheses related to shorebird activities and migration distance, I categorized shorebirds by average migration distance (short, intermediate and long) following Skagen and Knopf (1993). The shorebird community observed in the east TRV consisted of 4 short-distance, 12 intermediate-distance, and 6 long-distance

migrants (Skagen and Knopf 1993; Table 23). All wetland-dependent bird species observed other than shorebirds and waterfowl were placed into an "other waterbirds" category (Appendix II; Weller 1999). This category consisted of 11 species (indicated parenthetically) in the following families: Ardeidae (4), Gruidae (1), Laridae (2), Pelecanidae (1), Phalacrocoracidae (1), Podicipedidae (1), and Rallidae (1).

Statistical Analyses

Scan and focal sampling data were analyzed separately for shorebirds, waterfowl and other waterbirds. For scan sampling, the number of observations was summed by activity category. Percent occurrence per activity was calculated by dividing category totals by the total number of observations (n = 2,991 shorebirds; n = 1,016 waterfowl; and n = 1,265 other waterbirds). Differences in percent occurrence of activities were tested among species using a chi-square test of homogeneity (Zar 1999). I also used a chi-square test to quantify differences in percent occurrence of activities among short-, intermediate- and long-distance migrant shorebirds.

For focal samples, I calculated percent time spent per activity during one-minute surveys. Differences in average percent time expended were tested among species and activities using an analysis-of-variance (ANOVA). I also used a one-way ANOVA to test if time spent foraging by waterfowl differed among dabbling, tipping and diving tactics. If the overall ANOVA was significant, Tukey's Honestly Significant Difference (HSD) test was used to determine pairwise differences among species and activities. I did not test for normality because sample size was large ($n > 20$), and parametric tests (e.g., ANOVA) are robust to violations of normality for large-sample cases as per the

Central Limit Theorem (Hogg and Craig 1995). All statistical analyses were performed using the SAS® system at $\alpha = 0.05$ (Littell et al. 1991, Stokes et al. 2003).

Results

Scan Sampling

Shorebirds.—Percent occurrence of activities differed among short-, intermediate- and long-distance migrants ($\chi^2_{10} = 315.8$, $P < 0.001$). Feeding was the most common activity observed in intermediate- and long-distance migrants using mudflats, comprising 75% and 80% of instantaneous observations, respectively (Figure 16). Short-distance migrants were feeding in only 36% of observations. Resting was the most common behavior exhibited by short-distance migrants (39% occurrence), whereas this activity occurred in <5% of observations of intermediate- and long-distance migrants. All three groups were engaged in locomotive behavior in 11 – 16% of observations, with a slight increasing trend from long- to short-distance migrants. Occurrence of maintenance activities was similar among shorebird groups. Alert behaviors were seldom observed (<1% occurrence), and were only documented in short- and long-distance migrants. Antagonistic behavior was only observed in short-distance migrants, with occurrence <1% (Figure 16).

Percent occurrence of activities also differed among shorebird species ($\chi^2_{50} = 678.9$, $P < 0.001$). Feeding was the most common activity ($\geq$54% of observations) among shorebirds, excluding killdeer (*Charadrius vociferus*, 26%) and Wilson's snipe (*Gallinago delicata*, 49%), both which are short-distance migrants (Figure 17). Feeding behavior was very common ($\geq$80%) in sanderlings (*Calidris alba*) and least (*C.*

minutilla), pectoral (*C. melanotos*), and semipalmated sandpipers (*C. pusilla*). Locomotion represented ≤20% occurrence across shorebird species, except for semipalmated sandpipers, spotted sandpipers (*Actitis macularius*), and greater (*Tringa melanoleuca*) and lesser yellowlegs (*T. flavipes*), which were engaged in locomotion during 29 – 40% of observations (Figure 17).

Body maintenance represented 19% and 14% of observations for dunlin (*C. alpina*) and lesser yellowlegs, respectively, and 0 – 11% in all other shorebird species (Figure 17). Killdeer and Wilson's snipe were the only two species commonly observed resting on mudflats (45% and 22% occurrence, respectively). Among remaining species, resting accounted for ≤8% of instantaneous observations, and did not occur in lesser yellowlegs, sanderlings, semipalmated or spotted sandpipers. Alert and antagonistic behaviors were seldom observed, representing <1% of observations (Figure 17).

Waterfowl.—Feeding and locomotive behaviors were the most common activities exhibited by waterfowl using mudflats (42% and 32% occurrence, respectively; Figure 18a). Waterfowl were observed resting and performing maintenance activities on mudflats in 10 – 13 % of observations. Alert, antagonistic, and courtship behaviors rarely occurred in waterfowl, representing ≤3% occurrence (Figure 18a).

Percent occurrence of activities differed among waterfowl species ($\chi^2_{54} = 297.8$, $P < 0.001$). Feeding was the most common activity observed in American green-winged teal, gadwalls (*Anas strepera*), mallards, and northern shovelers (*A. clypeata*), occurring in 53 – 73% of individuals (Figure 19). Buffleheads (*Bucephala albeola*), hooded mergansers (*Lophodytes cucullatus*), and wood ducks (*Aix sponsa*) were engaged in locomotion in 49 – 100% of observations. Locomotion represented 7 – 36% occurrence

in all remaining waterfowl species, with northern shovelers engaging in locomotion the least (Figure 19).

American black ducks and blue-winged teal (*Anas discors*) were engaged in maintenance behavior 18 – 22% of observations; occurrence of this activity was ≤13 % in all remaining species and was not observed in buffleheads or wood ducks (Figure 19). Resting represented 22 – 29% of observations of blue-winged teal and Canada geese (*Branta canadensis*), but this behavior occurred in ≤14% of individuals of remaining species. Canada geese were alert in 8% of observations, whereas this behavior represented <2% occurrence in all other species. Antagonistic and courtship behaviors were only observed in hooded mergansers; each activity represented ≤2% occurrence (Figure 19).

Other Waterbirds.—Resting was the primary activity observed in other waterbirds using mudflats, occurring in 43% of observations (Figure 18b). This group was commonly engaged in locomotion (24% occurrence), maintenance (14%) and alert behaviors (11%). Feeding behavior occurred in only 7% of individuals, and no form of aggressive behavior was observed (Figure 18b).

Percent occurrence of activities differed among other waterbird species (χ^2_{40} = 285.6, $P < 0.001$). Resting was observed in ≥13% of observations of all other waterbird species, except little blue herons (0%, *Egretta caerulea*, Figure 20). All American coots (*Fulica americana*) observed on mudflats were resting, and this activity was observed in 56 – 67% of great blue herons (*Ardea herodias*) and great egrets (*A. alba*). Locomotion was the most common activity observed in double-crested cormorants (*Phalacrocorax auritus*), little blue herons, pied-billed grebes (*Podilymbus podiceps*), and ring-billed

gulls (*Larus delawarensis*), comprising 37 – 63% of observations. Locomotion was observed less frequently (18 – 27%) in Bonaparte's gulls (*L. philadelphia*) and the three other heron species (Figure 20).

Maintenance behavior was observed in 75% and 53% of American white pelicans (*Pelecanus erythrorhynchos*) and Bonaparte's gulls (Figure 20). This activity was not observed as often (17 – 24%) in great egrets, ring-billed gulls, and sandhill cranes (*Grus canadensis*). Double-crested cormorants, little blue herons, and pied-billed grebes were feeding in 22 – 38% of observations. Nearly all remaining species were documented foraging on mudflats, but this activity accounted for $\leq$13% of observations. Great blue herons, great egrets and sandhill cranes were alert in 9 – 20% of observations; this behavior represented $\leq$4% occurrence in all remaining species (Figure 20).

Focal Bird Sampling

Results presented below were from focal surveys and mirror those provided in the previous section using scan sampling. These results are presented, because the response is continuous (average time spent per activity), and differences could be tested among levels of effects (i.e., activities and species) without inflating Type I error (i.e., Tukey's HSD test used for post-hoc comparisons). In the previous section, overall differences in proportions were tested, but pairwise comparisons were merely discussed, because efficient algorithms do not exist to control experimentwise error for post-hoc comparisons of categorical data (Agresti 1990).

Shorebirds.—Time spent by short-, intermediate-, and long-distance migrants differed among activities ($F_{5,456} \geq 249.32$, $P < 0.001$; Table 24). Long- and intermediate-

distance migrants spent significantly more of their time feeding on mudflats than any other activity ($F_{5,456} \geq 249.32$, $P < 0.001$), whereas short-distance migrants spent more of their time resting ($F_{5,3370} = 519.54$, $P < 0.001$). Time spent feeding and resting also differed among migration distance categories ($F_{2,1108} \geq 147.12$, $P < 0.001$). Long- and intermediate-distance migrants spent twice the time feeding than short-distance migrants ($F_{2,1108} = 147.12$, $P < 0.001$). Time spent resting by short-distance migrants was over 5X greater than long- and intermediate-distance migrants ($F_{2,1108} = 177.99$, $P < 0.001$). Although significant differences were not detected ($F_{2,1108} = 2.58$, $P = 0.076$), time spent engaged in locomotion by short- and intermediate-distance migrants was 63 – 79% greater than long-distance migrants. Body maintenance represented 5 – 6% of shorebird activity budgets and was similar among groups ($F_{2,1108} = 0.30$, $P = 0.744$). Alert and antagonistic behaviors were rarely observed ($\leq$1%) and similar among migration groups ($F_{2,1108} \leq 0.96$, $P \geq 0.385$; Table 24).

For species comparisons, time spent by each shorebird species differed among activities ($F_{5,18} \geq 7.34$, $P \leq 0.001$; Table 25). Additionally, time spent feeding, resting, and engaged in locomotive and maintenance activities differed significantly among species ($F_{14,1086} \geq 2.95$, $P < 0.001$). All species (except American golden-plovers [*Pluvialis dominica*], greater yellowlegs, killdeer, and spotted sandpipers) spent significantly more time feeding than any other activity ($F_{5,18} \geq 7.34$, $P \leq 0.001$). Short-billed dowitchers (*Limnodromus griseus*) and least, pectoral, semipalmated, and western sandpipers (*Calidris mauri*) spent on average over 82% of their time feeding on mudflats. Excluding American golden-plovers and killdeer, all remaining species were observed foraging over 42% of the time (Table 25).

American golden-plovers and killdeer spent the majority of their time resting on mudflats ($F_{5,18} \geq 143.25$, $P < 0.001$; Table 25). Time spent resting by American golden-plovers was significantly greater than all other species except killdeer ($F_{14,1086} = 41.98$, $P < 0.001$). Killdeer spent more time resting than all remaining species except semipalmated plovers (*Charadrius semipalmatus*), solitary sandpipers (*Tringa solitaria*) and Wilson's snipe ($F_{14,1086} = 41.98$, $P < 0.001$). Resting represented on average 0 – 11% of time spent on mudflats for remaining species (Table 25).

On average, spotted sandpipers spent 48% of their time engaged in locomotion, which was significantly greater than any other species ($F_{14,1086} = 13.67$, $P < 0.001$; Table 25). Locomotion comprised ≤26% of activity budgets for remaining species. Although the overall test was significant ($F_{14,1086} = 2.95$, $P < 0.001$), post-hoc Tukey's HSD test failed to detect differences among species in time spent engaged in body maintenance. Maintenance represented 16 – 20% of dunlin and greater and lesser yellowlegs activity budgets, and ≤8% in remaining species. Alert and antagonistic behaviors were rarely observed, representing ≤3% and ≤0.5% of activity budgets, respectively. Significant differences in time spent engaged in these activities were not detected among species ($F_{14,1086} \leq 0.82$, $P \geq 0.652$; Table 25).

Waterfowl.—Time spent by each waterfowl species differed among activities ($F_{6,49} \geq 5.24$, $P < 0.001$; Table 26). Moreover, excluding antagonistic and courtship behaviors, time spent in all remaining activities differed significantly among species ($F_{8,471} \geq 2.29$, $P \leq 0.021$). American green-winged teal, gadwalls, mallards, and northern shovelers spent significantly more time feeding than any other activity ($F_{6,140} \geq 18.62$, $P < 0.001$). Feeding comprised on average 19 – 38% of the time spent on mudflats for

remaining species (Table 26). Of the time spent foraging on mudflats, all six dabbling duck species compared were observed dabbling 95 – 100% of the time ($F_{2,39} \geq 296.61$, $P < 0.001$), whereas hooded mergansers acquired food by diving 78% of the time ($F_{2,123} = 73.26$, $P < 0.001$; Table 27).

Excluding American green-winged teal and blue-winged teal, all waterfowl species spent 30 – 58% of their time engaged in locomotion (Table 26). Hooded mergansers and wood ducks spent significantly more time in locomotion than any other activity ($F_{6,483} = 84.69$ and $F_{6,126} = 26.61$, $P < 0.001$, respectively). Blue-winged teal spent the majority (60%) of their time resting on mudflats ($F_{6,49} = 5.24$, $P < 0.001$), and this was significantly greater than all other species ($F_{8,471} = 9.75$, $P < 0.001$). Other than American black ducks and Canada geese (24 – 26%), all other waterfowl species spent less than 10% of their time resting on mudflats (Table 26).

Although the overall test was significant ($F_{8,471} = 2.29$, $P = 0.021$), post-hoc Tukey's HSD test failed to detect differences among species in time allocated to body maintenance (Table 26). Blue-winged teal, Canada geese and mallards spent 12 – 15% of their time engaged in maintenance activities, whereas this behavior represented $\leq$7% of activity budgets for remaining species. All waterfowl species, except Canada geese, were alert $\leq$1.5% of the time. Time spent alert by Canada geese (10%) was significantly greater than all other species, except gadwalls and mallards ($F_{8,471} = 5.75$, $P < 0.001$). Antagonistic behavior was rarely observed ($\leq$0.1%), and was only documented in American green-winged teal, hooded mergansers and mallards. Courtship behavior also occurred infrequently ($\leq$2%), and only in hooded mergansers and mallards (Table 26).

Other Waterbirds.—Time spent by other waterbird species differed among activities ($F_{5,30} \geq 2.91$, $P \leq 0.029$; Table 28). Excluding antagonistic behavior, time spent engaged in all activities differed significantly among species ($F_{10,764} \geq 3.88$, $P < 0.001$). Overall, resting and locomotion were the most common activities observed in other waterbirds. Sandhill cranes and great blue and green herons (*Butorides virescens*) spent significantly more time resting than any other activity ($F_{5,174} \geq 9.73$, $P < 0.001$). Resting was observed on average 31 – 82% of the time in all species, except double-crested cormorants, little blue herons and pied-billed grebes. Time spent engaged in locomotion by double-crested cormorants, little blue herons, and pied-billed grebes was significantly greater than any other activity ($F_{5,96} \geq 8.10$, $P < 0.001$). Additionally, great egrets and ring-billed gulls spent more time feeding and engaged in locomotion than any other activity ($F_{5,780} \geq 34.99$, $P < 0.001$; Table 28).

Time spent engaged in body maintenance was highly variable among other waterbird species (Table 28). American white pelicans and Bonaparte's gulls spent 35 – 38% of their time in body maintenance, whereas all other species spent 0 – 19%. Feeding was observed in all other waterbird species, except American white pelicans and green herons. Time spent feeding by double-crested cormorants, little blue herons and pied-billed grebes was significantly greater than American white pelicans, Bonaparte's gulls, great blue herons and green herons ($F_{10,764} = 9.57$, $P < 0.001$). Alert behavior was rarely observed (0 – 2%) in most species, but great blue herons, great egrets and sandhill cranes were alert on average 8 – 18% of the time. Although the overall test was significant ($F_{10,764} = 3.38$, $P < 0.001$), Tukey's HSD test did not detect differences among species in

time spent alert. Antagonistic behavior was observed only in great blue herons and ring-billed gulls (Table 28).

Discussion

Results of my study suggest that mudflats exposed during reservoir drawdowns in the east TRV provide important foraging and resting habitat for migrating and wintering waterbirds. Long- and intermediate-distance migrant shorebirds spent more time feeding and less time resting on mudflats than short-distance migrants. Waterfowl typically used TRV mudflats for feeding, and their primary foraging tactic was dabbling in shallow water near the mudflat-water interface. Reservoir drawdowns appear to attract a diverse assemblage of waterbirds that utilize exposed mudflats for a variety of purposes. In the following section, a discussion of differences in time allocated to activities is discussed, and possible mechanisms driving activity budgets on mudflats is provided.

Shorebirds

Feeding was the most common activity (42 – 99.5%) observed in 12 of 15 shorebird species using mudflats in the east TRV. Elliot-Smith (2003) also reported a high occurrence of feeding (78%) among six species using reservoir mudflats in Illinois. During fall, shorebird activities are influenced by energetic demands associated with migration to wintering sites (O'Reilly and Wingfield 1995, DeLeon and Smith 1999). Food acquisition also was the most common activity (46 - 80%) observed during fall migration at interior stopovers in the Great Plains (Wishart and Sealy 1980, Davis and Smith 1998*b*, DeLeon and Smith 1999, Kostecke and Smith 2003, Andrei et al. 2007).

Thus, TRV mudflats likely function similar to mudflats in depressional wetlands, and serve as important stopover sites for migrating shorebirds to acquire food resources. Other studies of interior mudflat wetlands occurring within river systems have made similar conclusions (e.g., Taylor et al. 1993, Elliot-Smith 2003).

Shorebirds migrating longer distances spent more time feeding (75 – 80%) on TRV mudflats than short-distance migrants (37%). In contrast, resting was less frequent (8 – 9%) among intermediate- and long-distance migrants compared to those migrating shorter distances (45%). The same trend was observed in shorebirds using other interior stopovers (Davis and Smith 1998*b*, DeLeon and Smith 1999, Elliot-Smith 2003, Andrei et al. 2007). Excluding Elliot-Smith (2003), all previous studies were based on comparisons of various long-distance migrants with American avocets – a large-bodied, short-distance migrant (Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). The large body size of American avocets, however, may have confounded previous inferences on migration distance. Using average body lengths from O'Brien et al. (2006) as an index of body size (Skagen and Knopf 1993), American avocets averaged 254% larger than all of the longer-distance migrant species they were compared to in previous Great Plains studies (Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). I used killdeer and Wilson's snipe as short-distance migrants in my comparisons, which are more comparable in size to most long- and intermediate-distance migrants. Killdeer and Wilson's snipe averaged 98 and 124% larger, respectively, than the long- and intermediate-distance migrants used in my study, except for greater yellowlegs which are actually a fraction larger than killdeer and snipe. In Illinois, killdeer spent considerably less time foraging (63%) than one long-distance (82%) and

four intermediate-distance migrants (78 – 90%; Elliot-Smith 2003). Thus, my results and Elliot-Smith (2003) support the hypothesis that longer-distance migrants have greater energetic requirements during migration.

Killdeer spent less time feeding (26%) and more time resting (54%) than all other species observed (≥42% and ≤29%, respectively) except American golden-plovers, although sample size was small (n = 4) for this species. In Illinois, feeding was more common in killdeer (63%), but less frequent than in all other species observed (≥78%; Elliot-Smith 2003). Interestingly, Elliot-Smith (2003) reported that sleeping, which was included in the resting category for my study, was not observed in killdeer in Illinois. Alert behavior also was more common (24%) in Illinois than in the TRV (<1%). Potentially greater time spent resting or sleeping in the TRV may be related to whether birds were migrating or wintering. Given that Tennessee is positioned farther south than Illinois, killdeer in Tennessee may have less energetic demands, because continued migration is less likely. This hypothesis also may explain why feeding rates were higher in Illinois for killdeer.

Wilson's snipe are considered short-distance migrants but were observed feeding more often (66%) than five shorebird species classified as intermediate- or long-distance migrants (≤64%). This species may have greater energetic requirements than other short-distance migrants, because they migrate further distances each year. For instance, killdeer and American avocets migrate approximately 2,100 – 3,400 km between breeding and wintering areas, whereas snipe migrate 3,900 km on average (Skagen and Knopf 1993; Table 23). In addition, killdeer and American avocets occur in their respective regions (e.g., TRV and Great Plains) as residents and migrants (Fowler 1983,

DeCecco and Cooper 1996, Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). In contrast, Wilson's snipe exist in the TRV only as migrants (DeCecco and Cooper 1996). Thus, this species may spend more time feeding than other short-distance migrants, because they have greater energy expenditures associated with possibly longer migration.

Pectoral sandpipers spent more time (85%) foraging on TRV mudflats than most other shorebird species. Elliot-Smith (2003) also reported that pectoral sandpipers fed frequently (82%) on reservoir mudflats in Illinois. This also may be a consequence of greater energy expenditure from flying longer distances. Each fall, pectoral sandpipers migrate approximately 16,500 km from their arctic breeding grounds to wintering areas in South America (Skagen and Knopf 1993; Table 23). This distance is 11 – 485% greater than that traversed by the 14 remaining shorebird species that were included in my activity budget analyses.

Body size also may contribute to species-specific differences in time spent foraging (Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). Three of the five species that spent the greatest amount of time to feeding (i.e., least, semipalmated and western sandpipers) are considered small-bodied (Skagen and Knopf 1993; Table 23). Small-bodied sandpipers lose heat at a greater rate and have higher metabolic rates than larger-bodied shorebirds (Pienkowski and Evans 1984, Gill 2006). These physiological demands may drive the need for smaller shorebirds to acquire food resources more often (Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). Body size very likely interacts with migration distance, as most small-bodied shorebirds tend to migrate farther distances than larger species (Skagen and Knopf 1993).

In the TRV, time spent foraging by least and semipalmated sandpipers (82 – 86%) was comparable to that reported by Elliot-Smith (2003) on reservoir mudflats in Illinois (90%). Western sandpipers also fed frequently (99.5%) on TRV mudflats, although sample size was relatively small (n = 7). In the Great Plains, these three species were observed feeding less often during fall migration. On mudflats in depressional wetlands, least, semipalmated and western sandpipers spent roughly 62 – 73%, 70 – 78%, and 63 – 82% of their time foraging, respectively (Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). It is hypothesized that food densities and the availability and connectivity of stopovers sites can impact foraging rates, especially in small-bodied shorebirds (Davis et al. 2005). These factors may partly explain why small-bodied sandpipers fed more often in the TRV compared to the Great Plains. A discussion of each of these possible mechanisms follows.

Shorebirds occurring in habitats with lower invertebrate densities spend more time foraging to acquire adequate food resources (Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). I quantified invertebrate abundance on TRV mudflats (Chapter II), but currently these analyses are ongoing so the availability of invertebrates at my study sites is unknown. When completed, invertebrate abundance on TRV mudflats will be compared with other regions to help explain differences in activity budgets. Previous estimates of invertebrate biomass on reservoir mudflats in Illinois (2.40 g/m^2; Elliot-Smith 2003) were comparable to those reported on mudflats associated with depressional wetlands in the Great Plains (e.g., 1.21 g/m^2 [playa lakes], 0.79 g/m^2 [saline lakes], 2.68 – 6.26 g/m^2 [Cheyenne Bottoms]; Helmers 1991, Davis and Smith 1998*a*, Andrei 2005). However, Elliot-Smith (2003) suggested that invertebrate prey size

may be smaller on reservoir mudflats compared to depressional wetlands. If this is true, consumption of smaller prey items on reservoir mudflats may require shorebirds to spend more time foraging. Beauchamp (2006) reported that pecking rates of semipalmated sandpipers increased in response to declining prey size.

Small-bodied sandpipers may have had greater energetic demands while migrating through the TRV, because of longer distances between suitable stopovers compared to the Great Plains. Beeri and Phillips (2007) reported wetland densities as high as 7.6 basins/km^2 in portions of the Prairie Pothole Region. Similarly, some regions of the Southern High Plains have as many as 0.4 wetlands/km^2 (Haukos and Smith 1994). Although dependent on precipitation and evapotranspiration patterns, the relatively high density of potential stopovers within the Great Plains results in a high availability of mudflats for shorebirds during migration (Skagen and Knopf 1994*a*). Greater wetland densities also facilitate shorter flights between stopover sites. Farmer and Parent (1997) estimated that in a typical year suitable stopover sites exist at least every 10 km throughout the Great Plains.

In contrast, the mountainous terrain traversed by shorebirds migrating through the Appalachian Region restricts them to relatively fewer stopover habitats occurring within river valleys and reservoirs (e.g., Chapter II, Freed 1982-83, Fowler 1983, Slack 1986). Moreover, not all rivers or reservoirs have suitable mudflats in this region (Smith 2006), because the floodplain gradient often is steep (TVA 1942, 1949). In fact, only 9 of the 49 reservoirs occurring in the TRV are thought to provide stopover habitat for shorebirds (Smith 2006). Using digital orthophotography, Smith (2006) estimated 93 potential stopovers throughout in the entire TRV. This equates to less than 0.001 potential

stopovers/km^2, which represents only a fraction of the stopover densities occurring in the Great Plains. Further, mudflats in the TRV are not always available because exposure is controlled by reservoir drawdowns (Chapter II, Smith 2006), which may not occur until later in the fall due to a delay in drawdown to accommodate late-summer recreational use (Cordell and Bergstrom 1993, Ungate 1996, Jakus et al. 2000). Farmer and Parent (1997) documented that pectoral sandpipers moved less frequently among wetlands and foraged more often on mudflats separated by greater distances. Thus, it seems likely that small-bodied shorebirds fed more frequently on TRV mudflats compared to Great Plains depressional wetlands due to their lower availability on the landscape. Differences in mudflat quality (as indexed by aquatic invertebrate density) remain to be determined.

Maintenance activities were infrequent (≤8%) among most shorebird species in the TRV except dunlin and greater and lesser yellowlegs (16 – 20%). This behavior typically constitutes <10% of shorebird activity budgets during fall migration (e.g., Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). Similarly, time spent engaged in antagonistic and alert behaviors comprised <3% of shorebird activity budgets in the TRV. These activities also were uncommon at other interior stopovers (Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007), and this further emphasizes the importance of mudflats as foraging sites for migrant shorebirds.

Waterfowl

The most common activities observed in waterfowl using TRV mudflats were feeding (41%) and locomotion (34%). In a review of waterfowl behavioral studies, Paulus (1988) reported that feeding and resting were the most common behaviors

observed in migrating and wintering waterfowl. In other mudflat wetlands, feeding and resting also have been reported as the predominant activities of waterfowl (Rave and Baldassarre 1989, White 1994). Differences between my study and others may be a consequence of sampling time. My surveys were completed before 5 hours after sunrise. In comparison, several of the studies reviewed by Paulus (1988) recorded activities throughout the day. Resting is typically more common during midday, whereas locomotion and feeding occur more often during early morning (Quinlan and Baldassarre 1984, Gaston and Nasci 1989, Rave and Baldassarre 1989).

Locomotive behavior may have been observed more frequently on TRV mudflats in dabbling ducks due to foraging tactic. All dabbling duck species were observed surface-feeding (i.e., dabbling and head-dipping) more often (≥95%) than tipping-up or diving. Johnson and Rohwer (2000) reported that surface-feeding was the most common feeding tactic in American green-winged teal (98%) and mallards (94%) foraging on tidal mudflats in Louisiana. Ducks that surface feed in shallow water frequently wade and swim (Poysa 1983, Nudds and Bowlby 1984) – activities categorized as locomotive movements.

