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Waterbird use of Kentucky Reservoir mudflats

Drew W. Wirwa
University of Tennessee

To the Graduate Council:

I am submitting herewith a thesis written by Drew W. Wirwa entitled "Waterbird use of Kentucky Reservoir mudflats." 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.

Matthew J. Gray, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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David Buehler

William G. Minser

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WATERBIRD USE OF KENTUCKY RESERVOIR MUDFLATS

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

Drew W. Wirwa
May 2009

DEDICATION

I dedicate this thesis to my wife, Jamie, for her inexhaustible love, support, and encouragement through all phases of this work.

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ABSTRACT

Mudflats associated with rivers in mid-continental United States are important for waterbirds to rest and replenish energy reserves during migration. Kentucky Reservoir is the largest reservoir in the Tennessee River Valley (TRV), and extensive mudflat acreage is exposed during annual drawdowns. It has been proposed that timing of drawdowns will significantly affect waterbird use of TRV mudflats. Thus, I quantified influences of drawdown of Kentucky Reservoir on waterbird use, available food resources, and mudflat characteristics. From August – December 2006 and 2007, I conducted waterbird surveys twice weekly at 9 mudflats in Kentucky Reservoir. I quantified temporal and spatial changes at mudflat sites by sampling mudflat acreage weekly and vegetation, aquatic invertebrates, soil characteristics, and water depth twice monthly. Initial mudflat exposure occurred in early to mid-August; mean mudflat acreage was 35 ha. I recorded 26 species of shorebirds, 20 species of waterfowl, and 25 species of other waterbirds (e.g., herons, gulls) using mudflats in Kentucky Reservoir. Mean shorebird abundance, richness, and diversity were greatest during September, while mean shorebird density was greatest during August when mudflat acreage was lowest. Most long-distance migrant shorebirds of high conservation concern were recorded during August and September, whereas shorter-distance migratory shorebirds and waterfowl were most common October – December. Invertebrates were the most abundant food resource available to shorebirds and waterfowl (1.5 – 3.6 g m^{-2}); Chironomidae was the most common taxa. Vegetation establishment and seed production decreased with decreasing mudflat elevation, which was related to duration of mudflat exposure. Soil moisture and compaction, water depth, and invertebrate density results revealed that optimal foraging conditions for shorebirds occurred within a 20-m band centered on the waterline. Shorebirds and waterfowl using mudflats spent the majority of their time feeding, while all other waterbirds spent most of their time resting. My results indicate that Kentucky Reservoir mudflats provide important foraging and resting habitat for a diverse assemblage of waterbirds. I recommend that mudflats in Kentucky Reservoir be exposed by 1 August (New Johnsonville gage height <108.81 m [357 ft] MSL) to provide habitat for rare long-distance migratory shorebirds and to facilitate vegetation establishment and seed production for waterfowl.

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CHAPTER I

INTRODUCTION

Since colonial times, development associated with flood control, navigation, agriculture, and urban expansion has destroyed or significantly altered the majority of wetlands in the conterminous United States (Dahl 2006, Fredrickson and Reid 1990, Mitsch and Gosselink 2007, Taft et al. 2002). The primary alteration causing degradation in wetlands is modification of the natural hydrology, which can reduce primary productivity and decrease habitat quality for wetland-dependent species (Fredrickson and Reid 1990, Reid 1993). For example, many waterbird populations have declined precipitously during the past 50 years due to reductions in the quantity and quality of wetlands (Howe et al. 1989, Morrison et al. 1994, Baldassarre and Bolen 2006). The cumulative loss and degradation of wetlands has facilitated the need for federal, state, and private organizations to intensively manage and monitor the remaining aquatic systems (Helmers 1992, 1993, Brown et al. 2001, USFWS 2006).

The focus of wetland management and research has been historically directed at waterfowl (Anseriformes) populations. Wetland biologists have recently placed more emphasis on managing the entire waterbird community, with particular focus on shorebirds (Charadriiformes), many species of which are known to be in decline (Howe et al. 1989, Laubhan and Fredrickson 1993, Brown et al. 2001). For example, Bart et al. (2007) reported that 23 of 30 shorebird species in the North Atlantic region are declining. However, limited information exists on shorebird life history, habitat requirements through the annual cycle, and demographics for many species. This information is necessary to effectively manage shorebird habitat to ensure populations are sustained above extinction thresholds (Myers et al. 1987, Hands et al. 1991, Brown et al. 2001).