Another explanation for greater locomotion on TRV mudflats may be differences in food resource densities. In general, waterfowl are opportunistic foragers and exploit the most locally abundant food resource (Fredrickson and Drobney 1979, Poysa 1983). Seeds and aquatic invertebrates are frequently consumed by migrating and wintering waterfowl (e.g., Gruenhagen and Fredrickson 1990, Anderson et al. 2000). On tidal mudflats, Gaston (1992) reported a high occurrence of aquatic invertebrates in American green-winged teal diets, but moist-soil seeds also were consumed. Estimates of aquatic

invertebrate production on TRV mudflats are currently unknown, but Mitchell and Grubaugh (2005) reported densities ranging from 300 – 433,000/m^2 on mudflats in the Mississippi Alluvial Valley. The overall average belowground biomass of moist-soil seeds in east TRV mudflats was 44.1 kg/ha (SE = 1.8; Chapter II). This density is below the food-density threshold (50 kg/ha) when waterfowl are believed to abandon foraging sites (Reinecke et al. 1989, Rutka 2004). In the Mississippi Alluvial Valley, seed biomass averaged 496 kg/ha across all moist-soil wetlands sampled by Kross et al. (2008). Thus, low seed biomass on TRV mudflats may partly explain why waterfowl were engaged in locomotion more often than in other studies (e.g., Turnbull and Baldassarre 1987, Rave and Baldassarre 1989). Aquatic invertebrates may be the primary food item that waterfowl are acquiring on east TRV mudflats, which has been suggested in previous studies in other mudflat wetlands (Rave and Baldassarre 1989, Johnson and Rohwer 2000). Planned comparisons of aquatic invertebrate biomass between TRV mudflats and those occurring in other regions will provide evidence of whether there is support for this hypothesis. Research on food-item selection by waterfowl on TRV mudflats is needed.

American green-winged teal spent more time feeding on TRV mudflats than any other species. Time spent foraging by this species (68%) was identical to that reported on tidal mudflats in Louisiana (Johnson and Rohwer 2000). Johnson and Rohwer (2000) suggested that this species may spend more time feeding compared to other species, because they have that higher metabolic rates and select smaller prey items. In Southern High Plains depressional wetlands, green-winged teal spent considerably less time foraging on mudflats (10 – 23%) than in the TRV (Quinlan and Baldassarre 1984). This

may be due to less coverage of agricultural fields in east Tennessee compared to the Southern High Plains. Gray (2002) reported that playa wetlands in the Southern High Plains are surrounded by >75% row-crop agriculture. In comparison, harvested cropland covers 13% of the landscape in the counties surrounding my east TRV study sites (U.S. Department of Agriculture 2004). Quinlan and Baldassarre (1984) reported that green-winged teal using mudflats in playa lakes also relied on high-energy foods acquired from nearby agricultural fields. Thus, green-winged teal may have spent more time foraging on TRV mudflats, because fewer opportunities existed to acquire agricultural grain from the surrounding landscape.

Feeding also was commonly observed in mallards (47%) and northern shovelers (60%) using TRV mudflats. Mallards spent slightly less time foraging (35%) on tidal mudflats in Louisiana (Johnson and Rohwer 2000). Similarly, northern shovelers spent only 38 – 51% of their time feeding while wintering in Mexico (Thompson and Baldassarre 1991). One explanation for the difference between my results and these studies may be greater thermoregulatory costs at higher latitudes. Waterfowl exposed to colder temperatures have greater heat loss, which often results in increased amount of time spent foraging (Bennett and Bolen 1978). For example, mallards wintering in Nebraska spent 78% of their time foraging during a severe winter and only 52% during a mild winter (Jorde et al. 1983). Another explanation could be differences in seed and aquatic invertebrate densities, although these were not quantified by Thompson and Baldassarre (1991) nor Johnson and Rohwer (2000), thus comparisons with TRV mudflats cannot be made.

Gadwalls spent the majority (55%) of their time foraging on TRV mudflats, but comparatively less than on a reservoir in Alabama (up to 95%; Benedict and Hepp 2000) and in Louisiana coastal marshes (64 - 77%; Paulus 1984, Gaston and Nasci 1989). Higher foraging rates in Alabama and Louisiana may be related to differences in diet composition and food quality. Aquatic plants (e.g., algae [various genera], dwarf spikerush [*Eleocharis parvula*], and Eurasian watermilfoil [*Myriophyllum spicatum*]) comprised 95 – 99% of gadwall diets while wintering in Alabama and Louisiana (Paulus 1982, McKnight and Hepp 1998). However, these plants rarely establish in TRV reservoirs due to the high turbidity and water level fluctuations associated with drawdowns and reflooding events (Wiebe 1946). Thus, gadwalls probably consumed moist-soil seeds and aquatic invertebrates on TRV mudflats. These food items have higher energy than aquatic plants (Baldassarre and Bolen 2006). Paulus (1982) hypothesized that gadwalls may spend more time foraging on aquatic plants because of their lower nutritional value.

Gadwalls spent considerably more time engaged in locomotion (31%) on TRV mudflats compared to those using habitats with aquatic plants (11 – 14%; Paulus 1984, Gaston and Nasci 1989). As mentioned earlier, this may be related to the high occurrence of dabbling in shallow water. Aquatic vegetation also may impede gadwall movements while foraging (Paulus 1982). For example, gadwalls in densely vegetated plots dominated by Eurasian watermilfoil spent less time swimming ($\leq$0.6%) than those observed in less dense plots comprised of native aquatic plants (1 – 51%; Paulus 1982).

In the east TRV, locomotion (37%), feeding (31%), and resting (24%) were the most common activities of American black ducks. This species spent a similar amount of

time foraging (37%) on mudflats within Tennessee National Wildlife Refuge (NWR) in the west TRV, but rested more (36%) and was engaged in locomotion less often (6%; White 1994). Although food densities on east and west TRV mudflats remain unknown, locomotion may have been more prevalent on east TRV mudflats because food densities were lower, requiring black ducks to more actively search for food. Another possibility is that black ducks in the west TRV may have already met most of their energetic demands by foraging in adjacent moist-soil wetlands on Tennessee NWR. Tennessee NWR impoundments are intensively managed for waterfowl and hunting is not allowed, thereby providing habitat with minimal disturbance and potentially higher food density than mudflats (White 1994). Few intensively managed moist-soil wetlands existed near my east TRV study sites, thus black ducks and other waterfowl may rely more heavily on food resources provided on mudflats in the east TRV. White (1994) compared black duck activity patterns among different habitat types on the refuge and found that feeding was more common in moist-soil impoundments (54%). Thus, west TRV mudflats in Tennessee NWR may serve primarily as loafing or resting areas for waterfowl.

Compared to most dabbling duck species, wood ducks spent less time feeding (38%) and more time engaged in locomotion (56%) on TRV mudflats. Feeding may have been less frequent by wood ducks because they typically prefer forested wetlands as foraging sites (Thompson and Baldassarre 1988). Drobney and Frederickson (1979) reported that wood ducks spent 34 – 73% of their time foraging in forested wetlands. Wood ducks primarily consume acorns and other tree seeds during winter (Delnicki and Reinecke 1986). However, these foods were extremely scarce ($\bar{x}$ = 3.2 kg/ha, Chapter

II) on TRV mudflats. In general, mudflats probably do not provide ideal foraging habitat for wood ducks.

Hooded mergansers spent less time foraging (28%) on TRV mudflats compared to forested wetlands (45%; Dugger et al. 1994). Similar to wood ducks, differences may have been related to food preference and availability. Previous studies suggest that fish and crayfish are the primary foods consumed by hooded mergansers (e.g., Salyer and Lagler 1940). Although densities of fish and crawfish were not quantified on TRV mudflats, these foods probably were less abundant than in forested wetlands, because shallowly flooded areas associated with mudflats provide very little cover. Fish and crayfish are often more abundant in areas with abundant cover and slow-moving water (Pratt and Smokorowski 2003, Jowett et al. 2008). Forested wetlands are considered the primary foraging sites of hooded mergansers (Dugger et al. 1994).

Canada geese spent the majority of their time engaged in locomotion (30%) and resting (26%) on mudflats. Reservoir mudflats provide roosting (night) and loafing (day) habitat for Canada geese (Raveling 1969*a*). During the early fall and winter, resting was the primary activity (40 – 75%) of Canada geese observed using wetlands in Illinois and Wisconsin (Gates et al. 2001). Gates et al. (2001) also reported that locomotion comprised ≤10% of Canada goose activity budgets. This behavior may have been more prevalent in the TRV, because my sampling occurred during the morning, whereas Gates et al. (2001) sampled throughout the day. Waterfowl tend to feed more often in the morning (e.g., Jorde et al. 1984, Quinlan and Baldassarre 1984). Canada geese browse vegetation on mudflats (Rundle and Fredrickson 1981), and often walk while foraging. Thus, a higher locomotion rate on TRV mudflats may be associated with foraging

activities, which my personal observations confirm. Departure flights from mudflats also are common in morning, especially when agricultural fields containing waste grain are nearby (Raveling 1969*a*).

Canada geese spent 22% of their time feeding on TRV mudflats. In other wetland types, the occurrence of feeding is highly variable (5 – 40%, Gates et al. 2001). Geese are known to browse vegetation on mudflats (Rundle and Fredrickson 1981). In Chapter II, I documented 28 species of plants occurring on east TRV mudflats, including *Echinochloa*, *Eleocharis*, and *Polygonum* spp., which are readily consumed by Canada geese (McKenzie 1987). However, the timing of drawdown influences the availability of vegetation browse on TRV mudflats for Canada geese. Aboveground standing crop of vegetation on Douglas Reservoir mudflats that were initially exposed during August averaged 162.5 – 164.7 g/m^2, whereas mudflats at Chickamauga Reservoir (initially exposed in October) produced only 0 – 0.1 g/m^2. Thus, TRV mudflats provide important food resources for Canada geese if they are exposed early enough in the growing season to facilitate propagule germination and vegetation growth. Canada geese are also known to feed in harvested agricultural fields (Craven and Hunt 1984, Gawlik and Slack 1996). However, this food resource typically is not available until November when most agricultural fields are harvested in Tennessee (M. Foster, University of Tennessee, unpublished data). Further, agricultural grains disappear rapidly (<3 months post-harvest) in Tennessee (M. Foster, University of Tennessee, unpublished data), thus availability of natural vegetation browse on TRV mudflats may be especially important for Canada geese.

Alert behavior was rarely observed (≤1%) in most waterfowl species, suggesting that disturbance (e.g., predators, hunting pressure) was minimal on east TRV mudflats. This behavior also was infrequently observed (≤3%) in waterfowl using mudflats in other regions (Quinlan and Baldassarre 1984, Rave and Baldassarre 1989, White 1994). The exception was Canada geese, which were alert 10% of the time. Previous studies reported similar occurrence (11 – 12%) of alert behavior in Canada geese during fall and winter (Gawlik and Slack 1996, Gates et al. 2001). This species may have been alert more frequently than other waterfowl because of extended parental behavior. Unlike dabbling ducks, geese remain in family groups during the nonbreeding season (Raveling 1969*b*), and adults exhibit alert behavior in protecting goslings from predators and during conspecific antagonistic interactions (Lazarus and Inglis 1978, Randler 2003). In Illinois and Wisconsin, adult Canada geese were alert up to 35% of the time during the fall (Caithamer et al. 1996).

Other Waterbirds

The variability in activity budgets among the remaining species of coexisting waterbirds indicates that multiple functions are provided by TRV mudflats. In the TRV, sandhill cranes were observed resting 44% of the time. The high occurrence of resting suggests that TRV mudflats served as roosting and loafing sites for sandhill cranes. Sandhill cranes rested 57 – 100% of the time on sandbars in the Platte River (Nebraska) used for roosting (Norling et al. 1991). Sparsely vegetated mudflats with adjacent shallowly flooded areas are considered ideal roost sites for sandhill cranes (Lovvorn and Kirkpatrick 1981). In Chapter II, I documented that mudflats in Chickamauga Reservoir

were largely void of vegetation (98 – 99% bare ground), and were surrounded by relatively shallow water (5 – 18 cm depths). All sandhill cranes (n = 2,532) were observed using mudflats in this reservoir. High use of these mudflats likely was associated with a large staging and wintering population (ca. 14,000 birds) at Hiwassee Wildlife Refuge (W. Akins, Tennessee Wildlife Resources Agency, unpublished data). I documented over 2,500 sandhill cranes using TRV mudflats near Hiwassee Refuge during my two-year study. Lovvorn and Kirkpatrick (1981) acknowledged the importance of roosting sites in Chickamauga Reservoir for migrating sandhill cranes in the eastern United States.

In the TRV, both gull species spent a considerable amount of time resting (38 – 52%) and engaged in maintenance activities (18 – 25%). Thus, TRV mudflats likely served as roosting or loafing habitat for gulls also. This finding agrees with previous studies (Burger and Staine 1993, Darnell and Smith 2004), although Burger (1988) reported that mudflats also are foraging sites for gulls. Foraging was infrequent (0.5 – 5.5%) in gulls using TRV mudflats, but I believe these habitats still provided important food resources for gulls. Scavenging is the primary tactic of food acquisition in ring-billed gulls (Burger 1988). This species was commonly engaged in locomotion (37%) on TRV mudflats, likely in search of invertebrates and other potential food items. Locomotion occurred less frequently (13%) in Bonaparte's gulls; however, this species forages almost exclusively from the air (Burger 1988). Bonaparte's gulls likely foraged in open water areas adjacent to mudflats, but this activity was not documented, because flying individuals were not randomly selected for focal observations.

Little blue herons spent more time feeding (20%) than the other wading birds (0 – 8%; great blue herons, great egrets and green herons) observed on TRV mudflats. In contrast, this species fed the least (2%) among the same four species of wading birds (4 – 12%) in Louisiana coastal marshes (DuBowy 1996). However, DuBowy (1996) speculated that little blue herons may have been foraging in adjacent forested wetlands. In the TRV, little blue herons may have fed more than the other wading birds because of differences in diet. Fish are typically the main prey item consumed by all four wading species that I documented, but little blue herons tend to feed on smaller-sized fish and aquatic insects (Niethammer and Kaiser 1983, Smith 1997). When prey items are of similar composition (e.g., fish), smaller prey contain less total energy than larger prey items (e.g., Nudds and Bowlby 1984). Thus, consumption of smaller prey may have lead to increased foraging time.

Previous studies documented a negative correlation between time spent feeding and wading bird body size (e.g., Ntiamoa-Baidu et al. 1998). All wading bird species observed in the TRV fit this trend, except for green herons, which were not documented feeding during focal sampling. In order of increasing body size, green herons, little blue herons, great egrets and great blue herons spent 0, 20, 8, and 1% of their time foraging, respectively. Green herons may not have been documented feeding because only 12 individuals were observed. However, DuBowy (1996) reported that green herons fed less frequently (5%) than expected in Louisiana coastal marshes. Green herons often feed from perches (Robinson 1994, DuBowy 1996), and may have foraged in forested wetlands adjacent to TRV mudflats.

In the TRV, locomotion was the most common activity (64%) of little blue herons, whereas resting comprised the majority (63 – 82%) of great blue heron and green heron activity budgets. In contrast, great egrets spent roughly equal amounts of time engaged in locomotion (37%) and resting (31%). These differences in wading bird activity budgets may have been associated with species-specific differences in foraging tactics. Kushlan (1976) reported that little blue herons actively pursued prey 95% of the time, whereas great blue herons were "stand-and-wait" predators. These behaviors correspond to the prevalence of locomotion (64%) and resting (63%) observed in little blue herons and great blue herons, respectively. In contrast, great egrets commonly use both foraging techniques (Kushlan 1976), which may account for the moderate occurrence (31- 37%) of both activities on TRV mudflats.

In general, wading birds observed on TRV mudflats were engaged in locomotion more often and rested less frequently than those using coastal marshes in Louisiana. Great egrets observed in Louisiana rested 80% of the time but locomotion was rarely observed (1%; DuBowy 1996). In the TRV, resting and locomotion comprised 31% and 37% of great egret activity budgets, respectively. Time allocated to resting and locomotion may have been related to differences in habitat type and prey availability. In terms of vegetation structure, the marshes surveyed by DuBowy (1996) were quite different than the mudflats I surveyed in the TRV. All observations of wading birds in Louisiana marshes occurred within "two predominant vegetation zones" (DuBowy 1996:342). In contrast, Chickamauga mudflats were completely void of vegetation (98 – 100% bareground) and Douglas mudflats were only 18 – 43% vegetated during August and September, when 87% of the wading birds were observed at that reservoir (Chapter

II). In addition, most wading birds were observed near mudflat-water interface or in the flooded zone (J. Laux, personal observation), which was completely unvegetated. Papakostas et al. (2005) documented lower rates of locomotion in squacco herons (*Ardeola ralloides*) foraging in highly vegetated areas compared to sparsely vegetated canal banks. Many fish species congregate near emergent and aquatic vegetation (e.g., Werner et al. 1983), thus providing opportune scenarios for sit-and-wait foraging tactics. In contrast, shallowly flooded mudflats provide little cover for fish (Pratt and Smokorowski 2003) or for predator concealment, and may have necessitated active pursuit of prey, thus increased locomotion.

In the TRV, double-crested cormorants, pied-billed grebes and American coots spent the majority of their time engaged in locomotion (53 – 65%). Locomotion may have been associated with foraging behavior because all three species commonly swim while searching for food (Ryan and Dinsmore 1979, Forbes and Ankney 1987, King et al. 1995). However, feeding was less frequent (5%) in American coots than in the two other species (19 – 21%). American coots may have fed less, because of low availability of vegetation on TRV mudflats (Chapter II). Plant material constitutes >90% of American coot diets (Eley and Harris 1976, Ivey 1987). Feeding was more common (49 – 69%) by American coots in prairie wetlands that contained aquatic plants (Ryan and Dinsmore 1979). The high occurrence of resting (37%) for American coots suggests that TRV mudflats may have served as loafing sites more so than foraging sites for this species. In contrast, pied-billed grebes and double-crested cormorants commonly consume aquatic invertebrates and fish, respectively (Forbes and Ankney 1987, Fenech et al. 2004). The availability of these food items for avian predators typically increases during reservoir

drawdowns as prey becomes concentrated (Kushlan 1976, Fredrickson 1991). Sprandel et al. (2002) reported that capture rates of year-0 fish by waterbirds were 2.4X greater following the fall drawdown of Lake Talquin in Florida. Thus, TRV mudflats may provide better foraging opportunities for predatory waterbirds compared to exclusively herbivorous waterbirds, with the exception of Canada geese that browse emergent vegetation shoots.

Conclusions and Conservation Implications

The high prevalence of feeding activities on TRV mudflats suggest they are important foraging sites for migrating and wintering waterbirds. Interior mudflats associated with river systems may be as or more important than mudflats associated with interior depressional wetlands, because the coverage of reservoir mudflats is less, especially in the TRV. The importance of reservoir mudflats for migrating shorebirds has been acknowledged in Pennsylvania, Illinois, Alabama, Georgia, Tennessee, and many portions of the Intermountain West (Ortego et al. 1979, Freed 1982-83, Fowler 1983, Taylor et al. 1993, Shuford et al. 2002, Strauss et al. 2002, Elliot-Smith 2003). Nevertheless, mudflats associated with impounded river systems historically have not been identified as important stopover sites for shorebird conservation (Brown et al. 2001). My results from Chapters II and III provide evidence that a diverse shorebird community uses TRV mudflats to acquire food resources and meet other important life cycle needs. Therefore, I recommend that mudflats in the Tennessee River Valley be added to the Western Hemisphere Shorebird Reserve Network as a "Landscape Site of Regional Importance."

My results also support previous conclusions that small-bodied shorebird species that migrate longer distances spent more time foraging than large-bodied shorebirds that migrate shorter distances, perhaps due to greater energetic requirements (Davis and Smith 1998*b*, DeLeon and Smith 1999, Andrei et al. 2007). Long-distance migrant species of high conservation concern that I documented foraging on TRV mudflats included American golden-plovers, sanderlings, short-billed dowitchers, and buff-breasted (*Tryngites subruficollis*), solitary and western sandpipers (Brown et al. 2001). In Chapter II, I reported that these and other intermediate- and long-distance migrant shorebirds use TRV mudflats from late July through September. Studies of shorebirds using interior mudflats in the mid-latitudinal United States also have reported greatest use during August and September (Reid et al. 1983, Short 1999, Elliot-Smith 2003). Short-distance migratory shorebirds (e.g., killdeer and Wilson's snipe) tend to use TRV mudflats from October – January, and some undoubtedly overwinter in Tennessee (Chapter II). The availability of mudflats in the TRV is determined by reservoir drawdown date, which is controlled by the Tennessee Valley Authority (Smith 2006). In Chapter II, I provided a conceptual drawdown schematic, where TRV mudflats are exposed sequentially and continuously from late July through November. Providing newly-exposed mudflats through this duration will ensure that food resources are available for short- and long-distance migratory shorebirds. I encourage Tennessee Valley Authority to consider scheduling reservoir drawdowns so they provide mudflat habitat for shorebirds and other waterbirds throughout migration, while complimenting the needs for hydropower generation, flood control, navigation and water recreation. Providing mudflats in the TRV from late July – November will provide stopover habitat for at least 25 shorebird

species (Chapter II; D. Wirwa, University of Tennessee, unpublished data), which represents 50% of the species that breed in North America (Brown et al. 2001). Of the species that D. Wirwa (University of Tennessee, unpublished data) and I documented, approximately 88% have shown evidence of decline in at least one region of North America (Howe et al. 1989, Morrison et al. 1994, Brown et al. 2001, Bart et al. 2007).

Additionally, D. Wirwa (University of Tennessee, unpublished data) and I provided evidence that 22 waterfowl species use TRV mudflats to acquire food resources (Chapter II). Waterfowl also frequently used TRV mudflats for resting and roosting. Previous studies (e.g., Wiebe 1946, Morse and Steenis 1948, Steenis 1950, White 1994) suggested that TRV mudflats provided little benefit to waterfowl compared to other habitats. Although I did not compare use on mudflats with other wetland types or agricultural habitats, my results suggest that TRV mudflats are utilized by waterfowl. More research is needed comparing waterfowl use of TRV mudflats with other habitat types. I hypothesize that use of mudflats by waterfowl would decline as coverage of other wetland types (e.g., moist-soil wetlands) and cropland agriculture increase, because these latter habitats usually have higher food densities (Fredrickson and Taylor 1982, Baldassarre and Bolen 2006). Given that wetlands and row-crop agriculture have low coverage in the east TRV, mudflats along the Tennessee River and its tributaries likely are the primary habitat used by migrating and wintering waterfowl in the region.

My study did not focus on the types of food items that waterfowl are consuming on mudflats, but undoubtedly ducks are acquiring seed and aquatic invertebrates. Geese that were foraging on mudflats were browsing recently germinated herbaceous plants (J. Laux, personal observation). Thus, it is important that portions of mudflats are exposed

early enough in the growing season to facilitate moist-soil plant establishment. Given that it takes approximately 70 days for most moist-soil plants to reach maturity and produce seed (Ahn et al. 2006), and on average the growing season in the TRV ends in early November (Natural Resources Conservation Service 2001), I recommend that higher elevations of mudflats be exposed no later than September to encourage plant establishment and seed production for waterfowl. If mudflats reflood during rain events, ducks will utilize available seed resources, which occurred in fall 2007 at Kentucky Reservoir (D. Wirwa, University of Tennessee, unpublished data). Otherwise, it is reasonable to assume that seeds from mature moist-soil plants will become incorporated in the seed bank, and be available for waterfowl during drawdown the following year (Chapter II). Seed production on mudflats also helps ensure that seeds are available for germination and production of browse for geese in subsequent years. The late July – November drawdown schedule that I outlined in Chapter II and above for shorebirds will meet these needs of waterfowl as well. Lastly, other waterbirds (e.g., gulls, herons, egrets) will utilize mudflats as they become exposed or water levels reach species-specific optimal foraging depths.

During my study, I documented 68 species of birds using east TRV mudflats from late July through January; most of these were waterbirds (59 species). Mudflats in the TRV are unique wetlands and provide important habitat for a diversity of resident, migratory and wintering waterbird species. I encourage that TRV mudflats are incorporated into conservation and management plans for waterbirds, and that the Tennessee Valley Authority make efforts to ensure their availability for these birds during migration and winter.

CHAPTER IV

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

My study provided evidence that mudflats exposed during reservoir drawdowns in the east Tennessee River Valley (TRV) provide migratory stopover and wintering habitat for at least 68 waterbird species, including 22 shorebird and 18 waterfowl species (Chapter II). Foraging, resting and locomotion were the most common waterbird activities, which suggests that east TRV mudflats function primarily as foraging and resting habitat for waterbirds (Chapter III). In the following paragraphs, I provide a summary of my results, conclusions, and management recommendations from Chapters II and III.

Total shorebird abundance on mudflats in Chickamauga Reservoir was two times greater than in Douglas Reservoir, and the shorebird community was primarily composed of short-distance migrants that overwinter in Tennessee (Chapter II). In contrast, total shorebird richness (i.e., number of species) on Douglas mudflats was two times greater than on Chickamauga mudflats, and most species observed were longer-distance migrants. Shorebirds responded opportunistically to the availability of newly exposed mudflats in both reservoirs, regardless of drawdown date, with a trend that shorebird abundance and richness were greater at Douglas Reservoir during August and September but greater at Chickamauga Reservoir from October – January. Nearly all other waterbird guilds followed this trend (Chapter II).

Mean acreage exposed per mudflat in Douglas Reservoir was greater than in Chickamauga Reservoir from August – October but similar between reservoirs from

November – January (Chapter II). Due to the later (1 October) drawdown of Chickamauga Reservoir, no mudflats were exposed during August or September. Mean biomass, height, species richness, and percent horizontal and vertical cover of vegetation were greater on Douglas mudflats than on Chickamauga mudflats both years. At Chickamauga Reservoir, no vegetation became established on mudflats in 2006, and seed production did not occur either year because mudflats were exposed too late in the growing season. In contrast, roughly 98 kg/ha of moist-soil seed was produced on Douglas mudflats but production was largely confined to the higher elevations exposed in late July and August. Differences in belowground seed biomass from core samples were not detected between reservoirs; however, biomass was two times greater in Douglas mudflats. Differences in soil characteristics and water depth and quality were not detected between reservoirs. Soil moisture decreased slightly following the exposure of Douglas mudflats, and soil compaction increased slightly following the exposure of Chickamauga mudflats. My regression models indicated that shorebird abundance was positively associated with mudflat acreage, and negatively associated with percent horizontal cover of vegetation, water depth, percent of total mudflat exposure, and reservoir gage height (Chapter II). I also quantified aquatic invertebrates in core samples from mudflats, but those analyses are ongoing and will be included in the resulting peer-refereed paper.

Long- and intermediate-distance migrant shorebirds spent more time foraging on east TRV mudflats than short-distance migrants, which spent the majority of their time resting (Chapter III). Waterfowl spent most of their time foraging and engaged in locomotion. Surface-feeding was the primary foraging technique of dabbling ducks using

TRV mudflats. Activity budgets among remaining species were highly variable, which suggests that TRV mudflats provide multiple functions to different guilds of waterbirds (Chapter III).