Each year, shorebirds in North America migrate between arctic and subarctic breeding grounds and winter in the southern United States, Mexico, and Central and South America (Helmers 1992, Skagen and Knopf 1994*a*). Long-distance migration is extremely energetically demanding (Myers 1983, Skagen and Knopf 1993, 1994*a*). Shorebirds require stopover sites along migration routes that contain high densities of energy-rich organisms (Skagen and Knopf 1993, 1994*a*). It is estimated that an average-sized shorebird requires at least 8 g of aquatic invertebrates per day to maintain body mass and build sufficient lipid reserves to continue migration (Loesch et al. 2000). Thus, the availability of high quality stopover sites is critical for shorebird population sustainability (Skagen and Knopf 1993, Helmers 1992, 1993).

The Tennessee River Valley (TRV) is the fifth largest watershed in the nation, encompassing 106,190 km^2 in 7 southeastern states (Figure 1, Tennessee Valley Authority 2004), and an important annual migratory stopover and wintering location for thousands of North American shorebirds and waterfowl (Brown et al. 2001, USFWS 2005, Laux 2008). Historically, the Tennessee River fluctuated naturally according to basin physiography and seasonal precipitation (Tennessee Valley Authority 2004). However, in 1933, Tennessee Valley Authority (TVA) began constructing dams in the TRV, and there are now 9 main-stem reservoirs and 40 tributary reservoirs in the TRV that are owned and operated by TVA. Tennessee Valley Authority manages water levels in each reservoir, with the primary goals of facilitating navigation, producing hydroelectric power, cooling nuclear reactors, and flood control (TVA 2004). Generally, reservoir water levels are the highest during summer (called summer pool) and drawn down in winter (i.e., winter pool) to generate power and accommodate precipitation and runoff during the following spring. During fall drawdown of TRV reservoirs, extensive acreage of mudflats is exposed that provides habitat for migrating waterbirds (TVA 2004, Smith 2006, Laux 2008).

Prior to reservoir construction, the majority of TRV mudflats were agriculture fields and hardwood bottomlands adjacent to the Tennessee River (TVA 1951). Thus, reservoir construction increased the acreage of mudflats in the TRV (TVA 1951, Johnson and Montalbano 1989). Despite the loss of hardwood bottomlands, this conversion in landscape cover from forest and agriculture to mudflats had positive impacts on many wildlife species. For example, Laux (2008) reported 59 species of waterbirds using mudflats in the eastern TRV. Migratory waterbirds are probably attracted to TRV mudflats as feeding and resting sites (Laux 2008). Aquatic invertebrate densities can be high on TRV mudflats (J. Laux, University of Tennessee, unpublished data), which are an important food item for many migratory waterbirds (Fredrickson and Reid 1986, Eldridge 1990). Moist-soil seed also is present on TRV mudflats (Laux 2008), and likely consumed by dabbling ducks (Anatini) and possibly shorebirds. Seeds on mudflats also germinate and provide herbaceous browse for several waterfowl species (e.g., Canada goose [*Branta canadensis*], Laux 2008). Therefore, although extensive acreage of mudflats did not occur historically in the TRV, mudflats created during reservoir construction now provide habitat for thousands of resident and migratory waterbirds. These mudflats are especially important given the historic widespread destruction of riverine wetlands in the interior United States. The TRV also is positioned between the Atlantic and Mississippi Flyways, thus may serve as an important migratory corridor between flyways (Johnson and Motalbano et al. 1989).

Kentucky Reservoir is the lowermost and largest among the TRV reservoirs. It is located between the interior plateau and the southeastern plains of western Tennessee and western Kentucky. Kentucky Dam was constructed in 1938 and is located 35.4 km upstream from the confluence of the Tennessee and Ohio Rivers. Due to its size and close proximity to the Mississippi Alluvial Valley, this reservoir provides habitat for the greatest abundance and diversity of migratory waterbirds among TRV reservoirs. In addition, Tennessee National Wildlife Refuge (NWR) is positioned 105 km along Kentucky Reservoir, which winters >150,000 waterfowl annually (USFWS 2005). Tens of thousands of migrating and wintering waterbirds use mudflats and associated shallowly flooded wetlands on the refuge when water levels drop in Kentucky Reservoir (USFWS 2005).