The high occurrence of feeding among shorebirds observed in the east TRV (averaged 64% across species) suggests that mudflats exposed during reservoir drawdowns function as important foraging sites for shorebirds (Chapter III). In Chapter II, I estimated that mudflats in the TRV may support 450,000 shorebirds annually, which is comparable to the estimate in the Mississippi Alluvial Valley (i.e., 500,000 shorebirds; Loesch et al. 2000). In addition, a total of 32 shorebird species have been documented in the TRV (Chapter II; Fowler 1983; D. Wirwa, University of Tennessee, unpublished data), which exceeds shorebird diversity in fall for nearly all other regions in North America (Chapter II). My results collectively suggest that mudflats in the TRV are critical stopover habitats for migrating shorebirds (Chapters II and III). Thus, I recommend that TRV mudflats be added to the Western Hemisphere Shorebird Reserve Network as a "Landscape Site of Regional Importance" (Chapter III).

Previous studies have suggested that TRV mudflats have little value to migrating and wintering waterfowl (Wiebe 1946, Morse and Steenis 1948, Steenis 1950, White 1994). However, my results suggest that TRV mudflats provide important foraging and loafing sites for waterfowl (Chapter III). Seed densities are lower on TRV mudflats compared to early successional moist-soil wetlands in the Southeast (Chapter II). Aboveground seed production (98 kg/ha [Douglas Reservoir]) and belowground seed biomass (44 kg/ha [both reservoirs]) on east TRV mudflats were slightly above and below, respectively, the food density (50 kg/ha) proposed by Reinecke et al. (1989) and

Rutka (2004) where waterfowl abandon sites to forage elsewhere because it is no longer energetically profitable. If this "giving-up" density is true, my results suggest that waterfowl are foraging on other foods (e.g., aquatic invertebrates) on TRV mudflats. Future research needs to focus on what foods waterfowl are acquiring on TRV mudflats compared to adjacent wetlands and agricultural habitats to determine their functional importance (Chapter III).

Of the 11 shorebird species I documented on Douglas mudflats only, six are considered species of high concern (American golden-plover, sanderling, short-billed dowitcher, and buff-breasted, solitary and western sandpipers) according to the U.S. Shorebird Conservation Plan (Brown et al. 2001). These species occurred in August and September during peak shorebird migration. I also documented one federally-endangered wood stork in August 2006 using a shallowly flooded site adjacent to the Douglas mudflats. Thus, providing newly exposed mudflats in August and September is critical for several migratory waterbirds of conservation concern. Exposing mudflats in late summer and early fall also will benefit several species of resident and early migratory waterfowl and wading birds (Chapter II).

The later (1 October) drawdown of Chickamauga Reservoir did not provide mudflats during peak shorebird migration, but my results suggest that providing newly exposed habitat in October and November still benefited waterbirds (Chapter II). Chickamauga mudflats received a considerable amount of use by later migrant and wintering shorebird species (e.g., killdeer, least sandpiper and Wilson's snipe). Providing shallowly flooded habitat from October – January also benefited other waterbird guilds,

such as waterfowl and sandhill cranes, which typically arrive in the east TRV during these months (Chapter II).

This study provided evidence that early and late drawdowns of TRV reservoirs are beneficial to waterbirds (Chapter II). In Chapter II, I provided a hypothetical drawdown schedule for nine reservoirs in the east and west TRV (pp. 60 – 61). This drawdown schedule was designed to provide newly-exposed mudflats from late July – November to meet the habitat needs of migrating and wintering waterbirds in the TRV. I proposed a staggered drawdown where reservoirs are sequentially drawn down in the east and west TRV. In the east TRV, the recommended drawdown schedule is Watauga (15 July), Douglas (1 August), Nottely (15 August), Hiwassee (15 September), Chickamauga (1 October) and Cherokee (1 October). An additional benefit of a staggered drawdown is that it may accommodate late summer recreational demands on reservoirs that receive high use (e.g., Cherokee). In the west TRV, Kentucky Reservoir is the only reservoir with a drawdown initiated before September. Thus, I recommend that its current drawdown initiation date is maintained. Providing wildlife habitat and recreational opportunities are only two of the reservoir uses that the Tennessee Valley Authority (TVA) must consider in making potential changes to the reservoir operations protocol. Additional uses include flood control, hydropower production, year-round navigation, water supply, and cooling nuclear reactors (Miller et al. 1996). I recommend that TVA consider an interactive approach to planning where all stakeholders are invited to discuss possible reservoir management scenarios. Waterbird conservation and management should be integrated into the TVA drawdown decision-making process (Chapter II).

Finally, I made an observation that drawdown rate also may impact mudflat characteristics and waterbird use. Douglas Reservoir was drawn down 5.3X faster than Chickamauga Reservoir (–6.9 vs. –1.3 cm/day). Slow drawdowns prolong the availability of suitable habitat for shorebirds and other waterbirds (Rundle and Fredrickson 1981, Hands et al. 1991). Although Chickamauga Reservoir was drawn down later, it was used by waterbirds from initial exposure in October through the end of sampling in January, and likely through winter. In contrast, very few birds used Douglas Reservoir mudflats after September, because water was restricted to the main channel of the French Broad River. When water recedes slowly from mudflats, the soil remains moist and the adjacent shallowly flooded habitat is maintained for longer duration, which likely facilitates probing and food acquisition by shorebirds. Thus, an additional strategy to maximize waterbird habitat in the TRV would be to drawdown reservoirs at a slower rate. If feasible, I recommend that TRV reservoirs be drawn down as slow or slower than Chickamauga Reservoir (i.e., preferably $\leq$1 cm/day). Slowing the rate of TRV reservoir drawdowns also may provide natural control over nuisance plant species, such as rough cockleburr, while promoting the establishment of a more diverse and desirable wetland plant community on mudflats (Chapter II). In addition, slow drawdowns may further accommodate water recreation because higher water levels would be maintained later into the fall. Future research should quantify the effects of drawdown rate by examining waterbird use and mudflat characteristics in reservoirs drawn down on the same date but at different rates.

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APPENDIX I

TABLES AND FIGURES

Table 1. Mean daily abundance, richness, and diversity of shorebirds per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

			Reservoir				
			Douglas		Chickamauga		
Metric[a]	Year	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
ABUN	2005	August	8.55 A	8.55	0 A	0	0.453
		September	20.53 A	7.20	0 B	0	0.021
		October	2.22 A	2.22	21.78 A	13.22	0.219
		November	3.16 A	2.43	66.00 B	17.00	0.030
		December	0.25 A	0.25	40.36 B	15.46	0.027
		January	0 A	0	67.69 B	31.01	0.021
	2006	August	64.75 A	43.75	0 B	0	0.021
		September	32.56 A	26.29	0 B	0	0.069
		October	2.14 A	1.27	6.36 A	5.58	1.000
		November	1.64 A	1.33	36.91 B	3.36	0.029
		December	0.34 A	0.24	50.94 B	31.02	0.029
		January	0 A	0	76.06 B	58.87	0.021
RICH	2005	August	1.05 A	1.05	0 A	0	0.453
		September	1.72 A	0.62	0 B	0	0.021
		October	0.11 A	0.11	1.31 A	0.63	0.124
		November	0.38 A	0.22	2.22 B	0.28	0.029
		December	0.11 A	0.11	1.72 B	0.10	0.025
		January	0 A	0	2.06 B	0.19	0.020
	2006	August	2.72 A	1.23	0 B	0	0.021
		September	2.44 A	1.34	0 B	0	0.069
		October	0.39 A	0.25	0.58 A	0.39	1.000
		November	0.22 A	0.16	1.38 B	0.22	0.028
		December	0.13 A	0.07	1.72 B	0.12	0.028
		January	0 A	0	1.38 B	0.26	0.021
DIV	2005	August	0.26 A	0.26	0 A	0	0.453
		September	0.40 A	0.14	0 B	0	0.021
		October	0 A	0	0.30 B	0.15	0.069
		November	0.02 A	0.02	0.48 B	0.03	0.027
		December	0.02 A	0.02	0.36 B	0.06	0.027
		January	0 A	0	0.43 B	0.07	0.021
	2006	August	0.43 A	0.20	0 B	0	0.069
		September	0.42 A	0.24	0 B	0	0.069
		October	0.07 A	0.05	0.15 A	0.11	0.878
		November	0.02 A	0.02	0.27 B	0.06	0.027
		December	0 A	0	0.33 B	0.06	0.021
		January	0 A	0	0.28 B	0.05	0.021

Table 1 (continued).

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[a]ABUN = abundance, RICH = richness, DIV = diversity.

[b]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 2. Mean daily abundance of shorebird species per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005 – January 2006.

		Reservoir				
		Douglas		Chickamauga		
Species[a]	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
DUNL	August	0.10 A	0.10	0 A	0	0.453
	November	0 A	0	0.97 A	0.74	0.186
GRYE	October	0 A	0	0.06 A	0.06	0.453
	November	0 A	0	0.03 A	0.03	0.453
KILL	August	4.15 A	4.15	0 A	0	0.453
	September	9.86 A	2.82	0 B	0	0.021
	October	2.22 A	2.22	10.34 A	5.00	0.219
	November	3.13 A	2.40	47.81 B	17.29	0.030
	December	0.08 A	0.08	31.22 B	15.09	0.027
	January	0 A	0	56.44 B	30.56	0.021
LBDO	November	0.03 A	0.03	0 A	0	0.453
LESA	August	1.45 A	1.45	0 A	0	0.453
	September	3.39 A	1.86	0 B	0	0.069
	October	0 A	0	3.63 A	2.51	0.186
	November	0 A	0	2.72 A	2.69	0.186
	December	0 A	0	1.53 A	1.45	0.186
	January	0 A	0	2.25 A	2.17	0.186
LEYE	August	0.05 A	0.05	0 A	0	0.453
	September	0.08 A	0.08	0 A	0	0.453
	October	0 A	0	0.09 A	0.09	0.453
PESA	August	1.30 A	1.30	0 A	0	0.453
	September	4.92 A	1.67	0 B	0	0.021
	October	0 A	0	0.03 A	0.03	0.453
SAND	September	0.03 A	0.03	0 A	0	0.453
SEPL	August	0.10 A	0.10	0 A	0	0.453
	September	0.97 A	0.97	0 A	0	0.453
SESA	August	1.30 A	1.30	0 A	0	0.453
	September	0.72 A	0.37	0 B	0	0.069
	October	0 A	0	0.38 A	0.38	0.453
SOSA	August	0.10 A	0.10	0 A	0	0.453
WESA	September	0.56 A	0.42	0 A	0	0.186
WISN	October	0 A	0	7.25 B	5.33	0.069
	November	0 A	0	14.47 B	5.42	0.021
	December	0.17 A	0.17	7.61 B	2.28	0.027
	January	0 A	0	9.00 B	3.91	0.021

[a]DUNL = dunlin (*Calidris alpina*), GRYE = greater yellowlegs (*Tringa melanoleuca*), KILL = killdeer (*Charadrius vociferus*), LBDO = long-billed dowitcher

Table 2 (continued).

(*Limnodromus scolopaceus*), LESA = least sandpiper (*Calidris minutilla*), LEYE = lesser yellowlegs (*T. flavipes*), PESA = pectoral sandpiper (*Calidris melanotos*), SAND = sanderling (*Calidris alba*), SEPL = semipalmated plover (*Charadrius semipalmatus*), SESA = semipalmated sandpiper (*Calidris pusilla*), SOSA = solitary sandpiper (*T. solitaria*), WESA = western sandpiper (*Calidris mauri*), WISN = Wilson's snipe (*Gallinago delicata*).

[b]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 3. Mean daily abundance of shorebird species per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2006 – January 2007.

		Reservoir				
		Douglas		Chickamauga		
Species[a]	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
AMAV	December	0 A	0	0.06 A	0.03	0.181
AMGP	September	0.16 A	0.16	0 A	0	0.453
	October	0.06 A	0.06	0 A	0	0.453
BBSA	September	0.03 A	0.03	0 A	0	0.453
DUNL	November	0 A	0	0.06 A	0.06	0.453
GRYE	August	0.47 A	0.47	0 A	0	0.453
	September	1.00 A	0.76	0 B	0	0.069
	October	0 A	0	0.42 A	0.42	0.453
KILL	August	44.06 A	28.51	0 B	0	0.021
	September	17.13 A	12.53	0 B	0	0.069
	October	1.33 A	0.80	2.81 A	2.48	1.000
	November	1.56 A	1.24	30.13 B	3.04	0.029
	December	0.34 A	0.24	43.39 B	28.54	0.029
	January	0 A	0	66.19 B	51.86	0.021
LESA	August	7.03 A	5.85	0 B	0	0.069
	September	5.53 A	5.37	0 A	0	0.186
	October	0.72 A	0.44	1.83 A	1.83	0.869
	November	0.08 A	0.08	2.94 A	1.57	0.124
	December	0 A	0	3.64 A	3.64	0.453
	January	0 A	0	7.75 A	7.75	0.453
LEYE	August	0.22 A	0.19	0 A	0	0.186
	September	0.84 A	0.76	0 A	0	0.186
	October	0 A	0	0.08 A	0.08	0.453
PESA	August	7.58 A	5.54	0 B	0	0.069
	September	4.25 A	3.72	0 B	0	0.069
	October	0.03 A	0.03	0 A	0	0.453
SAND	September	1.22 A	0.92	0 A	0	0.186
SBDO	August	0.11 A	0.08	0 A	0	0.186
	September	0.16 A	0.16	0 A	0	0.453
SEPL	August	1.22 A	1.19	0 A	0	0.186
	September	0.78 A	0.66	0 A	0	0.186
SESA	August	0.94 A	0.74	0 A	0	0.186
	September	0.38 A	0.38	0 A	0	0.453
SOSA	August	0.14 A	0.11	0 A	0	0.186
SPSA	August	2.22 A	0.97	0 B	0	0.069
	September	0.13 A	0.05	0 B	0	0.067
STSA	August	0.50 A	0.50	0 A	0	0.453
	September	0.91 A	0.91	0 A	0	0.453

Table 3 (continued).

		Reservoir				
		Douglas		Chickamauga		
Species[a]	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
WILL	August	0.08 A	0.08	0 A	0	0.453
WISN	August	0.17 A	0.11	0 A	0	0.186
	September	0.06 A	0.04	0 A	0	0.181
	October	0 A	0	1.22 A	0.82	0.186
	November	0 A	0	3.78 B	1.85	0.069
	December	0 A	0	3.86 B	1.29	0.021
	January	0 A	0	2.13 B	0.92	0.069

[a]AMAV = American avocet (*Recurvirostra americana*), AMGP = American golden-plover (*Pluvialis dominica*), BBSA = buff-breasted sandpiper (*Tryngites subruficollis*), DUNL = dunlin (*Calidris alpina*), GRYE = greater yellowlegs (*Tringa melanoleuca*), KILL = killdeer (*Charadrius vociferus*), LESA = least sandpiper (*Calidris minutilla*), LEYE = lesser yellowlegs (*Tringa flavipes*), PESA = pectoral sandpiper (*Calidris melanotos*), SAND = sanderling (*Calidris alba*), SBDO = short-billed dowitcher (*Limnodromus griseus*), SEPL = semipalmated plover (*Charadrius semipalmatus*), SESA = semipalmated sandpiper (*Calidris pusilla*), SOSA = solitary sandpiper (*Tringa solitaria*), SPSA = spotted sandpiper (*Actitis macularius*), STSA = stilt sandpiper (*Calidris himantopus*), WILL = willet (*Tringa semipalmata*), WISN = Wilson's snipe (*Gallinago delicata*).

[b]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 4. Mean daily abundance, richness, and diversity of waterfowl per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

			Reservoir				
			Douglas		Chickamauga		
Metric[a]	Year	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
ABUN	2005	August	11.350 A	11.019	0 A	0	0.186
		September	2.278 A	0.927	0.611 A	0.611	0.219
		October	0.417 A	0.288	14.750 A	8.672	0.183
		November	0.719 A	0.638	25.806 A	16.995	0.301
		December	3.917 A	3.662	43.778 B	10.797	0.029
		January	13.500 A	13.334	35.188 A	18.417	0.191
	2006	August	12.417 A	3.947	0.722 B	0.578	0.061
		September	6.969 A	4.508	0.778 A	0.778	0.219
		October	2.750 A	1.327	12.861 A	9.832	0.665
		November	0.444 A	0.444	9.469 B	7.279	0.055
		December	3.625 A	2.888	17.222 A	10.138	0.191
		January	45.438 A	45.438	17.813 A	6.938	0.301
RICH	2005	August	0.500 A	0.436	0 A	0	0.186
		September	0.306 A	0.115	0.028 A	0.028	0.122
		October	0.111 A	0.079	0.406 A	0.187	0.301
		November	0.156 A	0.094	1.167 A	0.626	0.460
		December	0.083 A	0.053	2.306 B	1.180	0.080
		January	0.125 A	0.072	2.563 B	1.012	0.028
	2006	August	1.111 A	0.318	0.139 B	0.053	0.029
		September	0.531 A	0.290	0.056 A	0.056	0.219
		October	0.167 A	0.096	0.472 A	0.200	0.183
		November	0.028 A	0.028	0.875 B	0.445	0.027
		December	0.156 A	0.094	1.278 A	0.652	0.191
		January	0.250 A	0.250	1.938 B	0.874	0.104
DIV	2005	August	0.071 A	0.071	0 A	0	0.453
		September	0.024 A	0.018	0 A	0	0.186
		October	0 A	0	0.011 A	0.011	0.453
		November	0.012 A	0.012	0.254 A	0.138	0.124
		December	0.006 A	0.006	0.562 A	0.326	0.408
		January	0 A	0	0.536 B	0.225	0.021
	2006	August	0.230 A	0.078	0 B	0	0.021
		September	0.048 A	0.038	0 A	0	0.186
		October	0.007 A	0.007	0.027 A	0.018	0.408
		November	0 A	0	0.131 A	0.081	0.186
		December	0.005 A	0.005	0.264 A	0.172	0.408
		January	0.003 A	0.003	0.493 A	0.289	0.124

[a]ABUN = abundance, RICH = richness, DIV = diversity.

[b]Means within rows followed by unlike letters are different ($P \leq 0.10$) by

Table 4 (continued).

Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 5. Mean daily abundance of waterfowl species per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005 – January 2006.

		Reservoir				
		Douglas		Chickamauga		
Species[a]	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
ABDU	November	0 A	0	0.25 A	0.25	0.453
	December	0 A	0	1.33 A	1.33	0.453
	January	0 A	0	0.63 A	0.63	0.453
AMWI	November	0 A	0	0.06 A	0.06	0.453
BUFF	November	0 A	0	0.28 A	0.28	0.453
	December	0 A	0	0.17 A	0.17	0.453
BWTE	September	0.72 A	0.72	0 A	0	0.453
	October	0 A	0	0.06 A	0.06	0.453
CAGO	August	1.75 A	1.75	0 A	0	0.453
	September	0 A	0	0.61 A	0.61	0.453
	October	0.11 A	0.11	14.47 A	8.59	0.124
	November	0.19 A	0.19	7.75 A	7.46	0.408
	December	3.53 A	3.53	16.22 B	7.79	0.104
	January	13.38 A	13.38	13.06 A	6.52	0.539
GADW	October	0 A	0	0.09 A	0.09	0.453
	November	0 A	0	7.86 A	4.83	0.186
	December	0 A	0	9.44 B	5.82	0.069
	January	0 A	0	12.00 B	6.92	0.021
GWTE	October	0.14 A	0.14	0 A	0	0.453
	November	0.44 A	0.40	0.22 A	0.19	0.878
	December	0.19 A	0.19	2.83 A	2.72	0.620
	January	0 A	0	2.56 A	2.02	0.186
HOME	November	0 A	0	5.92 A	5.92	0.453
	December	0 A	0	3.97 B	3.09	0.069
	January	0 A	0	3.94 B	3.20	0.069
MALL	August	8.50 A	8.17	0 A	0	0.186
	September	1.50 A	0.72	0 B	0	0.069
	October	0.17 A	0.17	0.09 A	0.09	1.000
	November	0.09 A	0.06	2.72 A	1.60	0.645
	December	0.19 A	0.19	5.42 A	3.14	0.408
	January	0.13 A	0.13	2.00 B	0.94	0.037
NOPI	November	0 A	0	0.03 A	0.03	0.453
NSHO	November	0 A	0	0.42 A	0.42	0.453
	December	0 A	0	4.08 A	3.22	0.186
	January	0 A	0	0.94 A	0.94	0.453
WODU	August	1.10 A	1.10	0 A	0	0.453
	September	0.06 A	0.03	0 A	0	0.181
	October	0 A	0	0.03 A	0.03	0.453
	November	0 A	0	0.31 B	0.14	0.069
	December	0 A	0	0.31 A	0.31	0.453
	January	0 A	0	0.06 A	0.06	0.453

[a]ABDU = American black duck (*Anas rubripes*), AMWI = American wigeon

Table 5 (continued).

(*Anas americana*), BUFF = bufflehead (*Bucephala albeola*), BWTE = blue-winged teal (*Anas discors*), CAGO = Canada goose (*Branta canadensis*), GADW = gadwall (*Anas strepera*), GWTE = American green-winged teal (*Anas crecca*), HOME = hooded merganser (*Lophodytes cucullatus*), MALL = mallard (*Anas platyrhynchos*), NOPI = northern pintail (*Anas acuta*), NSHO = northern shoveler (*Anas clypeata*), WODU = wood duck (*Aix sponsa*).

[b]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 6. Mean daily abundance of waterfowl species per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2006 – January 2007.

		Reservoir				
		Douglas		Chickamauga		
Species[a]	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
ABDU	November	0 A	0	0.38 A	0.38	0.453
	December	0 A	0	0.81 A	0.81	0.453
	January	0 A	0	0.75 A	0.75	0.453
BWTE	August	0.19 A	0.19	0 A	0	0.453
	September	0.53 A	0.49	0 A	0	0.186
	October	0.08 A	0.08	0 A	0	0.453
CAGO	August	1.42 A	0.55	0.47 A	0.47	0.219
	September	0.03 A	0.03	0.78 A	0.78	1.000
	October	1.17 A	0.70	11.50 A	9.77	0.645
	November	0.44 A	0.44	1.22 A	0.74	0.408
	December	3.53 A	2.83	0.94 A	0.55	0.645
	January	42.25 A	42.25	3.25 A	3.09	0.869
COGO	November	0 A	0	0.06 A	0.06	0.453
GADW	November	0 A	0	0.09 A	0.09	0.453
	December	0 A	0	0.75 A	0.44	0.186
	January	0 A	0	6.19 A	4.25	0.186
GRSC	December	0 A	0	0.06 A	0.06	0.453
GWTE	November	0 A	0	0.38 A	0.33	0.186
	December	0 A	0	0.03 A	0.03	0.453
	January	0 A	0	2.19 A	2.02	0.186
HOME	October	0 A	0	0.08 A	0.08	0.453
	November	0 A	0	6.78 B	6.37	0.069
	December	0 A	0	11.94 A	7.77	0.186
	January	0 A	0	2.06 B	1.65	0.069
LESC	November	0 A	0	0.28 A	0.28	0.453
MALL	August	9.97 A	3.46	0 B	0	0.021
	September	6.38 A	4.03	0 B	0	0.069
	October	1.50 A	1.50	0.22 A	0.14	0.869
	November	0 A	0	0.13 A	0.09	0.186
	December	0.06 A	0.06	2.69 B	1.44	0.027
	January	0.19 A	0.19	3.38 A	2.81	0.219
NOPI	December	0.03 A	0.03	0 A	0	0.453
RUDU	October	0 A	0	0.31 A	0.31	0.453
WODU	August	0.83 A	0.47	0.25 A	0.12	0.307
	September	0.03 A	0.03	0 A	0	0.453
	October	0 A	0	0.75 B	0.37	0.069
	November	0 A	0	0.16 A	0.09	0.186

[a]ABDU = American black duck (*Anas rubripes*), BWTE = blue-winged teal (*Anas*

Table 6 (continued).

discors), CAGO = Canada goose (*Branta canadensis*), COGO = common goldeneye (*Bucephala clangula*), GADW = gadwall (*Anas strepera*), GRSC = greater scaup (*Aythya marila*), GWTE = American green-winged teal (*Anas crecca*), HOME = hooded merganser (*Lophodytes cucullatus*), LESC = lesser scaup (*Aythya affinis*), MALL = mallard (*Anas platyrhynchos*), NOPI = northern pintail (*Anas acuta*), RUDU = ruddy duck (*Oxyura jamaicensis*), WODU = wood duck (*Aix sponsa*).

[b]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 7. Mean daily abundance, richness, and diversity of other waterbirds[a] per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

			Reservoir				
			Douglas		Chickamauga		
Metric[b]	Year	Month	$\bar{x}$ [c]	SE	$\bar{x}$	SE	*P*-value
ABUN	2005	August	3.650 A	2.155	0.150 A	0.150	0.408
		September	6.500 A	3.800	0.833 B	0.347	0.081
		October	0.389 A	0.289	2.625 B	0.652	0.029
		November	1.625 A	1.149	19.139 B	9.250	0.061
		December	0.056 A	0.032	47.028 B	15.024	0.028
		January	0 A	0	10.500 B	5.161	0.021
	2006	August	10.278 A	3.912	0.944 B	0.402	0.030
		September	18.344 A	15.425	0.917 A	0.381	0.471
		October	4.250 A	3.781	2.222 A	0.895	0.665
		November	0.194 A	0.194	23.094 B	9.254	0.027
		December	0.031 A	0.031	56.639 B	32.567	0.027
		January	0 A	0	39.438 B	30.282	0.021
RICH	2005	August	0.700 A	0.436	0.150 A	0.150	0.408
		September	1.306 A	0.491	0.583 A	0.228	0.191
		October	0.222 A	0.136	1.063 B	0.149	0.029
		November	0.250 A	0.102	1.583 B	0.237	0.028
		December	0.056 A	0.032	1.639 B	0.285	0.028
		January	0 A	0	1.250 B	0.228	0.021
	2006	August	1.806 A	0.306	0.611 B	0.225	0.042
		September	1.406 A	0.680	0.639 A	0.242	0.559
		October	0.583 A	0.319	1.028 A	0.404	0.312
		November	0.167 A	0.167	2.063 B	0.491	0.027
		December	0.031 A	0.031	1.667 B	0.297	0.027
		January	0 A	0	1.250 B	0.368	0.021
DIV	2005	August	0.138 A	0.094	0.035 A	0.035	0.408
		September	0.296 A	0.128	0.114 A	0.049	0.312
		October	0 A	0	0.199 B	0.023	0.021
		November	0.004 A	0.004	0.299 B	0.086	0.027
		December	0 A	0	0.282 B	0.120	0.021
		January	0 A	0	0.165 A	0.102	0.186
	2006	August	0.445 A	0.073	0.065 B	0.038	0.029
		September	0.303 A	0.139	0.107 A	0.062	0.301
		October	0.091 A	0.072	0.219 A	0.101	0.301
		November	0 A	0	0.385 B	0.144	0.021
		December	0 A	0	0.292 B	0.090	0.021
		January	0 A	0	0.143 A	0.097	0.186

[a]Other waterbirds include additional wetland-dependent species (Weller 1999; see Appendix II for list of species).

Table 7 (continued).

[b]ABUN = abundance, RICH = richness, DIV = diversity.

[c]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 8. Mean daily abundance of other waterbird species per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005 – January 2006.

		Reservoir				
		Douglas		Chickamauga		
Species[a]	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
AMCO	November	0 A	0	0.58 A	0.58	0.453
	December	0 A	0	0.06 A	0.06	0.453
AWPE	September	0.17 A	0.17	0 A	0	0.478
BOGU	December	0 A	0	0.14 A	0.14	0.453
CATE	September	0.03 A	0.03	0 A	0	0.453
DCCO	September	0.14 A	0.14	0.17 A	0.17	1.000
	October	0 A	0	0.28 A	0.21	0.186
	November	0 A	0	0.06 A	0.06	0.453
GBHE	August	0.25 A	0.15	0.05 A	0.05	0.408
	September	1.61 A	1.24	0.44 A	0.24	0.442
	October	0.39 A	0.29	1.91 A	0.64	0.110
	November	0.47 A	0.24	9.75 B	4.36	0.029
	December	0.03 A	0.03	12.75 B	4.38	0.027
	January	0 A	0	9.25 B	4.91	0.021
GREG	August	3.05 A	1.89	0.10 A	0.10	0.408
	September	4.47 A	2.23	0.22 B	0.09	0.029
	October	0 A	0	0.44 B	0.21	0.067
	November	0 A	0	0.72 B	0.29	0.069
	December	0 A	0	0.03 A	0.03	0.453
GRHE	September	0.03 A	0.03	0 A	0	0.453
LBHE	August	0.35 A	0.35	0 A	0	0.453
	September	0.06 A	0.03	0 A	0	0.181
PBGR	December	0 A	0	0.08 A	0.08	0.453
RBGU	November	1.16 A	1.16	4.56 A	2.09	0.219
	December	0.03 A	0.03	21.97 B	10.37	0.027
	January	0 A	0	0.69 B	0.37	0.067
SACR	November	0 A	0	3.47 B	3.10	0.020
	December	0 A	0	12.00 A	8.18	0.186
	January	0 A	0	0.56 A	0.56	0.453

[a]AMCO = American coot (*Fulica americana*), AWPE = American white pelican (*Pelecanus erythrorhynchos*), BOGU = Bonaparte's gull (*Larus philadelphia*), CATE = Caspian tern (*Hydroprogne caspia*), DCCO = double-crested cormorant (*Phalacrocorax auritus*), GBHE = great blue heron (*Ardea herodias*), GREG = great egret (*Ardea alba*), GRHE = green heron (*Butorides virescens*), LBHE = little blue heron (*Egretta caerulea*),

Table 8 (continued).

PBGR = pied-billed grebe (*Podilymbus podiceps*), RBGU = ring-billed gull (*Larus delawarensis*), SACR = sandhill crane (*Grus canadensis*).

[b]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 9. Mean daily abundance of other waterbird species per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2006 – January 2007.

		Reservoir				
		Douglas		Chickamauga		
Species[a]	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
AMCO	October	0 A	0	0.03 A	0.03	0.453
	November	0 A	0	0.34 A	0.34	0.453
AWPE	September	0.03 A	0.03	0 A	0	0.453
BCNH	August	0.03 A	0.03	0 A	0	0.453
BEKI	October	0 A	0	0.03 A	0.03	0.453
BLTE	September	0.06 A	0.06	0 A	0	0.453
BOGU	November	0 A	0	1.09 A	0.86	0.186
	December	0 A	0	0.83 A	0.83	0.453
CATE	September	0.03 A	0.03	0 A	0	0.453
DCCO	August	0.06 A	0.03	0 A	0	0.181
	September	0.59 A	0.43	0 B	0	0.069
	October	0.14 A	0.11	0.22 A	0.12	0.552
	November	0 A	0	0.50 A	0.33	0.186
	December	0 A	0	0.36 A	0.36	0.453
FOTE	September	0.03 A	0.03	0 A	0	0.453
GBHE	August	1.67 A	0.83	0.83 A	0.34	0.663
	September	4.19 A	3.41	0.67 A	0.28	0.665
	October	2.14 A	1.82	1.44 A	0.68	1.000
	November	0.19 A	0.19	4.34 B	1.46	0.027
	December	0.03 A	0.03	7.17 B	3.92	0.027
	January	0 A	0	8.44 B	4.71	0.021
GREG	August	7.56 A	3.21	0.11 B	0.06	0.028
	September	13.31 A	11.46	0.25 A	0.16	0.301
	October	1.89 A	1.89	0.36 A	0.18	0.539
	November	0 A	0	0.28 A	0.28	0.453
GRHE	August	0.78 A	0.26	0 B	0	0.020
	September	0.09 A	0.09	0 A	0	0.453
	October	0 A	0	0.03 A	0.03	0.453
LBHE	August	0.19 A	0.16	0 A	0	0.186
PBGR	October	0 A	0	0.08 A	0.05	0.186
	November	0 A	0	0.38 B	0.14	0.021
	December	0 A	0	0.03 A	0.03	0.453
RBGU	October	0.08 A	0.08	0.03 A	0.03	1.000
	November	0 A	0	11.06 B	6.16	0.069
	December	0 A	0	11.81 B	9.38	0.021
	January	0 A	0	0.31 A	0.24	0.186
SACR	November	0 A	0	5.09 A	5.05	0.186
	December	0 A	0	36.44 A	32.29	0.186
	January	0 A	0	30.69 A	30.69	0.453

[a]AMCO = American coot (*Fulica americana*), AWPE = American white pelican (*Pelecanus erythrorhynchos*), BCNH = black-crowned night-heron (*Nycticorax*

Table 9 (continued).

nycticorax), BEKI = belted kingfisher (*Megaceryle alcyon*), BLTE = black tern (*Chlidonias niger*), BOGU = Bonaparte's gull (*Larus philadelphia*), CATE = Caspian tern (*Hydroprogne caspia*), DCCO = double-crested cormorant (*Phalacrocorax auritus*), FOTE = Forster's tern (*Sterna forsteri*), GBHE = great blue heron (*Ardea herodias*), GREG = great egret (*Ardea alba*), GRHE = green heron (*Butorides virescens*), LBHE = little blue heron (*Egretta caerulea*), PBGR = pied-billed grebe (*Podilymbus podiceps*), RBGU = ring-billed gull (*Larus delawarensis*), SACR = sandhill crane (*Grus canadensis*).

[b]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 10. Mean daily abundance, richness, and diversity of other birds[a] per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

			Reservoir				
			Douglas		Chickamauga		
Metric[b]	Year	Month	$\bar{x}$ [c]	SE	$\bar{x}$	SE	*P*-value
ABUN	2005	September	101.81 A	60.13	0 B	0	0.069
		October	3.81 A	3.81	0.19 A	0.12	0.869
		November	4.66 A	4.33	7.64 A	5.37	0.309
		December	3.47 A	3.47	11.72 B	6.57	0.104
		January	0 A	0	2.00 B	0.96	0.069
	2006	August	59.03 A	54.69	0 B	0	0.021
		September	48.50 A	48.42	0 A	0	0.186
		October	1.44 A	1.17	0 A	0	0.186
		November	0 A	0	0.69 B	0.17	0.021
		December	0 A	0	9.08 B	5.36	0.021
		January	0 A	0	4.19 B	3.38	0.020
RICH	2005	September	0.17 A	0.07	0 B	0	0.069
		October	0.03 A	0.03	0.06 A	0.04	0.405
		November	0.16 A	0.12	0.56 A	0.10	0.110
		December	0.11 A	0.11	0.69 B	0.26	0.104
		January	0 A	0	0.50 B	0.23	0.069
	2006	August	0.25 A	0.05	0 B	0	0.020
		September	0.22 A	0.15	0 A	0	0.186
		October	0.14 A	0.08	0 A	0	0.186
		November	0 A	0	0.25 B	0.05	0.020
		December	0 A	0	0.53 B	0.19	0.021
		January	0 A	0	0.50 B	0.18	0.020
DIV	2005	September	0.01 A	0.01	0 A	0	0.453
		November	0.02 A	0.02	0.02 A	0.02	1.000
		December	0 A	0	0.05 A	0.05	0.453
		January	0 A	0	0.04 A	0.04	0.453
	2006	September	0.01 A	0.01	0 A	0	0.453

[a]Other birds include additional species not wetland-dependent (i.e., see Appendix II for list of species)

[b]ABUN = abundance, RICH = richness, DIV = diversity.

[c]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 11. Mean abundance of other bird species per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006– January 2006/2007.

			Reservoir				
			Douglas		Chickamauga		
Year	Species[a]	Month	$\bar{x}$ [b]	SE	$\bar{x}$	SE	*P*-value
2005	AMCR	September	0.11 A	0.11	0 A	0	0.453
		October	3.81 A	3.81	0.19 A	0.12	0.869
		November	4.41 A	4.08	7.56 A	5.28	0.309
		December	3.47 A	3.47	10.69 B	5.85	0.104
		January	0 A	0	1.63 B	0.87	0.069
	AMRO	December	0 A	0	0.64 A	0.64	0.453
		January	0 A	0	0.38 A	0.38	0.453
	EUST	September	0.31 A	0.31	0 A	0	0.453
		November	0.25 A	0.25	0 A	0	0.453
		December	0 A	0	0.06 A	0.06	0.453
	TRES	September	101.39 A	60.36	0 A	0	0.186
	TUVU	November	0 A	0	0.08 A	0.08	0.453
	WITU	December	0 A	0	0.33 A	0.33	0.453
2006	AMCR	August	0.28 A	0.14	0 B	0	0.067
		September	1.44 A	1.40	0 A	0	0.186
		October	1.44 A	1.17	0 A	0	0.186
		November	0 A	0	0.69 B	0.17	0.021
		December	0 A	0	9.06 B	5.36	0.021
		January	0 A	0	4.19 B	3.38	0.020
	AMKE	September	0.03 A	0.03	0 A	0	0.453
	NOMO	December	0 A	0	0.03 A	0.03	0.453
	TRES	August	58.33 A	54.69	0 A	0	0.186
		September	46.88 A	46.88	0 A	0	0.453
	TUVU	August	0.28 A	0.28	0 A	0	0.453
	WITU	August	0.14 A	0.14	0 A	0	0.453
		September	0.16 A	0.16	0 A	0	0.453

[a]AMCR = American crow (*Corvus brachyrhynchos*), AMKE = American kestrel (*Falco sparverius*), AMRO (*Turdus migratorius*), EUST = European starling (*Sturnus vulgaris*), NOMO = northern mockingbird (*Mimus polyglottos*), TRES = tree swallow (*Tachycineta bicolor*), TUVU = turkey vulture (*Cathartes aura*), WITU = wild turkey (*Meleagris gallopavo*).

[b]Means within rows followed by unlike letters are different ($P \leq 0.10$) by

Table 11 (continued).

Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 12. Mean acreage (ha) exposed per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

			Reservoir				
			Douglas		Chickamauga		
Metric	Year	Month	$\bar{x}$ [a]	SE	$\bar{x}$	SE	*P*-value
Mudflat	2005	August	0.74 A	0.74	0 A	0	0.453
Acreage		September	13.91 A	5.22	0 B	0	0.021
		October	22.85 A	9.40	1.38 B	1.11	0.030
		November	22.97 A	9.48	22.83 A	6.64	1.000
		December	22.98 A	9.48	24.93 A	9.56	0.885
		January	22.98 A	9.48	23.17 A	7.61	1.000
	2006	August	6.30 A	2.29	0 B	0	0.021
		September	17.87 A	7.08	0 B	0	0.021
		October	22.69 A	9.49	0.33 B	0.33	0.029
		November	22.94 A	9.45	6.85 A	2.26	0.112
		December	22.98 A	9.48	16.92 A	2.50	1.000
		January	22.98 A	9.48	19.14 A	3.80	1.000

[a]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 13. Mean plant species richness, height (cm), and vertical cover (%) of vegetation on mudflats between Douglas and Chickamauga Reservoirs in east Tennessee, August – November 2005 and 2006.

		Year and Reservoir					
		2005				2006	
		Douglas		Chickamauga		Douglas	
Metric[a]	Month	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE
RICH	August	3.50	0	NT	NT	2.96	0.66
	September	2.97	0.61	NT	NT	4.10	0.82
	October	8.13 A	0.42	1.33 A	0.67	6.19	0.69
	November	10.86 A	1.04	0.71 B	0.29	7.62	0.89
HGT	August	2.00	0	NT	NT	8.34	4.58
	September	4.86	3.28	NT	NT	15.70	8.43
	October	15.67 A	6.17	0.33 A	0.17	16.00	8.12
	November	19.79 A	4.96	0.20 B	0.08	15.56	7.89
VC	August	0.28	0	NT	NT	5.83	4.75
	September	2.33	2.04	NT	NT	13.33	8.15
	October	11.48 A	4.35	0 B	0	12.93	7.45
	November	11.83 A	3.17	0 B	0	10.20	6.26

[a]RICH = species richness, HGT = height, VC = percent vertical cover.

[b]NT = differences in means not tested between reservoirs in August and September 2005 or during any month of the 2006 growing season, because vegetation plots on Chickamauga mudflats were inundated.

[c]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 14. Horizontal cover (%) of vegetation on mudflats between Douglas and Chickamauga Reservoirs in east Tennessee, August – November 2005 and 2006.

		Year and Reservoir					
		2005				2006	
		Douglas		Chickamauga		Douglas	
Month	Life Form[a]	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE
August	Bare	82.0	0	NT	NT	57.4	11.8
	Dead	1.0	0	NT	NT	0.7	0.3
	Forb	4.9	0	NT	NT	33.9	13.8
	Grass	10.3	0	NT	NT	4.2	1.9
	Sedge	1.8	0	NT	NT	3.9	3.7
September	Bare	66.8	11.6	NT	NT	56.7	16.9
	Dead	1.5	0.7	NT	NT	0.2	0.2
	Forb	21.2	7.9	NT	NT	32.4	15.7
	Grass	5.9	3.8	NT	NT	7.4	3.9
	Sedge	4.7	3.6	NT	NT	3.3	3.2
October	Bare	20.7 A	11.7	98.8 A	0.5	39.3	13.5
	Dead	0.3 A	0.2	0.4 A	0.1	1.0	0.9
	Forb	56.9 A	9.8	0.7 A	0.3	45.6	9.4
	Grass	14.4 A	6.0	0 B	0	11.0	6.4
	Sedge	7.7 A	4.1	0.2 A	0.1	3.0	2.8
November	Bare	14.6 A	7.5	97.9 B	0.7	26.2	14.1
	Dead	0.4 A	0.2	0.8 A	0.4	0.6	0.5
	Forb	65.5 A	8.1	1.2 B	0.4	54.1	9.6
	Grass	13.2 A	8.5	0 B	0	16.6	8.8
	Sedge	6.4 A	4.5	0.1 B	0.1	2.5	2.2

[a]Bare = bareground; Dead = dead organic material; Forb = Asteraceae, Brassicaceae, Convolvulaceae, Lythraceae, Molluginaceae, Onagraceae, Polygonaceae, Rosaceae, and Scrophulariaceae; Grass = Poaceae; Sedge = Cyperaceae and Juncaceae.

[b]NT = differences in means not tested between reservoirs in August and September 2005 or during any month of the 2006 growing season, because vegetation plots on Chickamauga mudflats were inundated.

[c]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 15. Monthly vegetation biomass (g/0.0625-m^2) produced on mudflats between Douglas and Chickamauga Reservoirs, August – November 2005 and 2006.

		Year and Reservoir					
		2005				2006	
	Life	Douglas		Chickamauga		Douglas	
Month	Form[a]	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE
August	Forb	0.400	0	NT	NT	2.657	1.867
	Grass	0.457	0	NT	NT	0.562	0.540
	Sedge	0.028	0	NT	NT	0.156	0.150
September	Forb	1.660	1.292	NT	NT	6.110	3.986
	Grass	0.318	0.294	NT	NT	1.417	1.202
	Sedge	0.140	0.081	NT	NT	0.449	0.284
October	Forb	7.383 A	3.045	0 B	0	10.748	6.185
	Grass	0.691 A	0.256	0 B	0	1.533	1.030
	Sedge	0.472 A	0.264	0 B	0	0.494	0.433
November	Forb	10.549 A	1.793	0.010 B	0.006	8.555	3.621
	Grass	1.252 A	0.391	0 B	0	2.217	1.882
	Sedge	0.423 A	0.167	0.001 B	0.001	0.320	0.253

[a]Forb = Asteraceae, Brassicaceae, Convolvulaceae, Lythraceae, Molluginaceae, Onagraceae, Polygonaceae, Rosaceae, and Scrophulariaceae; Grass = Poaceae; Sedge = Cyperaceae and Juncaceae.

[b]NT = differences in means not tested between reservoirs in August and September 2005 or during any month of the 2006 growing season, because vegetation plots on Chickamauga mudflats were inundated.

[c]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 16. Mean end-of-year[a] vegetation biomass (g/m^2) produced on mudflats between Douglas and Chickamauga Reservoirs in east Tennessee, 2005 and 2006.

Life Form	Species	Year and Reservoir					
		2005				2006[b]	
		Douglas		Chickamauga		Douglas	
		$\bar{x}$ [c]	SE	$\bar{x}$	SE	$\bar{x}$	SE
Forb	*Ammannia coccinea* Rottb.	0.098 A	0.053	0 B	0	0.010	0.010
	Aster lanceolatus Willd.	0.588 A	0.588	0 A	0	0.385	0.385
	Bidens frondosa L.	0.109 A	0.090	0 A	0	0.035	0.029
	Cardamine pensylvanica Muhl. ex Willd.	11.695 A	6.478	0.101 A	0.048	5.189	2.117
	Cuscuta sp.	2.639 A	1.258	0 B	0	10.778	6.378
	Duchesnea indica (Andr.) Focke	0.074 A	0.074	0 A	0	0.001	0.001
	Eclipta prostrata (L.) L.	0.004 A	0.004	0 A	0	0	0
	Gnaphalium uliginosum L.	14.438 A	5.623	0 B	0	28.451	12.531
	Ipomoea lacunosa L.	0.613 A	0.373	0 A	0	0.352	0.261
	Lindernia dubia (L.) Pennell	0.399 A	0.371	0 B	0	1.245	0.392
	Ludwigia palustris (L.) Ell.	0.119 A	0.075	0 B	0	0.001	0.001
	Mazus pumilus (Burm.f.) Steenis	3.910 A	2.782	0 B	0	11.825	6.789
	Mollugo verticillata L.	0.285 A	0.175	0 B	0	0	0
	Polygonum lapathifolium L.	0.984 A	0.984	0 A	0	0	0
	Portulaca oleracea L.	0.698 A	0.698	0 A	0	0	0
	Rorippa palustris ssp. *fernaldiana*	1.073 A	0.748	0 B	0	0	0
	Rorippa sessiliflora (Nutt.) Hitchc.	1.485 A	0.858	0 A	0	0.030	0.030
	Rotala ramosior (L.) Koehne	0	0	0	0	0.075	0.074
	Rumex obtusifolius L.	0.018 A	0.018	0 A	0	0	0
	Xanthium strumarium L.	97.601 A	33.125	0 B	0	85.203	52.115
Grass	*Echinochloa crus-galli* (L.) Beauv.	0.311 A	0.286	0 A	0	0	0
	Eragrostis hypnoides (Lam.) B.S.P.	20.706 A	10.123	0 B	0	12.034	6.104
	Eragrostis spectabilis (Pursh) Steud.	1.139 A	0.532	0 B	0	3.194	1.272
Sedge	*Cyperus flavicomus* Michx.	1.680 A	1.230	0 B	0	0.299	0.163
	Eleocharis obtusa (Willd.) Schult.	0.094 A	0.077	0 A	0	0.008	0.008

Table 16 (continued).

Life Form	Species	Year and Reservoir: 2005 Douglas $\bar{x}$ [c]	2005 Douglas SE	2005 Chickamauga $\bar{x}$	2005 Chickamauga SE	2006[b] Douglas $\bar{x}$	2006[b] Douglas SE
Sedge	*Fimbristylis vahlii* (Lam.) Link	3.075 A	2.583	0 B	0	2.998	2.949
	Juncus tenuis Willd.	0.174 A	0.168	0.002 A	0.001	0.012	0.005
	Lipocarpha micrantha (Vahl) G. Tucker	0.730 A	0.710	0 A	0	0.329	0.328
	Mean Total Biomass per Plot	164.738 A	36.960	0.102 B	0.049	162.452	55.904

[a]Growing season durations for Douglas (i.e., 29 March – 4 November in Cocke County, TN) and Chickamauga Reservoirs (i.e., 31 March – 9 November in Bradley County, TN; Natural Resources Conservation Service 2001).

[b]Differences in means not tested between reservoirs in 2006 because all vegetation plots on Chickamauga mudflats were inundated.

[c]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 17. Aboveground seed production (g/m^2) by moist-soil plants on mudflats in Douglas Reservoir, 2005 and 2006.

	Douglas Reservoir[a]			
	2005[b,c]		2006	
Species	$\bar{x}$	SE	$\bar{x}$	SE
Ammania coccinea Rottb.	NE	NE	0.0152	0.0152
Aster lanceolatus Willd.	NE	NE	0.0036	0.0036
Bidens frondosa L.	NE	NE	0.0169	0.0169
Cuscuta sp.	NE	NE	6.7033	4.0828
Cyperus flavicomus Michx.	0.0534	0.0505	0.0873	0.0426
Echinochloa crus-galli (L.) Beauv.	0.2070	0.1886	0	0
Eleocharis obtusa (Willd.) Schult.	0.0004	0.0002	0.0006	0.0006
Eragrostis hypnoides (Lam.) B.S.P.	1.1403	0.5598	1.3740	0.7391
Fimbristylis vahlii (Lam.) Link	1.5356	1.4185	1.3375	1.3142
Ipomoea lacunosa L.	NE	NE	0.2231	0.1520
Lipocarpha micrantha (Vahl) G. Tucker	0.0324	0.0315	0.0167	0.0167
Polygonum lapathifolium L.	0.2077	0.2077	0	0
Mean Total Seed Yield per Plot	3.1795	1.4392	9.7783	4.3722

[a]No seed was produced by moist-soil plants on Chickamauga mudflats either year; thus, no comparisons were made between reservoirs.

[b]NE = seed production was not estimated for these species in 2005 and was not included in the 2005 total seed yield estimate.

[c]2005 total seed yield was calculated using average seed yield per plant estimates from 2006.

Table 18. Belowground seed biomass (g) in core samples (608.21-cm^3) per mudflat between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

		Year and Reservoir							
		2005/2006				2006/2007			
Seed		Douglas		Chickamauga		Douglas		Chickamauga	
Type[a]	Month	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
CB	August	0.1494	0	NT	NT	0.1378	0.0440	NT	NT
	September	0.2079	0.1218	NT	NT	0.0898	0.0780	NT	NT
	October	0.0202 A	0.0200	0 A	0	0.0050 A	0.0050	0.0049 A	0
	November	0.0091 A	0.0014	0 B	0	0.0032 A	0.0032	0 A	0
	December	0.0200 A	0.0107	0 B	0	0.0015 A	0.0015	0 A	0
	January	0.0051 A	0.0051	0 A	0	0.0072 A	0.0072	0 A	0
MS	August	0.1379	0	NT	NT	0.0853	0.0276	NT	NT
	September	0.0528	0.0059	NT	NT	0.0750	0.0411	NT	NT
	October	0.0194 A	0.0038	0.0253 A	0.0130	0.0225 A	0.0004	0.0533 A	0
	November	0.0192 A	0.0053	0.0115 A	0.0033	0.0166 A	0.0007	0.0141 A	0.0002
	December	0.0086 A	0.0041	0.0109 A	0.0022	0.0118 A	0.0014	0.0116 A	0.0033
	January	0.0139 A	0.0053	0.0113 A	0.0024	0.0125 A	0.0009	0.0140 A	0.0036
TR	August	0	0	NT	NT	0	0	NT	NT
	September	0	0	NT	NT	0.0013	0.0013	NT	NT
	October	0 A	0	0.0002 A	0.0002	0.0007 A	0.0007	0.0003 A	0
	November	0 A	0	0.0031 A	0.0031	0 A	0	0.0008 A	0.0008
	December	0.0005 A	0.0005	0.0018 A	0.0011	0 A	0	0.0025 A	0.0018
	January	0.0012 A	0.0012	0.0006 A	0.0003	0.0009 A	0.0009	0.0066 A	0.0059
TU	August	0	0	NT	NT	0.0005	0.0005	NT	NT
	September	0	0	NT	NT	0	0	NT	NT
	October	0 A	0	0 A	0	0 A	0	0 A	0
	November	0 A	0	0 A	0	0 A	0	0 A	0
	December	0.0011 A	0.0011	0 A	0	0 A	0	0 A	0
	January	0 A	0	0 A	0	0 A	0	0 A	0

Table 18 (continued).

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[a]CB = rough cockleburr seeds (*Xanthium strumarium* L.), MS = moist-soil seeds (e.g., *Cyperus, Echinochloa, Eragrostis*), TR = hard-mast tree seeds (e.g., *Acer, Quercus*), and TU = tubers.

[b]NT = differences in means not tested between reservoirs during August and September either year, because Chickamauga mudflats were inundated.

[c]Means within years and rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 19. Mudflat soil characteristics between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

			Year and Reservoir							
			2005/2006				2006/2007			
			Douglas		Chickamauga		Douglas		Chickamauga	
Metric[a]	Month	Age[b]	$\bar{x}$ [c,d]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
COMP	August	WI	20.00	0	NT	NT	20.28	14.09	NT	NT
	September		16.88	6.26	NT	NT	7.92	1.68	NT	NT
	October		30.97 A	18.47	67.50 A	4.33	24.86 A	7.36	43.75 A	0
	November		20.63 A	6.88	32.19 A	12.98	21.53 A	7.64	29.58 A	20.42
	December		18.96 A	5.63	35.10 A	11.44	40.63 A	21.46	46.08 A	15.20
	January		22.50 A	10.83	57.29 A	16.78	25.00 A	5.00	27.08 A	4.16
	August	PR	NT	NT	NT	NT	35.00	5.00	NT	NT
	September		63.33	31.14	NT	NT	60.42	20.06	NT	NT
	October		55.52	21.15	NT	NT	45.24	7.71	NT	NT
	November		26.01 A	3.31	63.33 A	14.42	32.19 A	2.81	85.00 A	0
	December		27.85 A	1.60	52.05 A	15.16	56.22 A	20.45	54.82 A	24.51
	January		25.83 A	0.83	48.58 A	12.74	39.76 A	6.90	45.28 A	27.36
MSTR	August	WI	92.67	0	NT	NT	99.75	0.08	NT	NT
	September		94.85	0.86	NT	NT	96.47	1.05	NT	NT
	October		94.46 A	1.38	97.58 A	0	94.42 A	3.25	98.63 A	0
	November		88.92 A	1.42	92.88 A	2.26	95.14 A	1.47	96.88 A	0.04
	December		90.44 A	3.61	95.75 A	0.36	92.67 A	0.92	94.50 A	1.70
	January		94.42 A	0.58	93.04 A	3.85	96.42 A	1.58	96.33 A	1.96
	August	PR	NT	NT	NT	NT	95.00	0	NT	NT
	September		93.22	1.47	NT	NT	91.92	1.45	NT	NT
	October		88.17 A	2.33	95.00 A	0	91.36	2.36	NT	NT
	November		93.87 A	0.27	84.50 A	4.27	91.44 A	0.19	97.60 A	0
	December		90.88 A	1.13	92.55 A	1.07	92.06 A	2.17	96.50 A	2.22
	January		95.50 A	0.17	94.92 A	1.74	97.95 A	1.38	97.47 A	0.12

Table 19 (continued).