Water in Kentucky Reservoir also is connected to Barkley Reservoir by a 2.4-km navigation channel, thus their water levels are interdependent. Water levels of Kentucky and Barkley Reservoirs are controlled by TVA and United States Army Corps of Engineers, respectively. Prior to 1980, TVA and United States Army Corps of Engineers initiated drawdown of these reservoirs on 15 June, resulting in exposed mudflats from mid-July – September (TVA 2004). However, in 1980, TVA changed the reservoir operation schedule to initiate drawdown on 1 July, which delayed mudflat exposure. Currently, Kentucky Reservoir elevation is maintained at 109.4 m (359 ft) MSL from April through 5 July and gradually lowered to 107.9 m (354 ft) MSL by December, where it remains at winter pool through March.

On 19 May 2004, the TVA Board of Directors implemented a new operations policy for the drawdown of TRV reservoirs, called the Reservoir Operation Study (ROS), which took effect on 1 June 2004 (TVA 2004). The new policy resulted in delay of the historic drawdown schedule for 35 of the 49 reservoirs, with a primary goal of increasing recreational opportunities. The policy was implemented after receiving input from citizens and representatives of state and federal agencies in the TRV. The drawdown schedule for Kentucky and Barkley Reservoirs were not changed because of concerns raised about the potential increase in flood risk and possible degradation of natural resources (TVA 2004). In particular, shorebirds may be negatively influenced, because mudflat stopover sites may be inundated during peak migration. In addition, waterfowl use of mudflats may decline if later drawdown results in reduced growing season and insufficient temperature for seed germination and moist-soil plant production (TVA 2004).

Tennessee Valley Authority funded two previous university studies examining the potential influences of delayed drawdown on migratory waterbirds in eastern Tennessee. Smith (2006) developed a simulation model that predicted acreage of suitable mudflats at Rankin Bottoms Wildlife Management Area using LiDAR data, gage height of Douglas Reservoir, and assuming mudflats were suitable for shorebirds up to 10 days following initial exposure. Smith (2006) determined that under the current ROS plan, the greatest acreage of suitable mudflats was present during September and October at Rankin Bottoms WMA, and did not provide substantial habitat during July and August. Laux (2008) expanded the study by Smith (2006) to investigate shorebird use and proximate factors associated with habitat selection between two reservoirs (Douglas and Chickamauga) drawn down at different dates (1 August vs. 1 October, respectively) in east Tennessee. Laux (2008) documented higher species richness and more long-distance migrants using mudflats in Douglas Reservoir compared to Chickamauga Reservoir. In contrast, he found that total shorebird abundance was greater in Chickamauga Reservoir, and the shorebird community was composed mostly of short-distance migrants and wintering species (Laux 2008). Models indicated that drawdown date, mudflat acreage, water depth at the water-mudflat interface, and vegetation coverage were important habitat variables driving shorebird responses (Laux 2008). Laux (2008) concluded that delays to reservoir drawdowns in the eastern TRV could negatively impact shorebird populations as well as other early migrant waterbirds.

Studies by Laux (2008) and Smith (2006) have established a baseline understanding of mudflat availability and factors associated with waterbird use in eastern Tennessee; however, no studies have been conducted in the western TRV. Kentucky Reservoir is a known migration and wintering area for numerous wetland avifauna, particularly because of its close proximity to the Mississippi Flyway (USFWS 2005). Also, if changes in drawdown date are approved on Kentucky Reservoir, prior to this study, there were no baseline data on existing mudflat acreage, spatial and temporal bird use, and food resource availability for post-hoc comparisons. These data are fundamental to providing science-based guidance to TVA in planning drawdowns for Kentucky Reservoir. This information also will be useful in determining the level of contribution TRV reservoirs provide to goals established by the North American Waterfowl Management Plan and United States Shorebird Conservation Plan. Thus, the **goal of my research** was to determine the influences of drawdown date on: (1) mudflat availability, (2) waterbird use of mudflats, 3) food resource densities, and 4) other habitat factors that potentially influence waterbird use. In Chapter II, I present results on these 4 objectives. I also quantified activities of waterbirds using Kentucky Reservoir mudflats to gain insight into the functional role that these habitats provide to migrating and wintering waterbirds. I present these results in Chapter III. Finally, in Chapter IV, I provide a summary of my conclusions and suggestions for operation of Kentucky Reservoir to provide habitat for migratory waterbirds.