			Year and Reservoir							
			2005/2006				2006/2007			
			Douglas		Chickamauga		Douglas		Chickamauga	
Metric[a]	Month	Age[b]	$\bar{x}$ [c,d]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
TEMP	August	WI	26.67	0	NT	NT	26.56	0.90	NT	NT
	September		23.78	0.33	NT	NT	20.96	0.45	NT	NT
	October		19.54 A	1.06	24.03 A	0	15.70 A	2.77	15.97 A	0
	November		10.81 A	0.16	11.64 A	1.88	9.84 A	2.85	11.78 A	1.09
	December		6.06 A	0.55	6.47 A	0.31	5.93 A	0.46	7.72 A	0.44
	January		6.53 A	0.23	9.65 A	0.70	6.76 A	3.15	7.66 A	0.59
	August	PR	NT	NT	NT	NT	26.94	2.50	NT	NT
	September		23.89	0.56	NT	NT	19.17	1.79	NT	NT
	October		20.04 A	0.52	22.22 A	0	15.86	1.70	NT	NT
	November		11.35 A	0.24	11.32 A	2.01	9.93 A	2.64	11.00 A	0
	December		6.34 A	0.51	6.52 A	0.15	5.47 A	0.60	7.62 A	0.48
	January		7.16 A	0.43	9.59 A	0.75	7.75 A	1.32	7.81 A	1.05

[a]COMP = soil compaction (lbs/in^2), MSTR = soil moisture (%), TEMP = soil temperature (˚C).

[b]Age refers to the duration of mudflat exposure at sampling locations; WI = water-interface transect at current shoreline during a sampling event, PR = previous transect midpoints from previous sampling events (see Figure 5).

[c]NT = differences in means not tested between reservoirs because either Chickamauga mudflats were inundated (i.e., August and September both years) or no previous sampling transects existed (i.e., October 2006, Age = PR).

[d]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 20. Simple linear regression models relating soil moisture (%) and compaction (lbs/in^2) on mudflats in Douglas and Chickamauga Reservoirs with duration of mudflat exposure, August 2005/2006 – January 2006/2007.

				Estimate				
Year	Reservoir	Model	Variable	Un-standardized	Standardized	*t*-value	*P*-value	R^2
2005	Douglas	Moisture	Intercept	94.9	0	52.3	<0.001	NA
			Weeks	-0.42	-0.25	1.9	0.058	0.06
		Compaction	Intercept	39.1	0	4.5	<0.001	NA
			Weeks	-0.06	-0.008	-0.06	0.952	<0.01
	Chickamauga	Moisture	Intercept	94.34	0	38.6	<0.001	NA
			Weeks	-0.48	-0.18	-1.3	0.19	0.03
		Compaction	Intercept	29.2	0	2.69	0.009	NA
			Weeks	4.72	0.36	2.91	0.005	0.13
2006	Douglas	Moisture	Intercept	95.1	0	60.2	<0.001	NA
			Weeks	-0.32	-0.21	-1.93	0.057	0.04
		Compaction	Intercept	37.1	0	5.39	<0.001	NA
			Weeks	0.72	0.11	1.02	0.313	0.01
	Chickamauga	Moisture	Intercept	97.9	0	42.1	<0.001	NA
			Weeks	-0.49	-0.25	-1.2	0.23	0.06
		Compaction	Intercept	25.6	0	1.25	0.23	NA
			Weeks	10.4	0.53	2.94	0.008	0.28

Table 21. Mean water depth (cm) and quality (mg/L) at mudflat shorelines between Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

			Reservoir				
			Douglas		Chickamauga		
Metric[a]	Year	Month	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	*P*-value
Depth	2005	August	1.60	0	NT	NT	NT
		September	16.37	6.73	NT	NT	NT
		October	26.95 A	24.82	12.10 A	0.36	1.000
		November	8.66 A	7.79	11.64 A	0.81	1.000
		December	28.53 A	25.53	15.68 A	2.55	1.000
		January	30.00 A	29.00	15.88 A	4.04	1.000
	2006	August	6.17	1.42	NT	NT	NT
		September	20.37	13.38	NT	NT	NT
		October	24.98 A	23.42	5.10 A	0	1.000
		November	26.05 A	21.75	17.58 A	4.08	1.000
		December	25.90 A	24.40	13.73 A	1.56	1.000
		January	26.05 A	24.55	13.53 A	2.08	1.000
NH_3		August	0.57	0.24	NT	NT	NT
		September	0.54	0.17	NT	NT	NT
		October	0.58 A	0.26	0.25 A	0	0.371
		November	0.52 A	0.40	0.13 A	0.01	1.000
		December	1.04 A	0.54	0.35 A	0.02	0.105
		January	0.62 A	0.19	0.20 A	0.08	0.105
NO_2		August	0.14	0.04	NT	NT	NT
		September	0.13	0.03	NT	NT	NT
		October	0.08 A	0.01	0.06 A	0	0.346
		November	0.09 A	0.01	0.12 A	0.04	1.000
		December	0.14 A	0.04	0.12 A	0.02	1.000
		January	0.13 A	0.01	0.13 A	0.03	1.000
NO_3		August	0.35	0.03	NT	NT	NT
		September	0.44	0.06	NT	NT	NT
		October	0.62 A	0.23	1.05 A	0	1.000
		November	0.41 A	0.02	0.46 A	0.05	0.699
		December	0.42 A	0.05	0.42 A	0.04	1.000
		January	0.47 A	0.01	0.46 A	0.01	0.481

[a]Depth = water depth, NH_3 = un-ionized ammonia, NO_2 = nitrite, NO_3 = nitrate.

[b]NT = differences in means not tested between reservoirs in August or September either year because Chickamauga mudflats were inundated.

Table 21 (continued).

[c]Means within rows followed by unlike letters are different ($P \leq 0.10$) by Wilcoxon two-sample test (i.e., normality was violated, Shapiro-Wilk test).

Table 22. Multiple linear regression models explaining significant variation in shorebird and waterfowl abundance on mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

Year	Group	Model[a]	Variable[b,c]	Estimates		*t*-value	*P*-value	Partial R^2	VIF[d]
				Un-standardized	Standardized				
2005	Shorebird	Acreage	Intercept	92.90	0	5.54	<0.0001	NA	0
			mn_mud	0.89	0.44	4.94	<0.0001	0.19	1.03
			mn_gage	-0.11	-0.47	-5.21	<0.0001	0.15	1.03
		Vegetation	Intercept	23.24	0	2.56	0.0171	NA	0
			mn_hc	-0.59	-0.87	-8.05	<0.0001	0.63	1.06
			period	4.88	0.31	2.86	0.0084	0.09	1.06
	Waterfowl	Acreage	Intercept	41.61	0	2.81	0.0061	NA	0
			period	2.50	0.32	3.33	0.0013	0.11	1.00
			mn_gage	-0.05	-0.31	-3.26	0.0016	0.10	1.00
		Substrate	Intercept	-289.08	0	-3.10	0.0037	NA	0
			mn_moist	2.66	0.37	2.77	0.0088	0.12	1.00
			mn_seed	537.60	0.47	2.46	0.0185	0.11	2.02
			period	6.78	0.65	3.42	0.0015	0.10	2.02
		Vegetation	Intercept	23.95	0	3.46	0.0019	NA	0
			mn_hc	-0.29	-0.44	-2.51	0.0186	0.20	1.00
2006	Shorebird	Acreage	Intercept	20.14	0	2.60	0.0110	NA	0
			mn_mud	1.51	0.43	3.38	0.0011	0.06	1.72
			mn_exp	-0.33	-0.29	-2.27	0.0257	0.05	1.72
		Substrate	Intercept	58.89	0	3.99	0.0003	NA	0
			mn_depth	-1.04	-0.27	-1.78	0.0830	0.08	1.00
		Vegetation	Intercept	106.57	0	3.47	0.0020	NA	0
			period	-14.96	-0.48	-2.68	0.0132	0.23	1.00
	Waterfowl	Acreage	Intercept	0.13	0	0.03	0.9790	NA	0
			period	1.32	0.20	2.02	0.0463	0.04	1.00
		Vegetation	Intercept	21.63	0	4.58	0.0001	NA	0
			period	-4.23	-0.79	-3.10	0.0052	0.26	2.67
			mn_vc	-0.40	-0.45	-2.73	0.0121	0.14	1.09
			mn_rich	2.27	0.45	1.73	0.0983	0.07	2.82

[a]Acreage variables included: mn_exp = percent exposure of total acreage, mn_gage = reservoir gage height (ft), mn_mud

Table 22 (continued).

= acreage of exposed mudflats (ha); substrate variables included: mn_comp = soil compaction (lbs/in^2), mn_depth = water depth (cm), mn_moist = percent soil moisture, mn_seed = moist-soil seed biomass (g/608.21-cm^3), mn_temp = soil temperature (˚C); vegetation variables included: mn_b25 = vegetation biomass (g/0.0625-m^2), mn_hc = horizontal cover of vegetation (%), mn_ht = vegetation height (cm), mn_rich = vegetation species richness (*S*), mn_vc = vertical cover of vegetation (%); and period = consecutive weeks in 2-week intervals from August through mid-January numbered 1 – 10 (2005/2006) and 1 – 12 (2006/2007).

[b]Habitat variables retained by stepwise selection process using entry and stay significance levels at $\alpha = 0.10$; all overall *F*-tests on final models were significant ($P \leq 0.083$) and coefficients of determination adjusted for number of variables in the model (i.e., $R^2_{adj} = 0.32$ and 0.70 for 2005 shorebird abundance: acreage and vegetation models, respectively; $R^2_{adj} = 0.19$, 0.28, and 0.16 for 2005 waterfowl abundance: acreage, substrate, and vegetation models, respectively; $R^2_{adj} = 0.09$, 0.05, and 0.20 for 2006 shorebird abundance: acreage, substrate, and vegetation models, respectively; $R^2_{adj} = 0.03$ and 0.39 for 2006 waterfowl abundance: acreage and vegetation models, respectively).

[c]All observations used in regression models represent means per mudflat per 2-week interval.

[d]VIF = variance inflation factor; VIF > 10 is suggestive of multicollinearity.

Table 23. Body size and migration distance classification (Skagen and Knopf 1993) of shorebird species observed using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

Body Size[a]	Species	Migration Distance[b]	Average Distance (km)[c]
L	American avocet	Short	2,100
M	killdeer		3,400
L	willet		3,600
M	Wilson's snipe		3,900
M	spotted sandpiper	Intermediate	6,300
M	dunlin		6,300
M	short-billed dowitcher		6,400
M	greater yellowlegs		6,700
M	long-billed dowitcher		8,900
S	least sandpiper		9,100
S	semipalmated plover		9,400
S	semipalmated sandpiper		9,500
S	western sandpiper		9,500
M	lesser yellowlegs		9,700
M	solitary sandpiper		9,800
M	sanderling		11,400
M	American golden-plover	Long	14,800
M	stilt sandpiper		15,000
M	pectoral sandpiper		16,500
S	Baird's sandpiper		16,700
M	buff-breasted sandpiper		16,800
S	white-rumped sandpiper		17,200

[a]S = small-sized ($\leq$190 mm in body length), M = medium-sized (195 – 350 mm), L = large-sized (>350 mm).

[b]Short = $\leq$ 3,900 km, Intermediate = 6,300 – 12,400 km, Long = $\geq$ 14,800 km.

[c]Average (one-way) migration distances were calculated by averaging the 1) shortest distance between breeding and wintering ranges, 2) the distance between the midpoints of the ranges, and 3) the distance between the extreme edges of the ranges (Skagen and Knopf 1993).

Table 24. Diurnal activity budgets of long-, intermediate-, and short-distance migrant shorebirds observed using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

	Migration Distance[a]					
	Long (n = 77)		Intermediate (n = 288)		Short (n = 746)	
Behavior	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE
Alert	0.22 Ca	0.11	0.80 Da	0.40	1.32 Da	0.32
Antagonistic	0.04 Ca	0.04	0.08 Da	0.04	0.19 Da	0.08
Feeding	80.06 Aa	3.50	74.84 Aa	1.89	37.28 Bb	1.35
Locomotion	5.85 BCb	1.07	10.47 Ba	1.07	9.55 Cab	0.56
Maintenance	4.66 BCa	2.07	5.77 Ca	1.19	6.32 Ca	0.70
Resting	8.51 Bb	2.41	7.87 BCb	1.13	45.35 Aa	1.29

[a]Classification based on migration distance index developed by Skagen and Knopf (1993).

[b]Means represented as percentage of time spent.

[c]Means within columns (i.e., within migration distance groupings) followed by unlike upper-case letters and means within rows (i.e., within activities) followed by unlike lower-case letter are different by repeated-measures analysis-of-variance and Tukey's HSD test ($P \leq 0.05$).

Table 25. Diurnal activity budgets of shorebirds species observed using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

		Behavior											
		Alert		Antagonistic		Feeding		Locomotion		Maintenance		Resting	
Species[a]	N	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
AMGP	4	0 Ca	0	0 Ca	0	9.6 BCd	3.1	17.5 Bbc	2.1	0 Ca	0	72.9 Aa	4.4
DUNL	14	0.5 Ba	0.5	0 Ba	0	63.9 Aabc	10.0	12.0 Bbc	5.7	19.8 Ba	9.6	3.8 Bc	1.7
GRYE	16	0.7 Ba	0.5	0.2 Ba	0.2	41.9 Abcd	8.7	26.1 ABb	7.7	20.4 ABa	9.6	10.6 Bc	5.7
KILL	530	0.8 Ea	0.3	0.3 Ea	0.1	25.7 Bcd	1.2	11.6 Cbc	0.7	8.0 Da	0.9	53.7 Aab	1.3
LESA	147	1.3 BCa	0.8	0 Ca	0	82.3 Aab	2.3	6.2 Bbc	1.1	3.7 BCa	1.3	6.2 Bc	1.4
LEYE	11	0 Ba	0	0 Ba	0	60.2 Aabc	12.0	12.3 Bbc	4.3	16.2 Ba	10.7	11.4 Bc	8.5
PESA	65	0.3 Ba	0.1	0.1 Ba	0.1	84.5 Aab	3.2	5.1 Bbc	1.1	3.9 Ba	2.0	5.4 Bc	2.0
SAND	10	0 Ca	0	0 Ca	0	77.2 Aab	5.3	19.7 Bbc	5.0	0.5 Ca	0.4	2.7 Cc	2.2
SBDO	4	0 Ba	0	0 Ba	0	87.1 Aab	7.2	4.2 Bc	2.5	2.9 Ba	2.9	5.8 Bc	5.3
SEPL	23	0 Ca	0	0.4 Ca	0.4	56.5 Aabc	7.9	9.9 Cbc	2.4	4.5 Ca	3.9	28.7 Bbc	5.8
SESA	37	0.3 Ba	0.2	0.2 Ba	0.2	86.4 Aab	3.5	5.2 Bbc	1.6	5.5 Ba	3.2	2.4 Bc	0.8
SOSA	4	0 Ba	0	0 Ba	0	70.8 Aabc	15.8	9.6 Bbc	5.8	0 Ba	0	19.6 Bbc	18.5
SPSA	15	0.9 Ba	0.9	0 Ba	0	42.6 Abcd	6.7	47.6 Aa	6.6	0.7 Ba	0.5	8.3 Bc	6.6
WESA	7	0 Ba	0	0 Ba	0	99.5 Aa	0.5	0 Bc	0	0.5 Ba	0.5	0 Bc	0
WISN	214	2.6 Ca	0.9	0 Ca	0	66.1 Aabc	2.7	4.0 Cc	0.6	2.0 Ca	0.8	25.2 Bbc	2.6

[a]AMGP = American golden-plover (*Pluvialis dominica*), DUNL = dunlin (*Calidris alpina*), GRYE = greater yellowlegs (*Tringa melanoleuca*), KILL = killdeer (*Charadrius vociferus*), LESA = least sandpiper (*Calidris minutilla*), LEYE = lesser yellowlegs (*T. flavipes*), PESA = pectoral sandpiper (*Calidris melanotos*), SAND = sanderling (*Calidris alba*), SBDO = short-billed dowitcher (*Limnodromus griseus*), SEPL = semipalmated plover (*Charadrius semipalmatus*), SESA = semipalmated sandpiper (*Calidris pusilla*), SOSA = solitary sandpiper (*T. solitaria*), SPSA = spotted sandpiper (*Actitis macularius*), WESA =

Table 25 (continued).

western sandpiper (*Calidris mauri*), WISN = Wilson's snipe (*Gallinago delicata*); species with ≥ 4 observations are represented.

[b]Means represented as percentage of time spent.

[c]Means within rows (i.e., within species) followed by unlike upper-case letters and means within columns (i.e., within activities) followed by unlike lower-case letters are different by repeated-measures analysis-of-variance and Tukey's HSD test ($P \leq 0.05$).

Table 26. Diurnal activity budgets of waterfowl species observed using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

		Behavior													
		Alert		Antagonistic		Courtship		Feeding		Locomotion		Maintenance		Resting	
Species[a]	N	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
ABDU	22	0.23 Cb	0.23	0 Ca	0	0 Ca	0	31.14 Abcd	6.95	38.94 Aab	7.89	5.45 BCa	3.78	24.24 ABbc	7.52
BWTE	8	0 Bb	0	0 Ba	0	0 Ba	0	18.96 Bd	12.77	6.04 Bc	4.96	14.58 Ba	11.80	60.42 Aa	17.40
CAGO	70	9.93 BCa	2.82	0 Ca	0	0 Ca	0	22.26 ABd	4.06	29.57 Aabc	4.34	11.95 BCa	2.98	26.29 Ab	3.79
GADW	89	1.48 Cab	1.10	0 Ca	0	0 Ca	0	55.45 Aabc	3.66	31.06 Babc	3.26	3.16 Ca	1.52	8.85 Cbcd	2.39
GWTE	30	0.56 Cb	0.56	0.11 Ca	0.11	0 Ca	0	67.97 Aa	7.27	20.92 Bbc	6.15	3.28 Ca	2.94	7.17 BCbcd	4.58
HOME	70	0 Cb	0	0.14 Ca	0.11	1.74 Ca	1.46	27.61 Bcd	3.44	58.25 Aa	3.89	7.04 Ca	2.48	5.22 Ccd	1.84
MALL	151	0.99 DEab	0.46	0.01 Ea	0.01	0.14 Ea	0.14	46.84 Aabcd	3.16	31.04 Babc	2.71	12.53 Ca	2.26	8.44 CDbcd	1.68
NSHO	21	0 Cb	0	0 Ca	0	0 Ca	0	60.00 Aab	9.20	30.16 Babc	8.44	0.16 Ca	0.16	9.68 BCbcd	6.55
WODU	19	0.26 Bb	0.26	0 Ba	0	0 Ba	0	38.29 Aabcd	7.98	55.66 Aa	7.93	4.47 Ba	3.33	1.32 Bd	0.84

[a]ABDU = American black duck (*Anas rubripes*), BWTE = blue-winged teal (*Anas discors*), CAGO = Canada goose (*Branta canadensis*), GADW = gadwall (*Anas strepera*), GWTE = American green-winged teal (*Anas crecca*), HOME = hooded merganser (*Lophodytes cucullatus*), MALL = mallard (*Anas platyrhynchos*), NSHO = northern shoveler (*Anas clypeata*), WODU = wood duck (*Aix sponsa*); species with ≥ 4 observations are represented.

[b]Means represented as percentage of time spent.

[c]Means within rows (i.e., within species) followed by unlike upper-case letters and means within columns (i.e., within activities) followed by unlike lower-case letters are different by repeated-measures analysis-of-variance and Tukey's HSD test ($P \leq 0.05$).

Table 27. Foraging techniques of waterfowl observed using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

		Foraging Technique					
		Surface-feeding		Tipping		Diving	
Species[a]	N	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE
ABDU	14	94.53 Aa	3.77	5.47 Ba	3.77	0 Bb	0
GADW	79	96.64 Aa	1.93	3.36 Ba	1.93	0 Bb	0
GWTE	25	100.00 Aa	0	0 Ba	0	0 Bb	0
HOME	42	22.27 Bb	5.73	0 Ca	0	77.73 Aa	5.73
MALL	116	97.34 Aa	1.16	2.66 Ba	1.16	0 Bb	0
NSHO	17	99.26 Aa	0.74	0.74 Ba	0.74	0 Bb	0
WODU	15	100.00 Aa	0	0 Ba	0	0 Bb	0

[a]ABDU = American black duck (*Anas rubripes*), GADW = gadwall (*Anas strepera*), GWTE = American green-winged teal (*Anas crecca*), HOME = hooded merganser (*Lophodytes cucullatus*), MALL = mallard (*Anas platyrhynchos*), NSHO = northern shoveler (*Anas clypeata*), WODU = wood duck (*Aix sponsa*); species with ≥ 4 observations are represented.

[b]Means represented as percentage of foraging time spent.

[c]Means within rows (i.e., within species) followed by unlike upper-case letters and means within columns (i.e., within foraging techniques) followed by unlike lower-case letters are different by repeated-measures analysis-of-variance and Tukey's HSD test ($P \leq 0.05$).

Table 28. Diurnal activity budgets of other waterbirds[a] observed using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007.

		Behavior											
		Alert		Antagonistic		Feeding		Locomotion		Maintenance		Resting	
Species[b]	n	$\bar{x}$ [c,d]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
AMCO	6	0 Ba	0	0 Ba	0	5.28 ABab	3.66	52.50 Aab	18.34	5.00 ABbc	5.00	37.22 ABabc	20.19
AWPE	6	0 Aa	0	0 Aa	0	0 Ab	0	16.67 Abc	16.67	38.33 Aa	16.85	45.00 Aabc	17.50
BOGU	11	0 Ca	0	0 Ca	0	0.45 Cb	0.32	12.88 BCbc	6.06	35.15 ABab	10.17	51.52 Aabc	10.71
DCCO	17	0 Ba	0	0 Ba	0	21.47 Ba	8.39	52.65 Aab	10.58	5.20 Bbc	5.20	20.69 Bbc	9.48
GBHE	443	14.46 Ba	1.43	0.19 Da	0.18	1.36 Db	0.29	14.33 Bbc	1.30	6.81 Cabc	0.96	62.85 Aab	2.05
GREG	131	8.05 BCa	1.65	0 Ca	0	7.53 BCab	1.58	36.67 Aabc	3.47	17.25 Babc	2.85	30.50 Aabc	3.14
GRHE	12	0.42 Ba	0.42	0 Ba	0	0 Bb	0	17.78 Bbc	8.81	0 Bc	0	81.81 Aa	9.13
LBHE	7	2.01 Ba	1.33	0 Ba	0	20.14 Ba	9.93	63.57 Aa	14.03	7.14 Babc	7.14	7.14 Bc	4.67
PBGR	8	0 Ba	0	0 Ba	0	19.17 Ba	11.65	64.58 Aa	12.80	5.83 Babc	2.85	10.42 Bbc	8.67
RBGU	104	1.66 Ca	0.79	0.05 Ca	0.05	5.46 Cab	1.48	36.65 Aabc	3.93	18.00 Babc	3.17	38.19 Aabc	3.78
SACR	30	17.56 Ba	5.35	0 Ba	0	14.00 Bab	5.27	6.00 Bc	2.42	18.61 Babc	5.53	43.83 Aabc	6.92

[a]Other waterbirds include additional wetland-dependent species (Weller 1999).

[b]AMCO = American coot (*Fulica americana*), AWPE = American white pelican (*Pelecanus erythrorhynchos*), BOGU = Bonaparte's gull (*Larus philadelphia*), DCCO = double-crested cormorant (*Phalacrocorax auritus*), GBHE = great blue heron (*Ardea herodias*), GREG = great egret (*A. alba*), GRHE = green heron (*Butorides virescens*), LBHE = little blue heron (*Egretta caerulea*), PBGR = pied-billed grebe (*Podilymbus podiceps*), RBGU = ring-billed gull (*L. delawarensis*), SACR = Sandhill crane (*Grus canadensis*); species with ≥ 4 observations are represented.

[c]Means are represented as percentage of time spent.

Table 28 (continued).

[d]Means within rows (i.e., within species) followed by unlike upper-case letters and means within columns (i.e., within activities) followed by unlike lower-case letters are different by repeated-measure analysis-of-variance and Tukey's HSD test ($P \leq 0.05$).

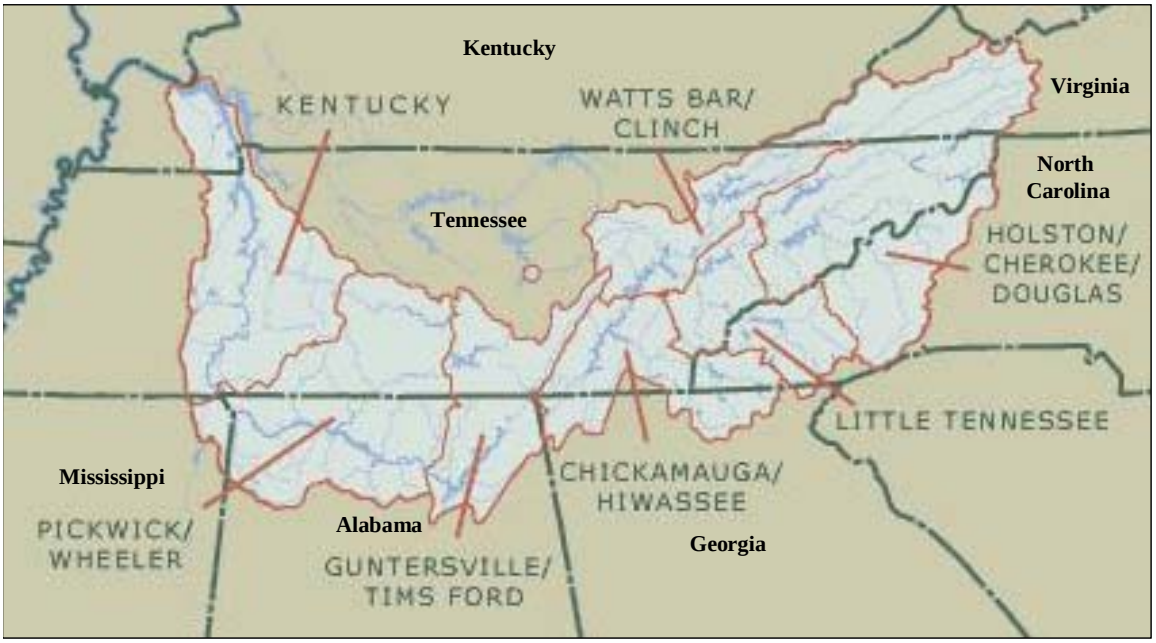


Figure 1. The Tennessee River Valley spans 106,190 km^2 and encompasses portions of seven southeastern states (SOURCE: http://www.tva.gov).

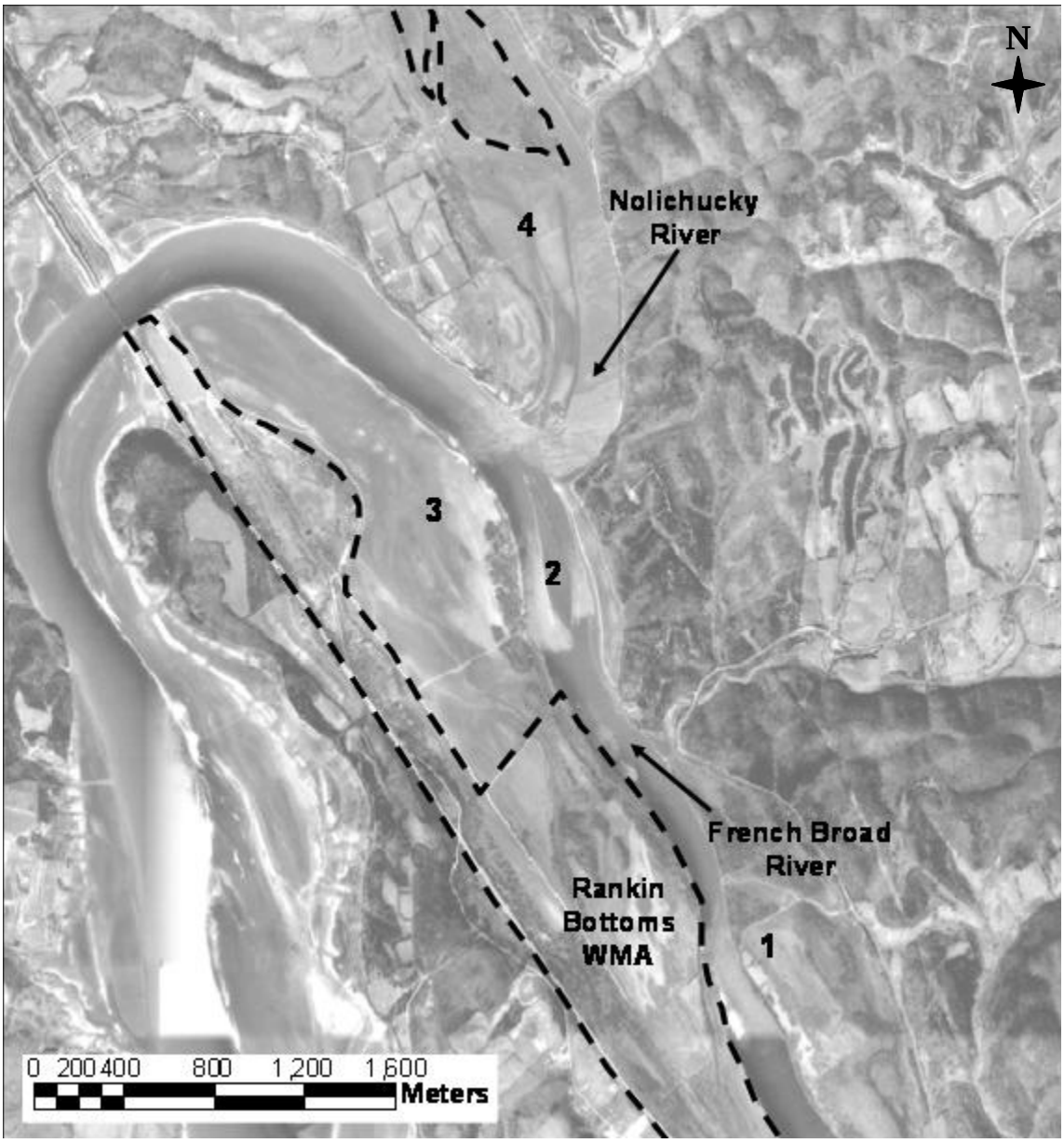


Figure 2. Mudflat locations (1-4) in Douglas Reservoir in relationship to Rankin Bottoms Wildlife Management Area (WMA) in Cocke (1,2), Jefferson (3), and Hamblen (4) counties, Tennessee, USA.

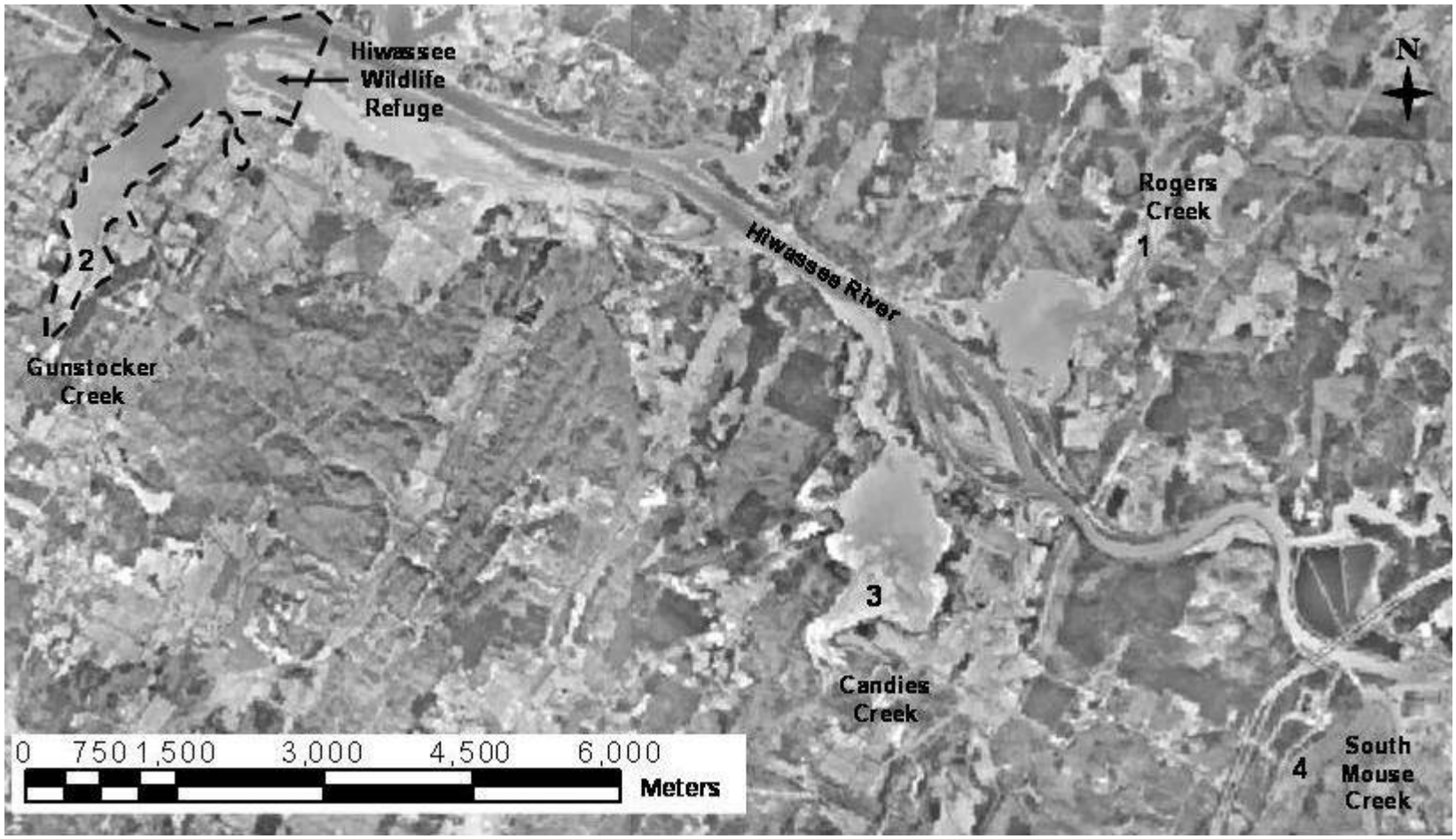


Figure 3. Mudflat locations (1-4) in Chickamauga Reservoir in relationship to Hiwassee Wildlife Refuge in McMinn (1), Meigs (2), and Bradley (3,4) counties, Tennessee, USA.

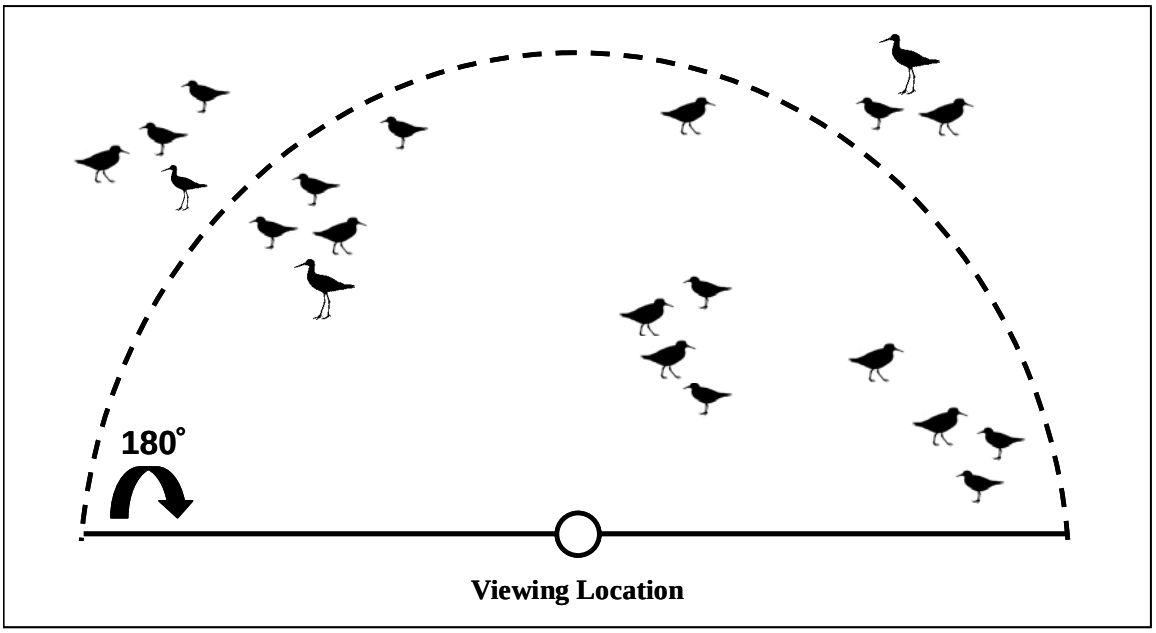


Figure 4. Waterbird survey design schematic at a permanent viewing location at each mudflat.

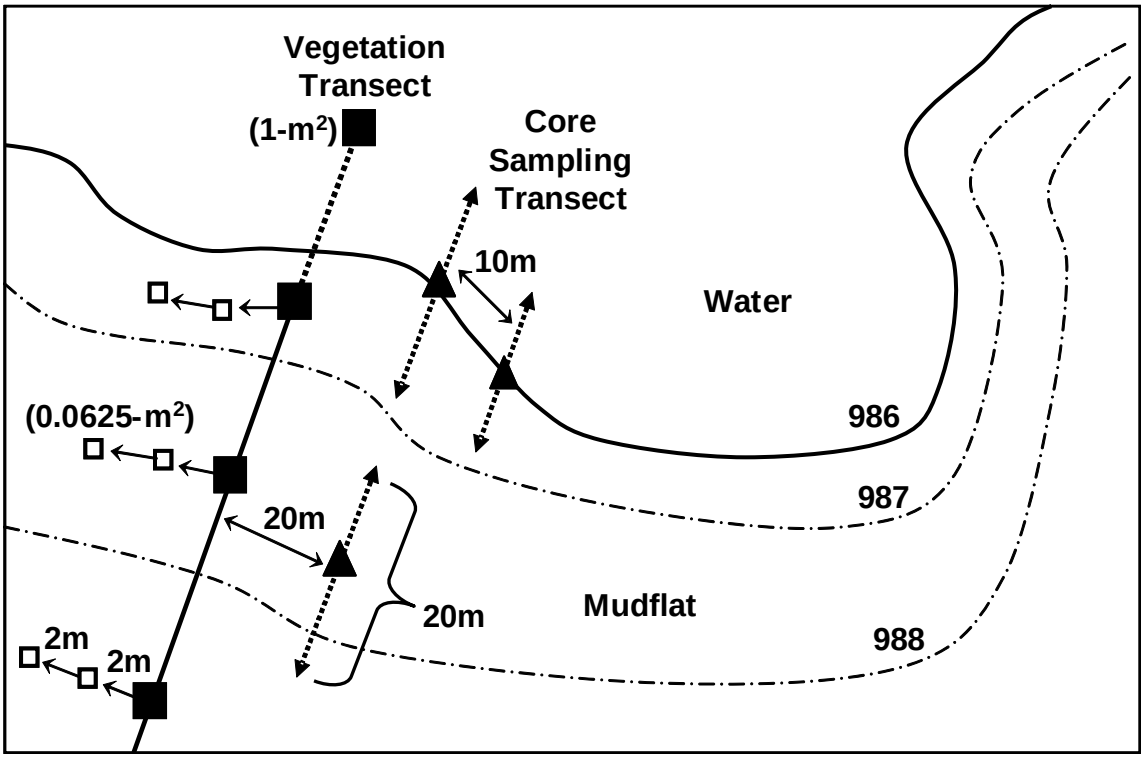


Figure 5. Schematic of vegetation and core sampling transects positioned on a typical mudflat.



Figure 6. Modified profile board (Nudds 1977) used to estimate vertical coverage of vegetation.

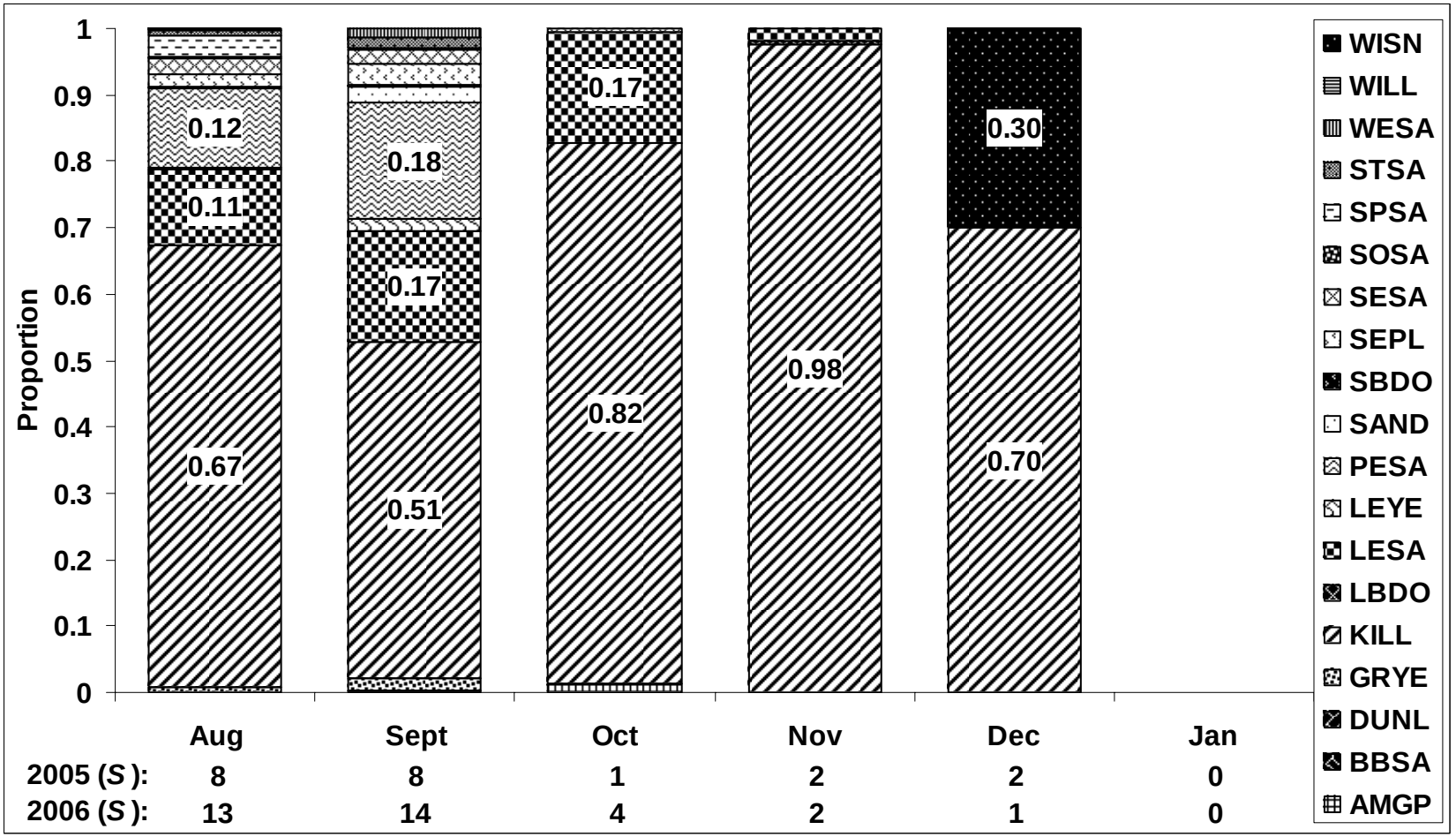


Figure 7. Species composition and monthly richness (*S*) of shorebirds observed using four mudflats in Douglas Reservoir in east Tennessee from August 2005/2006 – January 2006/2007 with years combined. AMGP = American golden-plover (*Pluvialis*

Figure 7 (continued).

dominica), BBSA = buff-breasted sandpiper (*Tryngites subruficollis*), DUNL = dunlin (*Calidris alpina*), GRYE = greater yellowlegs (*Tringa melanoleuca*), KILL = killdeer (*Charadrius vociferus*), LBDO = long-billed dowitcher (*Limnodromus scolopaceus*), LESA = least sandpiper (*Calidris minutilla*), LEYE = lesser yellowlegs (*Tringa flavipes*), PESA = pectoral sandpiper (*Calidris melanotos*), SAND = sanderling (*Calidris alba*), SBDO = short-billed dowitcher (*L. griseus*), SEPL = semipalmated plover (*Charadrius semipalmatus*), SESA = semipalmated sandpiper (*Calidris pusilla*), SOSA = solitary sandpiper (*Tringa solitaria*), SPSA = spotted sandpiper (*Actitis macularius*), STSA = stilt sandpiper (*Calidris himantopus*), WESA = western sandpiper (*Calidris mauri*), WILL = willet (*Tringa semipalmata*), WISN = Wilson's snipe (*Gallinago delicata*). If viewing this document in .pdf format, zoom in for full resolution.

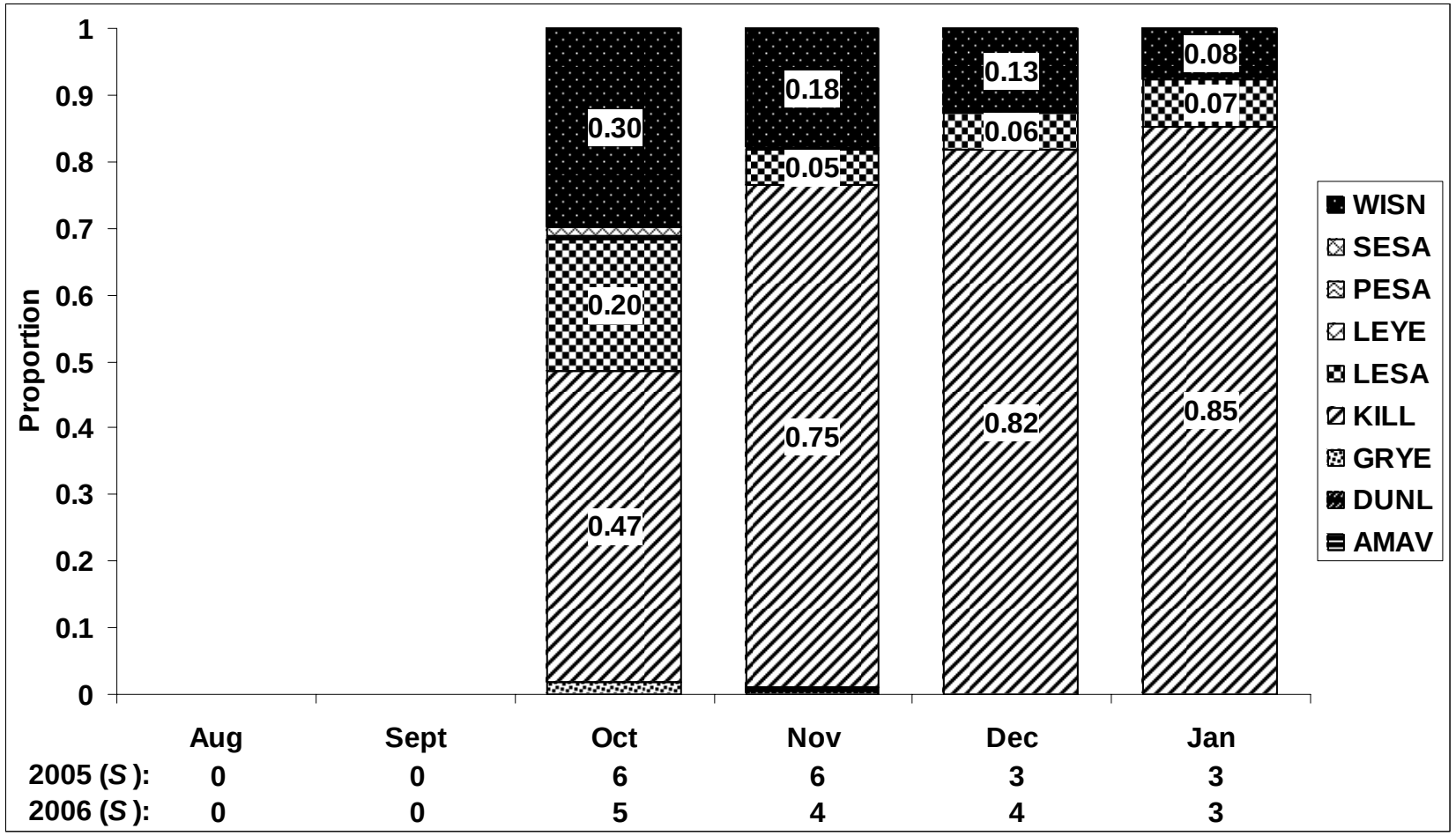


Figure 8. Species composition and monthly richness (*S*) of shorebirds observed using four mudflats in Chickamauga Reservoir in east Tennessee, August 2005/2006 – January 2006/2007 with years combined. AMAV = American avocet (*Recurvirostra americana*), DUNL = dunlin (*Calidris alpina*), GRYE = greater yellowlegs (*Tringa melanoleuca*), KILL = killdeer (*Charadrius*

Figure 8 (continued).

vociferus), LESA = least sandpiper (*Calidris minutilla*), LEYE = lesser yellowlegs (*T. flavipes*), PESA = pectoral sandpiper (*Calidris melanotos*), SESA = semipalmated sandpiper (*Calidris pusilla*), WISN = Wilson's snipe (*Gallinago delicata*). If viewing this document in .pdf format, zoom in for full resolution.

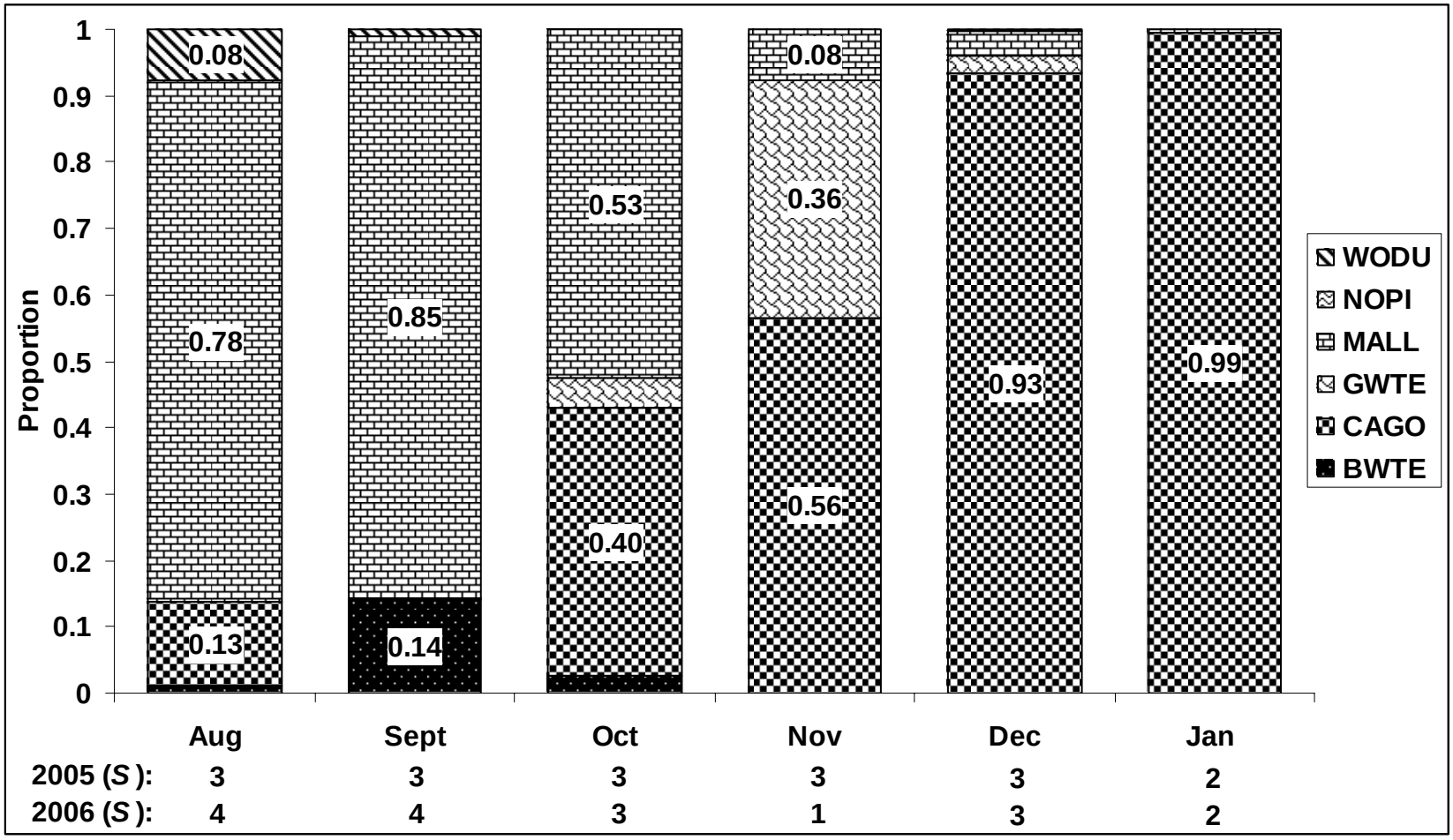


Figure 9. Species composition and monthly richness (*S*) of waterfowl observed using four mudflats in Douglas Reservoir in east Tennessee, August 2005/2006 – January 2006/2007 with years combined. BWTE = blue-winged teal (*Anas discors*), CAGO =

Figure 9 (continued).