CHAPTER 2

WATERBIRD USE OF RESERVOIR MUDFLATS IN THE TENNESSEE RIVER VALLEY

INTRODUCTION

Widespread decline and degradation of wetland systems in the interior United States have negatively impacted wetland-dependant species such as migratory waterbirds (Brown et al. 2001, USFWS et al. 2004, Dahl 2006, Mitsch and Gosselink 2007). For example, after decades of wetland losses, waterfowl populations in North America plummeted to an all-time low in the 1980s (Zimpfer et al. 2008). Although total waterfowl numbers have rebounded, there are several species that remain at low levels (e.g., northern pintail [*Anas acuta*], greater [*Aythya marila*] and lesser scaup [*Aythya affinis*], Zimpfer et al. 2008). There also is evidence that nearly half of North American shorebird species are in decline (Brown et al. 2001, Skagen 2006). A primary goal of the United States Shorebird Conservation Plan and the North American Waterfowl Management Plan is to identify and conserve important habitats for these waterbirds throughout their annual cycle (Brown et al. 2001, USFWS et al. 2004).

Waterfowl and shorebirds use shallowly flooded wetlands during migration and winter to acquire energy-rich seeds and aquatic invertebrates (Fredrickson and Reid 1988*a*, Skagen and Knopf 1993). Studies have documented the importance of coastal and depressional wetlands in providing food resources and resting sites for migratory waterbirds (e.g., Myers 1983, Bolen et al. 1989, Chabreck et al. 1989, Davis and Smith 1998*b*); however, few studies have quantified the use of riverine wetlands by migratory waterbirds. In particular, mudflats associated with rivers and reservoir systems may be very important stopover habitats for migratory waterbirds in the interior United States. Laux (2008) reported 59 species of waterbirds using reservoir mudflats in the eastern Tennessee River Valley. Birds in this study primarily used mudflats as feeding and resting sites (Laux 2008).

Large river systems in the United States frequently contain dams that create reservoirs upstream. Water levels in riverine reservoirs are manipulated for a variety of reasons including power generation, flood control, and navigation. When water levels are lowered, large expanses of mudflats can be exposed and provide habitat for migratory waterbirds (Johnson and Montalbano 1989, Mihue et al. 1997, Andres et al. 2007). Taylor et al. (1993) documented over 30 species of shorebirds using mudflats exposed by drawdown of American Falls Reservoir associated with the Snake River in Idaho. In the eastern United States, 23 shorebird species were reported using mudflats in Rend Lake, which is a reservoir of the Big Muddy River in Illinois (Elliot-Smith 2003). Lake Texoma, a reservoir of the Red River in Texas, provides habitat for 70,000 waterfowl annually (White and Malaher 1964). However, in order for riverine reservoirs to provide habitat for migratory waterbirds, water levels need to be lowered during migration to make mudflats available (Johnson and Montalbano 1989, Taylor et al. 1993, Collazo et al 2002). Although research has documented waterbird migration chronology in the mid-continental United States (Smith et al. 1991, Andrei et al. 2006, Baar et al. 2008), no published studies have documented waterbird use in relation to timing of mudflat availability in mid-continental river-reservoir systems. This information is fundamental to plan reservoir drawdown schedules that provide mudflat habitat for migratory waterbirds.