Canada goose (*Branta canadensis*), GWTE = American green-winged teal (*Anas crecca*), MALL = mallard (*Anas platyrhynchos*), NOPI = northern pintail (*Anas acuta*), WODU = wood duck (*Aix sponsa*). If viewing this document in .pdf format, zoom in for full resolution.

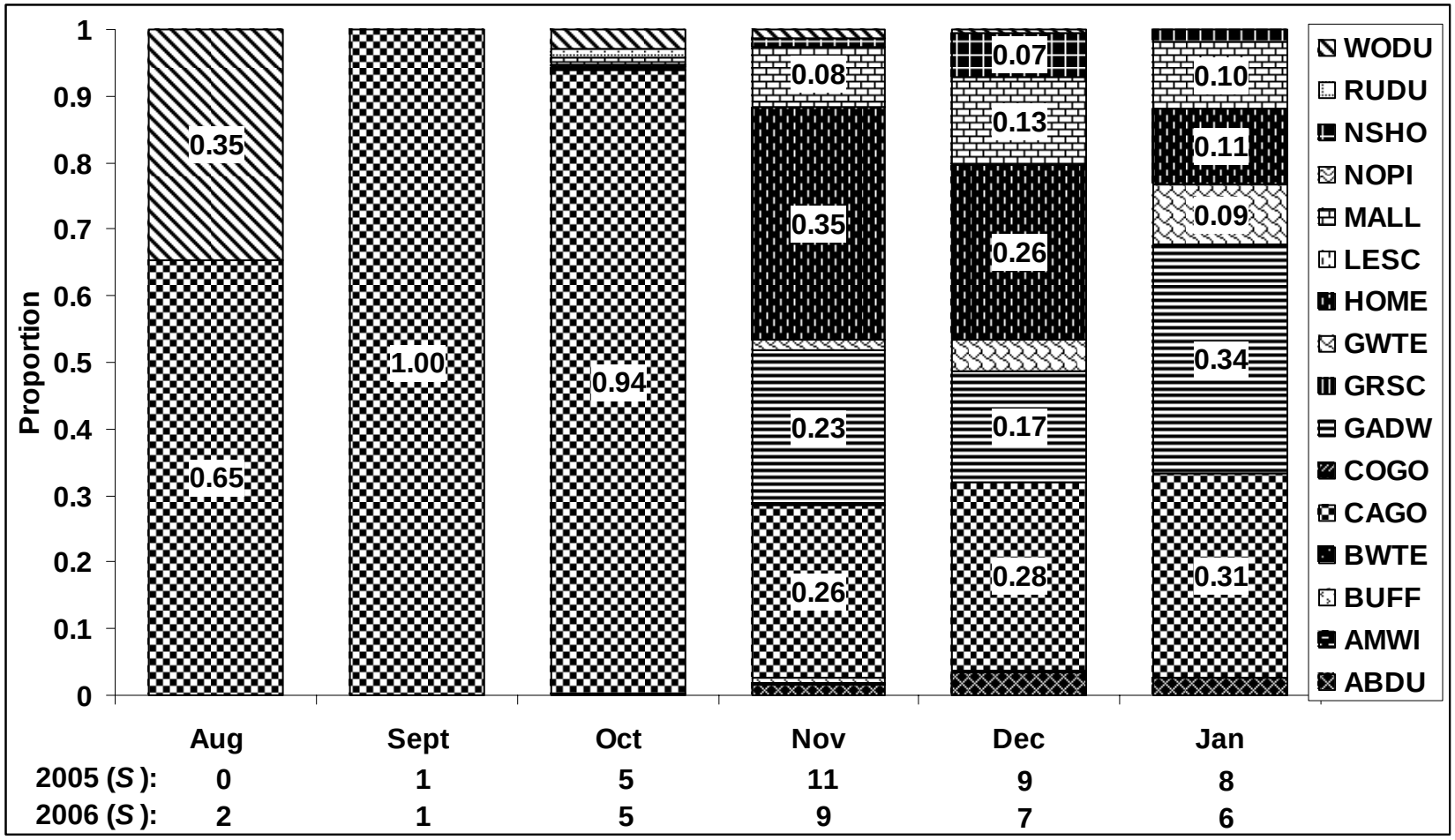


Figure 10. Species composition and monthly richness (*S*) of waterfowl observed using four mudflats in Chickamauga Reservoir in east Tennessee, August 20005/2006 – January 2006/2007 with years combined. ABDU = American black duck (*Anas rubripes*), AMWI = American wigeon (*Anas americana*), BUFF = bufflehead (*Bucephala albeola*), BWTE = blue-winged teal

Figure 10 (continued).

(*Anas discors*), CAGO = Canada goose (*Branta canadensis*), COGO = common goldeneye (*Bucephala clangula*), GADW = gadwall (*Anas strepera*), GRSC = greater scaup (*Aythya marila*), GWTE = American green-winged teal (*Anas crecca*), HOME = hooded merganser (*Lophodytes cucullatus*), LESC = lesser scaup (*Aythya affinis*), MALL = mallard (*Anas platyrhynchos*), NOPI = northern pintail (*Anas acuta*), NSHO = northern shoveler (*Anas clypeata*), RUDU = ruddy duck (*Oxyura jamaicensis*), WODU = wood duck (*Aix sponsa*). If viewing this document in .pdf format, zoom in for full resolution.

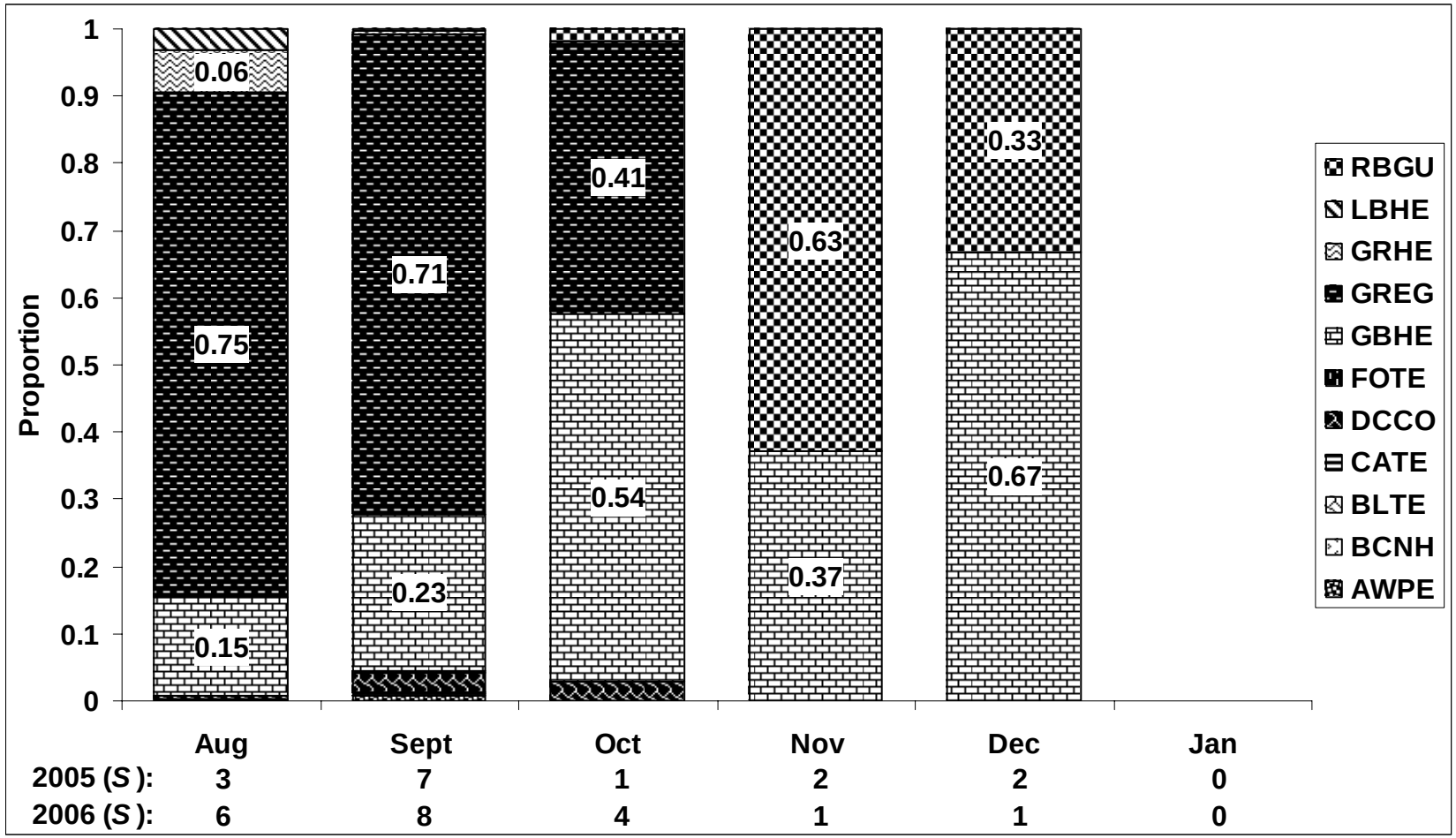


Figure 11. Species composition and monthly richness (*S*) of additional wetland-dependent species (i.e., other waterbirds) observed using four mudflats in Douglas Reservoir in east Tennessee, August 2005/2006 – January 2006/2007 with years

Figure 11 (combined).

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combined. AWPE = American white pelican (*Pelecanus erythrorhynchos*), BCNH = black-crowned night-heron (*Nycticorax nycticorax*), BLTE = black tern (*Chlidonias niger*), CATE = Caspian tern (*Hydroprogne caspia*), DCCO = double-crested cormorant (*Phalacrocorax auritus*), FOTE = Forster's tern (*Sterna forsteri*), GBHE = great blue heron (*Ardea herodias*), GREG = great egret (*A. alba*), GRHE = green heron (*Butorides virescens*), LBHE = little blue heron (*Egretta caerulea*), RBGU = ring-billed gull (*Larus delawarensis*). If viewing this document in .pdf format, zoom in for full resolution.

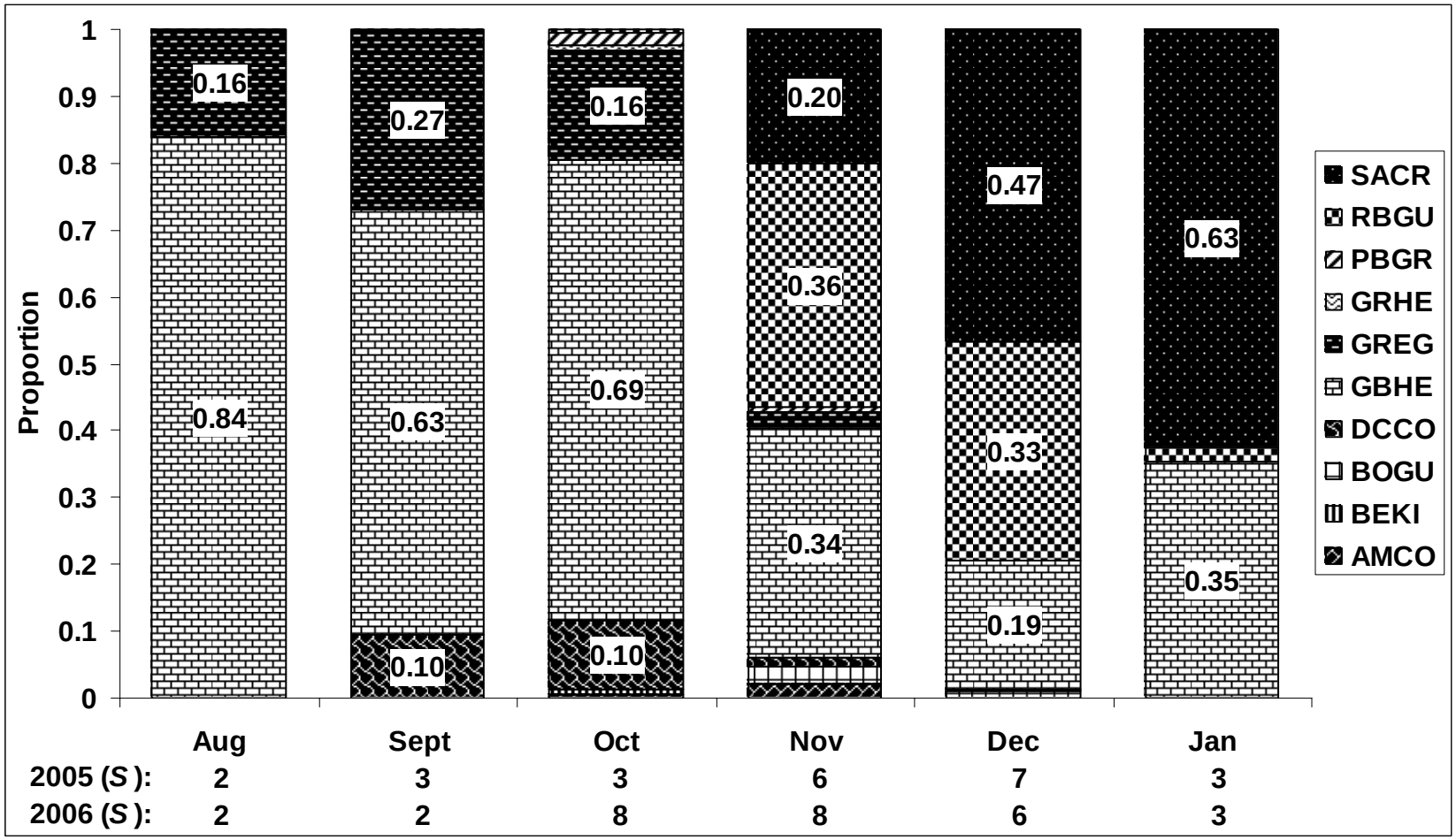


Figure 12. Species composition and monthly richness (*S*) of additional wetland-dependent species (i.e., other waterbirds) observed using four mudflats in Chickamauga Reservoir in east Tennessee, August 2005/2006 – January 2006/2007 with years

Figure 12 (continued).

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combined. AMCO = American coot (*Fulica americana*), BEKI = belted kingfisher (*Megaceryle alcyon*), BOGU = Bonaparte's gull (*Larus philadelphia*), DCCO = double-crested cormorant (*Phalacrocorax auritus*), GBHE = great blue heron (*Ardea herodias*), GREG = great egret (*A. alba*), GRHE = green heron (*Butorides virescens*), PBGR = pied-billed grebe (*Podilymbus podiceps*), RBGU = ring-billed gull (*L. delawarensis*), SACR = sandhill crane (*Grus canadensis*). If viewing this document in .pdf format, zoom in for full resolution.

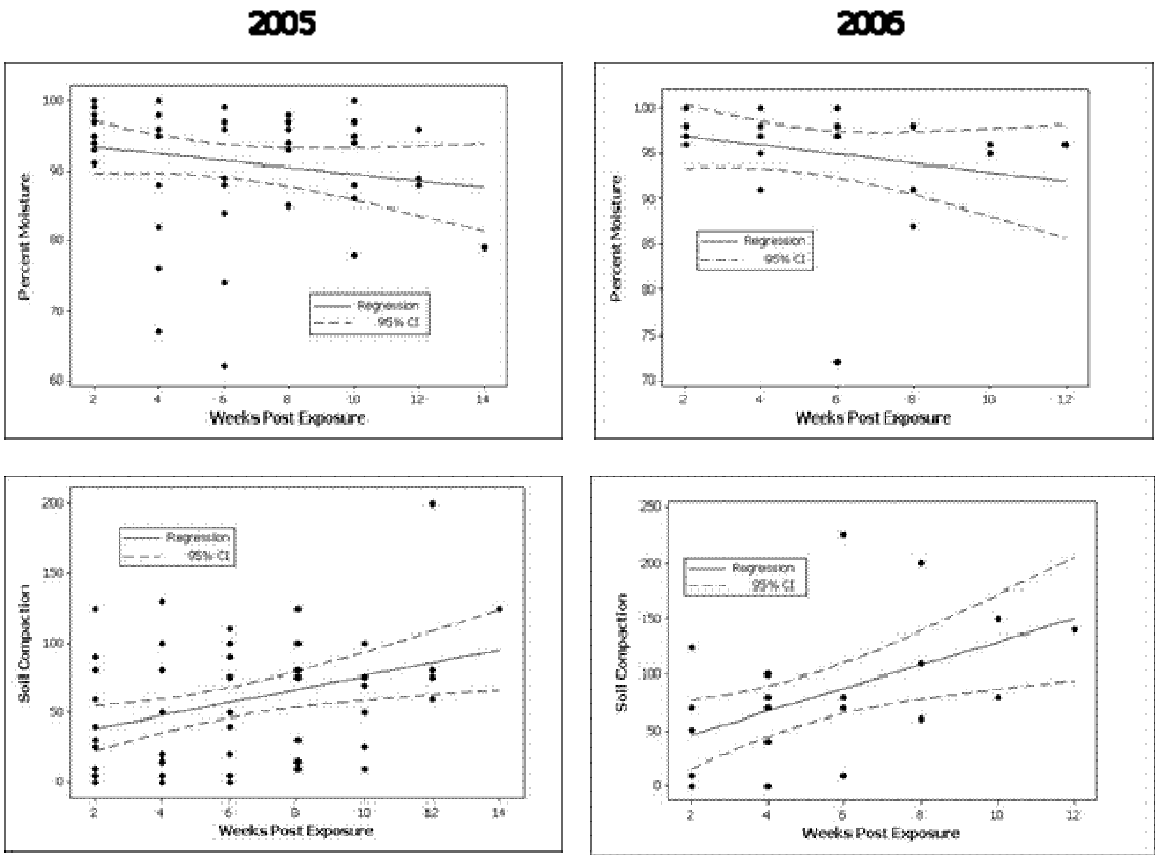


Figure 13. Soil moisture (%) and compaction (lbs/in^2) on mudflats in Chickamauga Reservoir following exposure, October – January 2005 (left) and 2006 (right). If viewing this document in .pdf format, zoom in for full resolution.

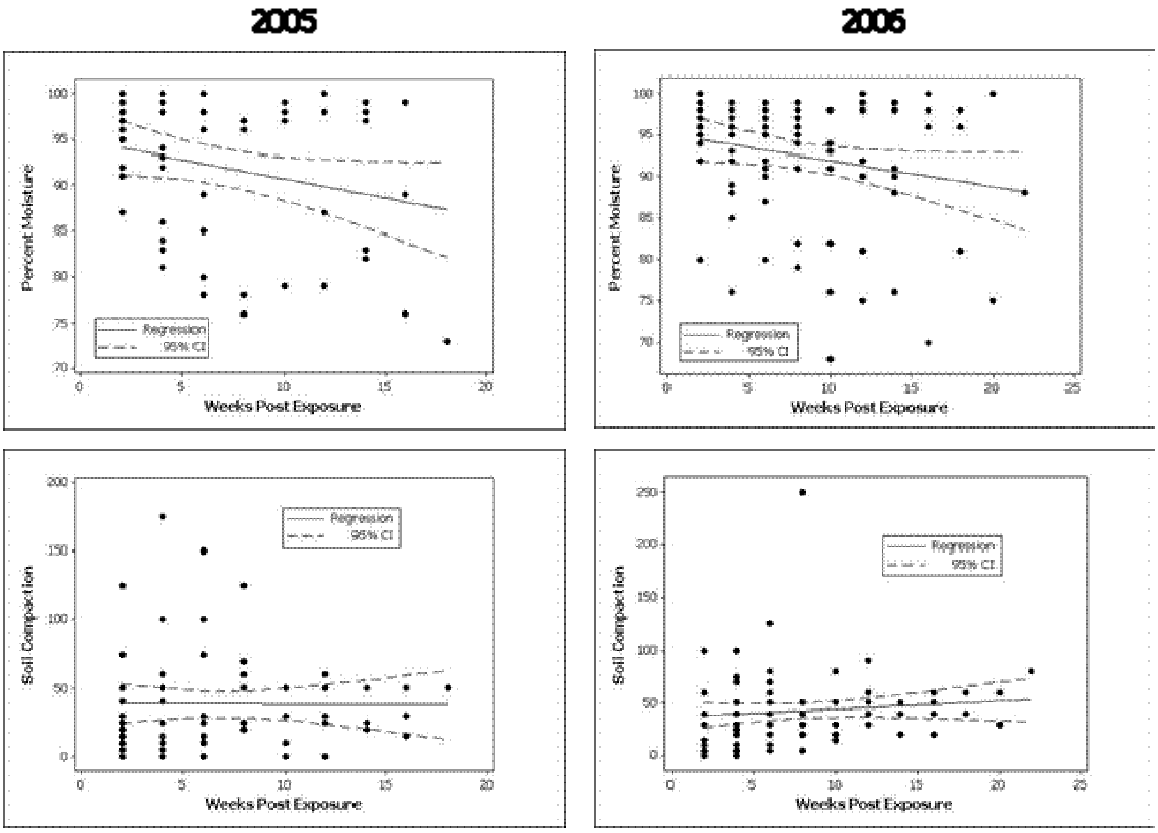
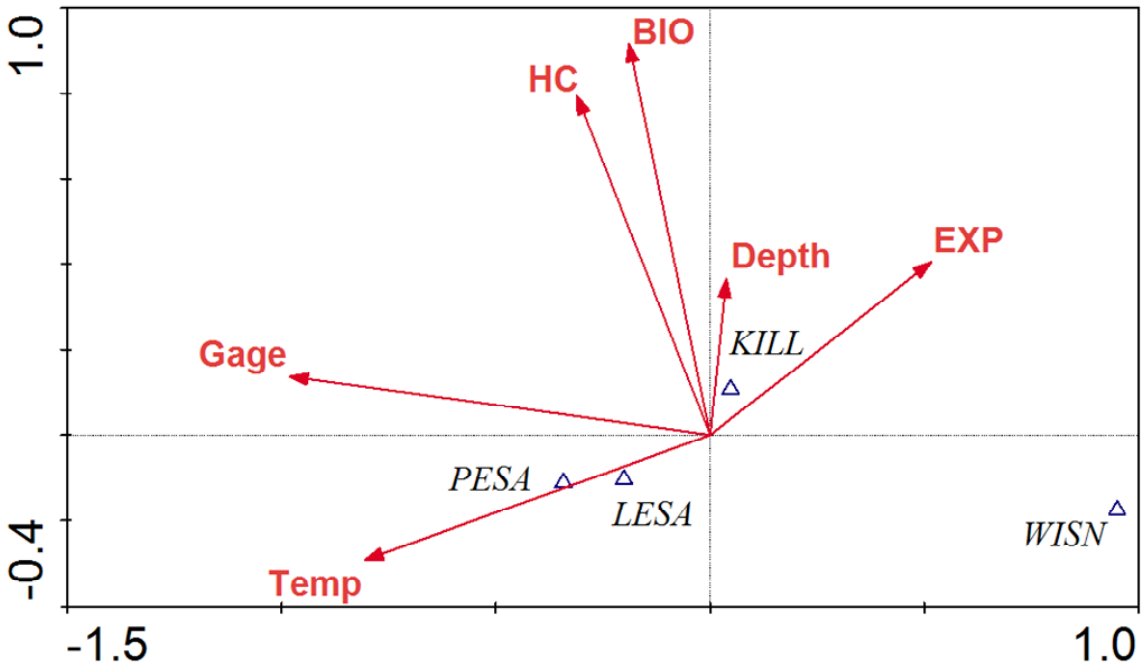


Figure 14. Soil moisture (%) and compaction (lbs/in^2) on mudflats in Douglas Reservoir following exposure, August – January 2005 (left) and 2006 (right). If viewing this document in .pdf format, zoom in for full resolution.

a)



b)

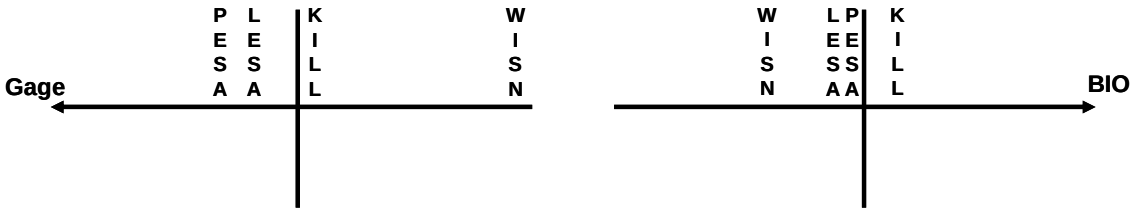


Figure 15. Canonical correspondence analysis of shorebird abundance (natural-log transformed) and habitat variables associated with eight mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August – January 2005-2006 and 2006-2007. (a) Species-environmental biplot where the length of eigenvectors represents the strength of the correlation between each habitat variable and the pattern of shorebird community composition; species closest to an eigenvector are most strongly associated with the corresponding habitat variable; BIO = vegetation biomass (g/0.0625-m^2), Depth = water

Figure 15 (continued).

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depth (cm), EXP = percent exposure of total mudflat acreage, Gage = reservoir gage height (ft), HC = percent horizontal coverage of vegetation, Temp = soil temperature (˚C). Shorebird species were KILL = killdeer (*Charadrius vociferus*), LESA = least sandpiper (*Calidris minutilla*), PESA = pectoral sandpiper (*Calidris melanotos*), and WISN = Wilson's snipe (*Gallinago delicata*). (b) Inferred ranking of species with significant habitat variables based on interpretation of biplots (see Figure 13 part a); the ranking was determined after extending the end of each eigenvector through the origin of the biplot and drawing intersecting orthogonal lines from each species to the eigenvector; the vertical segment bisecting each inferred ranking represents the origin of the biplot; species closer to the arrowhead end of the eigenvector are more positively correlated with the habitat variable. Conversely, species closer to the blunt end of the eigenvector are more negatively correlated with the habitat variable.

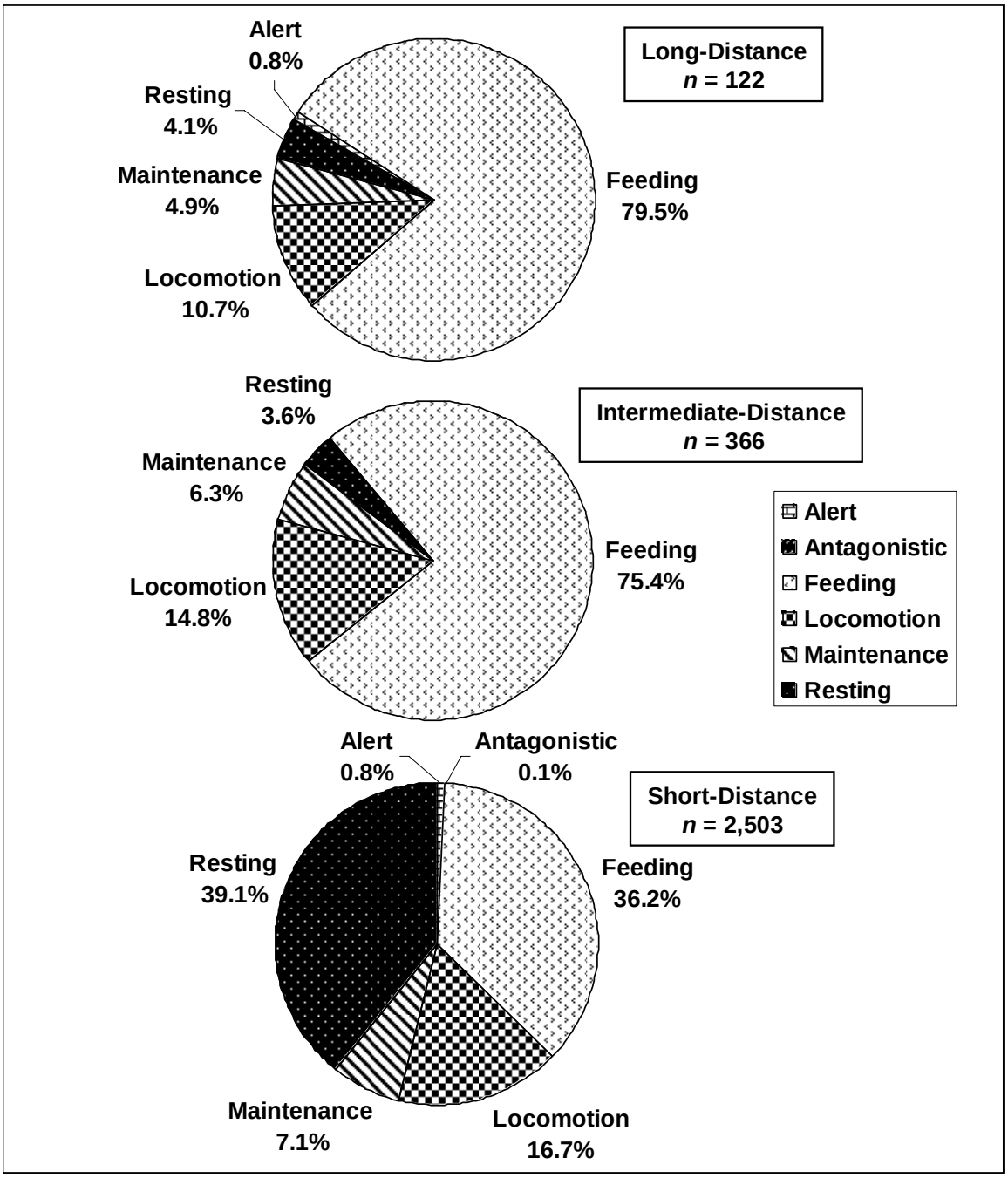


Figure 16. Percent occurrence of activities exhibited by long-, intermediate-, and short-distance migrant shorebirds using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007 (i.e., see Table 23 for classification of species based on average migration distance [Skagen and Knopf 1993]).

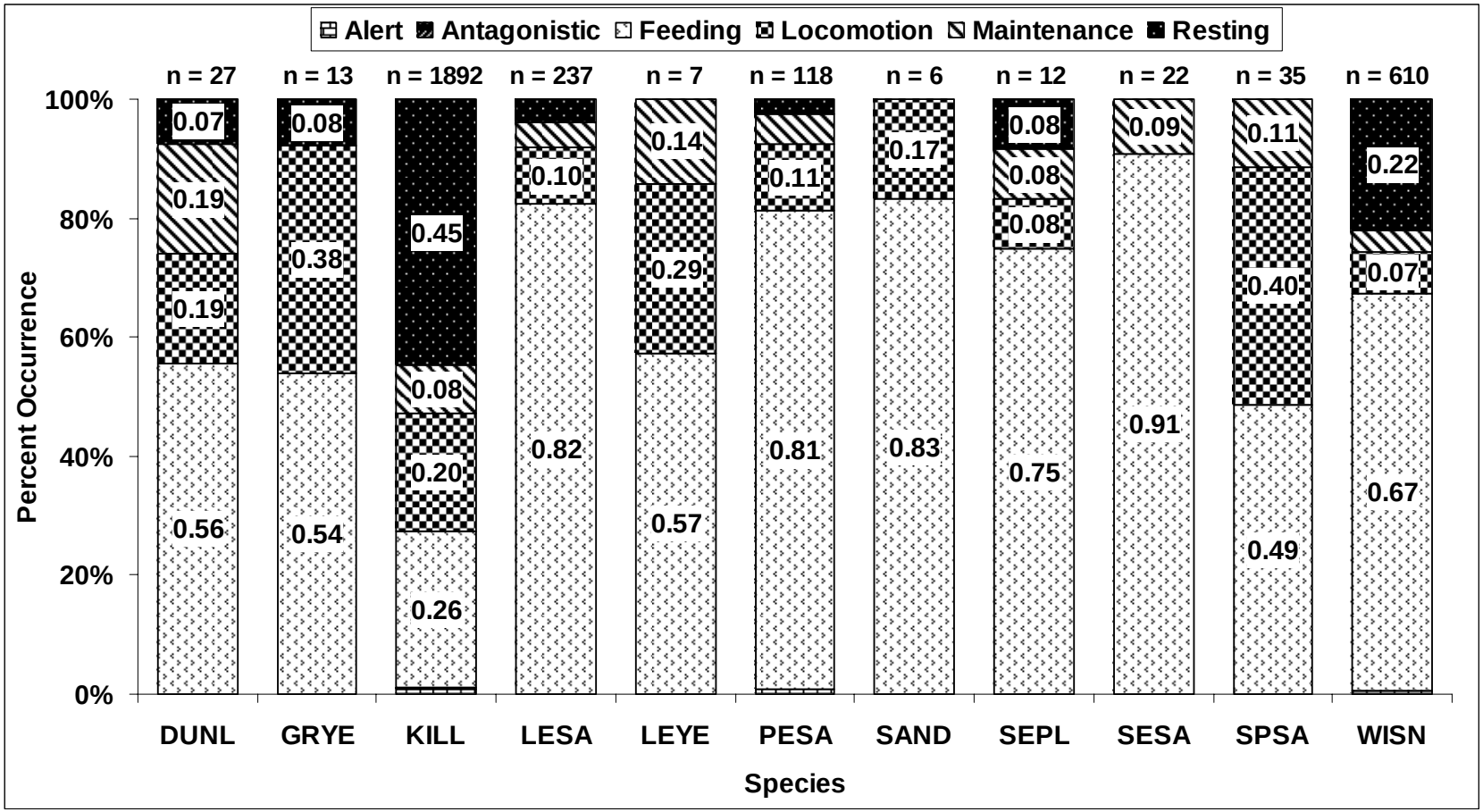
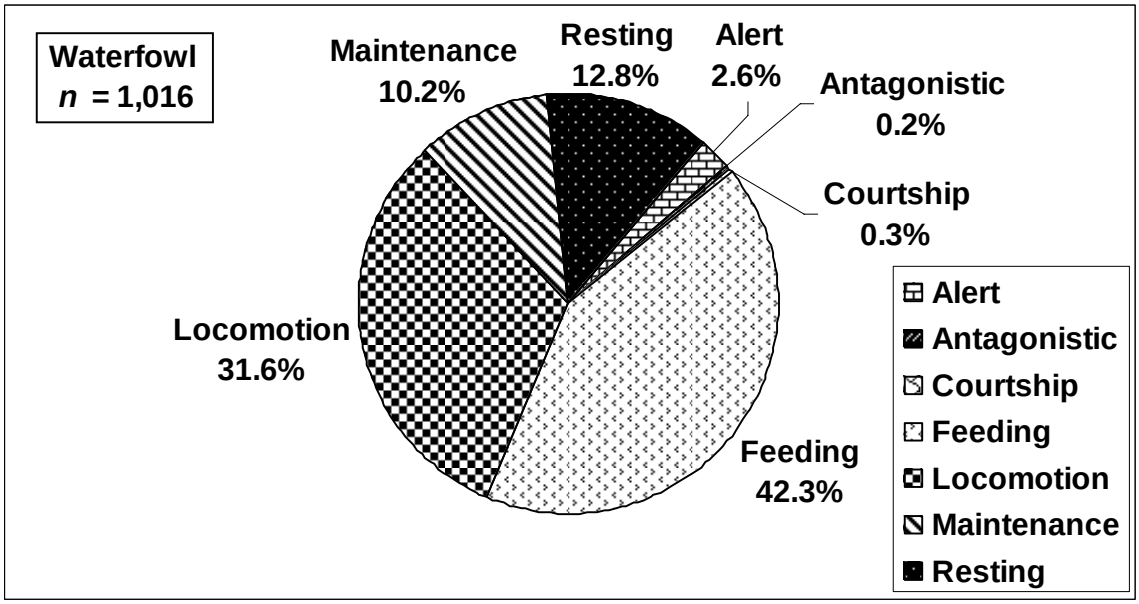


Figure 17. Percent occurrence of activities exhibited by individual shorebird species using mudflats in Douglas and Chickamauga Reservoirs, August 2005/2006 – January 2006/2007. DUNL = dunlin (*Calidris alpina*), GRYE = greater yellowlegs (*Tringa melanoleuca*), KILL = killdeer (*Charadrius vociferus*), LESA = least sandpiper (*Calidris minutilla*), LEYE = lesser yellowlegs

Figure 17 (continued).

(*T. flavipes*), PESA = pectoral sandpiper (*Calidris melanotos*), SAND = sanderling (*Calidris alba*), SEPL = semipalmated plover (*Charadrius semipalmatus*), SESA = semipalmated sandpiper (*Calidris pusilla*), SPSA = spotted sandpiper (*Actitis macularius*), WISN = Wilson's snipe (*Gallinago delicata*). If viewing this document in .pdf format, zoom in for full resolution.

a)



b)

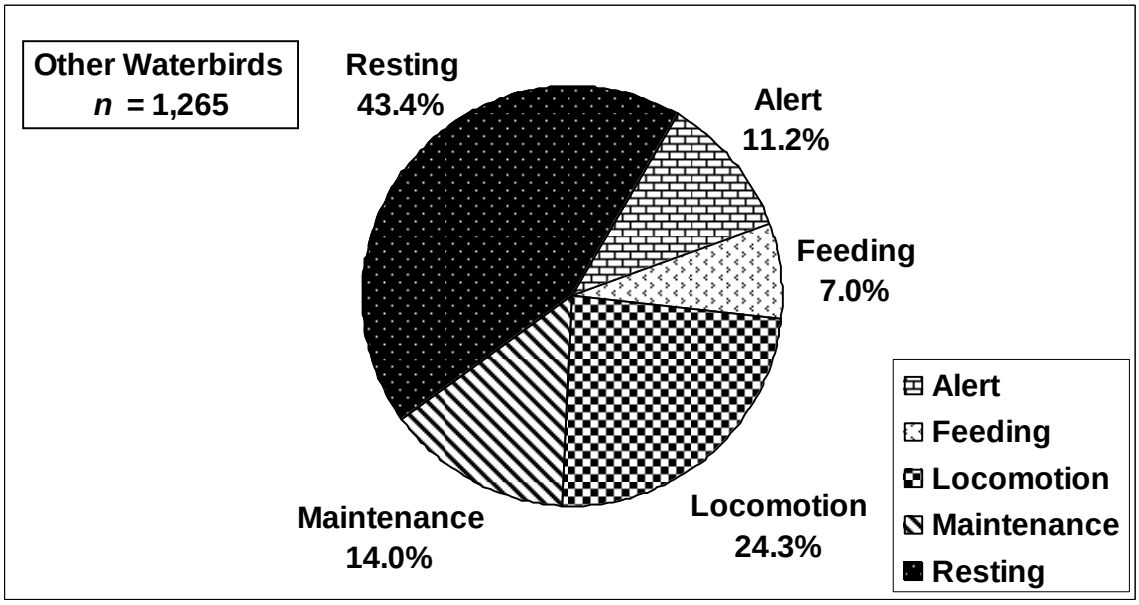


Figure 18. Percent occurrence of activities exhibited by (a) waterfowl and (b) other waterbirds using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007 (i.e., see Appendix II for list of species).

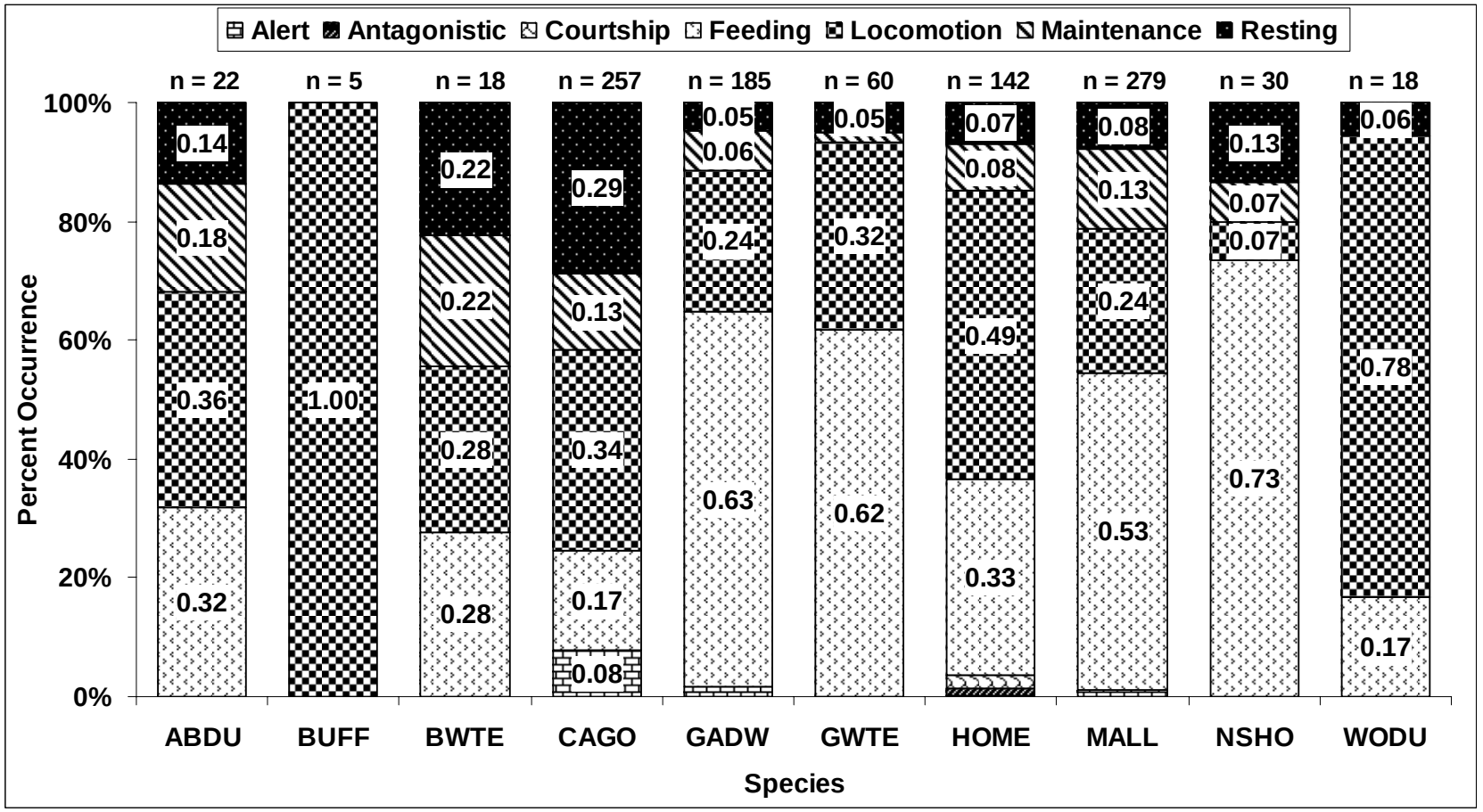


Figure 19. Percent occurrence of activities exhibited by individual waterfowl species using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007. ABDU = American black duck (*Anas rubripes*), BUFF = bufflehead (*Bucephala albeola*), BWTE = blue-winged teal (*Anas discors*), CAGO = Canada goose (*Branta*

Figure 19 (continued).

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canadensis), GADW = gadwall (*Anas strepera*), GWTE = American green-winged teal (*Anas crecca*), HOME = hooded merganser (*Lophodytes cucullatus*), MALL = mallard (*Anas platyrhynchos*), NSHO = northern shoveler (*Anas clypeata*), WODU = wood duck (*Aix sponsa*). If viewing this document in .pdf format, zoom in for full resolution.

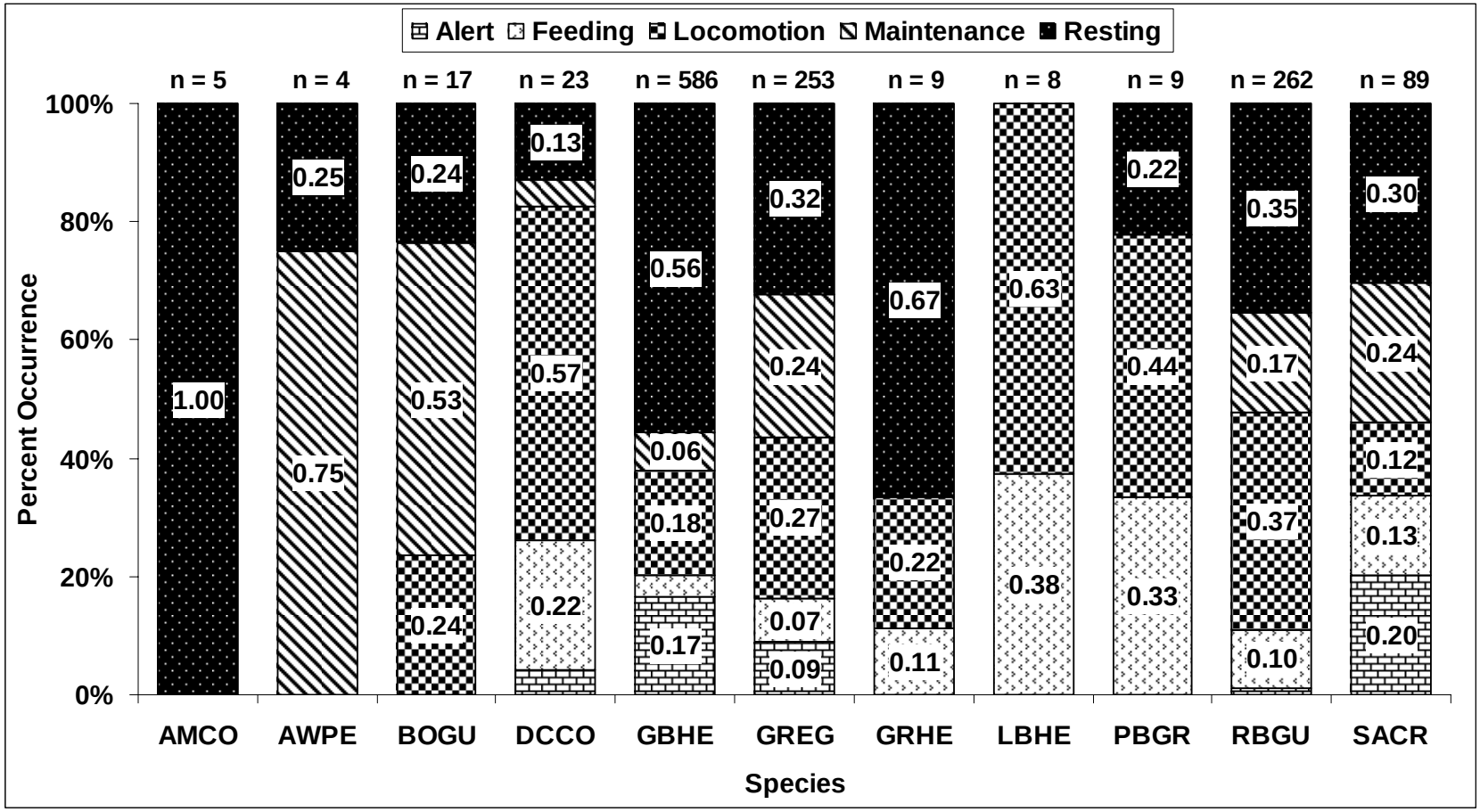


Figure 20. Percent occurrence of activities exhibited by individual other waterbird species using mudflats in Douglas and Chickamauga Reservoirs in east Tennessee, August 2005/2006 – January 2006/2007. AMCO = American coot (*Fulica americana*), AWPE = American white pelican (*Pelecanus erythrorhynchos*), BOGU = Bonaparte's gull (*Larus philadelphia*),

Figure 20 (continued).

DCCO = double-crested cormorant (*Phalacrocorax auritus*), GBHE = great blue heron (*Ardea herodias*), GREG = great egret (*A. alba*), GRHE = green heron (*Butorides virescens*), LBHE = little blue heron (*Egretta caerulea*), PBGR = pied-billed grebe (*Podilymbus podiceps*), RBGU = ring-billed gull (*L. delawarensis*), SACR = sandhill crane (*Grus canadensis*). If viewing this document in .pdf format, zoom in for full resolution.

APPENDIX II

REPORTED BIRD SPECIES OBSERVED USING MUDFLATS IN DOUGLAS AND CHICKAMAUGA RESERVOIRS, AUGUST 2005/2006 – JANUARY 2006/2007

Group[a]	Common Name[b]	Scientific Name
Shorebirds	American avocet	*Recurvirostra americana*
	American golden-plover	*Pluvialis dominica*
	Baird's sandpiper*	*Calidris bairdii*
	buff-breasted sandpiper	*Tryngites subruficollis*
	dunlin	*Calidris alpina*
	greater yellowlegs	*Tringa melanoleuca*
	killdeer	*Charadrius vociferus*
	least sandpiper	*Calidris minutilla*
	lesser yellowlegs	*Tringa flavipes*
	long-billed dowitcher	*Limnodromus scolopaceus*
	pectoral sandpiper	*Calidris melanotos*
	sanderling	*Calidris alba*
	semipalmated plover	*Charadrius semipalmatus*
	semipalmated sandpiper	*Calidris pusilla*
	short-billed dowitcher	*Limnodromus griseus*
	solitary sandpiper	*Tringa solitaria*
	spotted sandpiper	*Actitis macularius*
	stilt sandpiper	*Calidris himantopus*
	western sandpiper	*Calidris mauri*
	white-rumped sandpiper*	*Calidris fuscicollis*
	willet	*Tringa semipalmata*
	Wilson's snipe	*Gallinago delicata*
Waterfowl	American black duck	*Anas rubripes*
	American green-winged teal	*Anas crecca*
	American wigeon	*Anas americana*
	blue-winged teal	*Anas discors*
	bufflehead	*Bucephala albeola*
	Canada goose	*Branta canadensis*
	common goldeneye	*Bucephala clangula*
	gadwall	*Anas strepera*
	greater scaup	*Aythya marila*
	hooded merganser	*Lophodytes cucullatus*
	lesser scaup	*Aythya affinis*
	mallard	*Anas platyrhynchos*
	northern pintail	*Anas acuta*
	northern shoveler	*Anas clypeata*
	redhead*	*Aythya americana*
	ruddy duck	*Oxyura jamaicensis*
	snow goose*	*Chen caerulescens*
	wood duck	*Aix sponsa*
Other Waterbirds	American coot	*Fulica americana*
	American white pelican	*Pelecanus erythrorhynchos*
	belted kingfisher	*Megaceryle alcyon*
	black-crowned night-heron	*Nycticorax nycticorax*

Appendix II (continued).

Group[a]	Common Name (MDI)[b,c]	Scientific Name
	black tern	*Chlidonias niger*
	Bonaparte's gull	*Larus philadelphia*
	Caspian tern	*Hydroprogne caspia*
	double-crested cormorant	*Phalacrocorax auritus*
	Forster's tern	*Sterna forsteri*
	great blue heron	*Ardea herodias*
	great egret	*Ardea alba*
	green heron	*Butorides virescens*
	little blue heron	*Egretta caerulea*
	osprey*	*Pandion haliaetus*
	pied-billed grebe	*Podilymbus podiceps*
	ring-billed gull	*Larus delawarensis*
	sandhill crane	*Grus canadensis*
	white ibis*	*Eudocimus albus*
	wood stork*	*Mycteria americana*
Other Birds	American crow	*Corvus brachyrhynchos*
	American kestrel	*Falco sparverius*
	American robin	*Turdus migratorius*
	Cooper's hawk*	*Accipiter cooperii*
	European starling	*Sturnus vulgaris*
	northern mockingbird	*Mimus polyglottos*
	tree swallow	*Tachycineta bicolor*
	turkey vulture	*Cathartes aura*
	wild turkey	*Meleagris gallopavo*

[a]Other waterbirds includes additional water-dependent species (Weller 1999); other birds includes additional species not water-dependent.

[b]Common names followed by "*" indicate species that were observed using adjacent mudflats outside of permanent survey areas or outside of specified survey times (i.e., these species not included in analyses).

APPENDIX III

REPORTED PLANT SPECIES OBSERVED ON MUDFLATS IN DOUGLAS AND CHICKAMAUGA RESERVOIRS, AUGUST 2005/2006 - NOVEMBER 2006/2007

Group	Scientific Name	Common Name
Forb	*Ammannia coccinea* Rottb.	valley redstem
	Aster lanceolatus Willd.	white panicle aster
	Bidens frondosa L.	devil's beggar tick
	Cardamine pensylvanica Muhl. ex Willd.	Pennsylvania bitter cress
	Cuscuta sp.	dodder sp.
	Duchesnea indica (Andr.) Focke	Indian strawberry
	Eclipta prostrata (L.) L.	false daisy
	Gnaphalium uliginosum L.	marsh cudweed
	Ipomoea lacunosa L.	whitestar
	Lindernia dubia (L.) Pennell	yellowseed false pimpernel
	Ludwigia palustris (L.) Ell.	marsh seedbox
	Mazus pumilus (Burm.f.) Steenis	Japanese mazus
	Mollugo verticillata L.	green carpetweed
	Polygonum lapathifolium L.	curlytop knotweed
	Portulaca oleracea L.	little hogweed
	Rorippa palustris ssp. *fernaldiana*	Fernald's yellow cress
	Rorippa sessiliflora (Nutt.) Hitchc.	stalkless yellow cress
	Rotala ramosior (L.) Koehne	lowland rotala
	Rumex obtusifolius L.	bitter dock
	Xanthium strumarium L.	rough cockleburr
Grass	*Echinochloa crus-galli* (L.) Beauv.	barnyard grass
	Eragrostis hypnoides (Lam.) B.S.P.	teal love grass
	Eragrostis spectabilis (Pursh) Steud.	purple love grass
Sedge	*Cyperus flavicomus* Michx.	whiteedge flat sedge
	Eleocharis obtusa (Willd.) Schult.	blunt spike rush
	Fimbristylis vahlii (Lam.) Link	Vahl's fimby
	Juncus tenuis Willd.	path rush
	Lipocarpha micrantha (Vahl) G. Tucker	smallflower halfchaff sege

VITA

John William Laux was born in Albion, NE on March 31, 1982. In 1985, his family moved to Lexington, NE where he was raised and completed high school at Lexington High School in 2000. From there, he went to the University of Nebraska at Kearney and received his B.S. in Biology Comprehensive (Wildlife Emphasis) in 2004. John went on to the University of Tennessee to receive his M.S. in Wildlife and Fisheries Science in Spring 2008.