Waterbird use of reservoir mudflats is likely dependent on various habitat characteristics, including vegetation cover, water depth, moisture and compaction of the exposed substrate, and food resource density. Vegetation has been shown to affect wetland use by waterbirds

(Fredrickson and Taylor 1982, Helmers 1992), with shorebird use usually declining as coverage increases (Andrei et al. 2008). In addition, seed production by moist-soil vegetation on mudflats can be important to replenish seed banks and provide a food source for waterfowl (Fredrickson and Taylor 1982). Water depth and substrate characteristics can influence prey availability and foraging efficiency of waterbirds (Fredrickson and Reid 1988*b*, Boldoc and Afton 2004, Andrei et al. 2008). Aquatic invertebrate density also may be impacted by substrate characteristics (Colwell and Landrum 1993, Furey et al. 2006), especially as mudflats become exposed. Although it has been suggested that aquatic invertebrates are a primary food resource for waterbirds using mudflats (Skagen and Omen 1996, Anderson et al. 2000), there are no estimates of aquatic invertebrate biomass and composition for reservoir mudflats in the eastern United States. Invertebrate and seed biomass estimates can be used to estimate carrying capacity of mudflats for migratory waterbirds (Loesch et al. 2000). Understanding the relationship between habitat characteristics, food densities, and waterbird use on reservoir mudflats is fundamental to determining their importance to continental populations of migratory waterbirds.

The Tennessee River Valley (TRV) is the fifth largest watershed in the United States, encompassing 106,190 km^2 in 7 states (Tennessee Valley Authority 2004). Water levels in the TRV are controlled by the Tennessee Valley Authority (TVA) through a network of 49 dams and reservoirs. Generally, reservoir water levels are the highest during summer and are drawn down through winter to generate power and accommodate precipitation and runoff during the following spring. During fall drawdown, extensive acreage of mudflats can be exposed (Smith 2006), providing habitat for migrating waterbirds (TVA 2004, Laux 2008). Thus, the management of reservoirs in the TRV provides an ideal opportunity to examine the impacts of reservoir drawdown on mudflat exposure and waterbird use in a mid-continental river system.

The **goal of this study** was to determine the impact of reservoir drawdown on the timing and use of riverine mudflats by fall migrating waterbirds. I also was interested in quantifying habitat characteristics and food resources on exposed and shallowly flooded mudflats. Specific objectives were to: (1) quantify the temporal acreage of mudflats and relate mudflat acreage to watebird use, (2) quantify species richness, diversity, composition, relative abundance, and density of waterbirds using mudflats and compare use among months, (3) estimate invertebrate densities and seed production on mudflats, and (4) quantify soil and vegetation characteristics on mudflats and relate these characteristics to exposure duration, food densities, and waterbird use. I also was interested in identifying factors that may influence waterbird use and aquatic invertebrate density on mudflats, thus I constructed models that related abundance of these taxa to several possible explanatory variables.

METHODS

Study Area

I conducted my study on Kentucky Reservoir, which is the largest reservoir in the TRV and located between the interior plateau and the southeastern plains of western Tennessee and Kentucky (Figure 2). Under the current drawdown schedule, water levels are maintained at 109.4 m (359 ft) above mean sea level (MSL) from May through June and drawn down 1.5 m (5 ft) from July through November where they are maintained through March (Figure 3). At full pool, the surface area of Kentucky Reservoir is approximately 64,750 ha, and there are about 3,322 km of shoreline surrounding the reservoir. During winter pool, the reservoir surface area is approximately 52,609 ha, resulting in about 12,141 ha of exposed shoreline (Tennessee Valley

Authority 2009). Of this acreage, it is estimated that approximately 1,788 ha is suitable mudflats for shorebirds (T. H. Henry, Tennessee Valley Authority, unpublished data).

I conducted sampling on 9 mudflats distributed throughout Kentucky Reservoir (Figure 2). Five mudflats were concentrated near the Duck River and Tennessee River confluence, and the remaining four mudflats were near the Big Sandy River and Tennessee River confluence. Three of the mudflats were located within the Tennessee National Wildlife Refuge (Figure 2). Criteria for mudflat selection included known history of waterbird use as per discussions with local experts and topography. I sampled mudflats that had at least two 0.305-m (1-ft) contours exposed at low pool, so there would be a gradient of soil moisture and water depth across the mudflat. I sampled from 31 July – 30 December 2006 and from 30 July – 29 December 2007, which was from initial mudflat exposure in Kentucky Reservoir through peak fall migration for most waterbird species in the region (Reid et al. 1989, Helmers 1992).

Waterbird Use of Mudflats

I measured species-specific abundance and density of waterbirds at 9 permanent viewing locations (i.e., one per mudflat) 2X per week (Appendix II). On Mondays and Thursdays, the 5 mudflats near Duck River were surveyed; on Tuesdays and Fridays, the 4 mudflats near Big Sandy River were surveyed. I assume that waterbird use on the mudflats was similar on these days compared to the weekends. I believe this is a reasonable assumption, because recreational disturbances (e.g., waterfowl hunting, boating) appeared similar between weekdays and weekends (D. Wirwa, personal observation). I used a Swarovski® spotting scope (model STS-80) with 20-60X zoom to identify and count birds within a 180° semi-circle around each viewing location (Figure 4). At least 90% of each mudflat could be seen from the permanent viewing location. Because all viewing was from the same location at a maximum 60X, approximately the same viewing area was sampled at each mudflat. Nonetheless, I used weekly mudflat acreage (discussed below) to calculate waterbird density thus standardizing waterbird counts per mudflat. I conducted surveys between sunrise and 5 hrs after sunrise, and systematically rotated the surveying order among mudflats each week to avoid potential bias associated with systematic diurnal bird movements among mudflats (Davis and Smith 1998*b*, Andrei et al. 2008).

Mudflat Availability

I quantified mudflat area each week to relate habitat availability to waterbird use, and to standardize waterbird abundance among mudflats. I defined mudflats as the area between the down-slope extent of the woody vegetation to the waterline. I geo-referenced the waterline by walking along the waterline at least 100 m with a Trimble GeoExplorer® XM unit. I used Trimble Pathfinder® Office software and the Trimble® GPS Base Station of the Purchase Area Development District, located in Mayfield, Kentucky, to geo-correct waterline data. I used ESRI ArcGIS® 9.1 to estimate mudflat acreage each week using the geo-corrected waterlines.

Vegetation Response

Given that vegetation can influence waterbird use (Andrei et al. 2008), I measured temporal and spatial changes in vegetation composition, structure, and seed production on mudflats during drawdown. Vegetation sampling was associated with a permanent transect established perpendicular to the contour gradient on each mudflat, extending from the highest point of the mudflat to the waterline. I measured vegetation in plots (1-m^2) along each transect. I permanently marked the center of these plots with rebar at the midpoint distance of each 0.305-

m (1-ft) contour. I determined the locations of mudflat contours and their midpoints using LiDAR data available from TVA and a GPS unit. I used a LASERMARK® laser level and meter tape to locate contour midpoints when LiDAR data were unavailable. As the reservoir was drawn down, new mudflat contours were exposed and additional plots established.

I measured plant species richness, vegetation height, percent horizontal and vertical cover, and aboveground standing crop associated with each exposed contour every 2 weeks (Gray et al. 1999*c*). I recorded plant species in each plot and calculated species richness. Plant height was measured at plot center using a metric ruler. I visually estimated percent horizontal cover of vegetation for each quadrant of the 1-m^2 plots, and averaged among quadrants. To estimate vertical structure of vegetation, I used a modified 1-m tall profile board placed at plot center (Nudds 1977). This board had two 0.5-m height strata, each strata containing thirty 25-cm^2 (5×5 cm) alternately colored boxes. I indexed vertical structure from a kneeling position 2 m upslope by counting the number of boxes that were >50% covered by vegetation in each stratum. I measured aboveground biomass of vegetation by clipping all plants in a 0.0625-m^2 plot positioned 2 m from each 1-m^2 plot and parallel to the contour gradient. Because clipping is destructive, I clipped a different 0.0625-m^2 plot positioned 2 m from the previous plot every two weeks (Figure 5). I placed vegetation in bags, and labeled and froze them at -20ºC until lab processing. At the end of the growing season (i.e., 12 November, Natural Resources Conservation Service 2002), I clipped all vegetation within the 1-m^2 plots for an estimate of aboveground biomass. For seed producing plants, I collected seed heads from $\geq$30 random plants per species outside the 1-m^2 plot, placed them separately in labeled bags, and froze them to calculate average seed yield per plant species for each contour (discussed below).

I thawed vegetation biomass samples collected from 0.0625-m^2 and 1-m^2 plots, sorted plants by species, oven-dried samples at 50ºC for 24 hours (Laubhan and Fredrickson 1992), weighed them to the nearest 0.01 g, and reported estimates as dry biomass (g 0.0625-m^{-2} and g 1-m^{-2}). I also summed biomass across species for an estimate of total biomass per contour. I tallied stem densities of seed-producing species within clipped 1-m^2 plots for an estimate of seed production per contour. I hand threshed seed heads from the randomly selected subsamples, dried them to constant mass, and weighed dry seed mass to the nearest 0.0001 g (Laubhan and Fredrickson 1992; Gray et al. 1999*a*,*b*). Finally, I multiplied average dried seed mass per plant species by its corresponding stem density in each 1-m^2 for an estimate of seed yield. I also summed across species for an estimate of total seed yield (g m^{-2}) per contour.

Aquatic Invertebrates and Seeds

Food resources, such as macroinvertebrates and moist-soil seeds, can influence waterbird use of habitats (Colwell and Landrum 1993, Laubhan and Gammonley 2000). Therefore, I measured aquatic macroinvertebrate familial composition and mass, and the mass of moist-soil seeds in the seed bank using standard benthic core sampling (Murkin et al. 1996). I conducted sampling along transects that were positioned parallel to and 10 m from the transect used for vegetation sampling (Figure 5). These transects were 20 m in length and perpendicular to the water, with the center positioned at the waterline (i.e., the location where shorebirds and waterfowl frequently forage; Helmers 1992, Johnson and Rohwer 2000). I permanently marked the center of the transect with rebar and marked the position with a GPS unit. I collected five core samples (8.8-cm diameter, Whittington 2005) to 10 cm soil depth (i.e., assumed maximum soil depth that waterfowl can acquire food resources, Stafford et al. 2006) along the transect. I took one core sample at the upper end of the transect and one at the lower end. I took the remaining 3 cores at the center of the transect: one at the waterline at one 2 m up-and down-slope of the waterline (Figure 5). Every two weeks as the water receded, I established a new transect at the new waterline. If water receded <20 m (i.e., the length of the transect) between sampling periods, I established the new transect 10 m from and parallel to the previous transect so that the same locations were not sampled. To document trends in food resource abundance as the mudflat dried, I also returned to the permanently marked midpoint of all previously sampled transects and collected 1 core sample 1 m from the previously collected sample parallel to the contour gradient. I deposited soil core contents in a Wildco® bucket with a 500 µm screen to remove mud and water, then placed the sieved contents in storage bags and froze them at -20^{o}C until lab processing.

I thawed core samples and stained them with Rose Bengal solution overnight to facilitate invertebrate sorting and detection (Manley et al. 2004). I enumerated invertebrates by family or the lowest taxa possible and reported estimates as individuals per 608.21-cm^3 (Anderson and Smith 2000). Similar to seed yield estimates, I calculated mean biomass for an independent subsample of invertebrates for each taxonomic group, multiplied them by density in each core sample, and summed across taxa for an overall estimate of total invertebrate biomass (g m^{-2}) per contour. I sorted seeds in core samples into four categories: moist-soil seeds (e.g., *Echinochloa, Panicum, Polygonum*), tree seeds (e.g. acorns, samaras), tubers (e.g., *Cyperus*), and common cocklebur (*Xanthium strumarium*). These categories represent waterfowl food resources from herbaceous and woody plants (McKenzie 1987, Heitmeyer 2006), respectively, and a moist soil plant (cocklebur) that has low food value yet may dominate coverage on mudflats (Laux 2008).

I oven-dried seeds of each category at 50ºC for 24 hours, weighed them to the nearest 0.0001 g, and reported estimates as dry biomass (g 608.21-cm^{-3}) per contour.

Soil Characteristics and Water Depth

Soil characteristics and water depth could influence habitat use by waterbirds by impacting food resources abundance and availability (Bolduc and Afton 2004). Therefore, I measured soil compaction, moisture, and temperature at each benthic core sampling site that was positioned above the waterline, including the permanently marked midpoint of all previously sampled transects. I used a DICKEY-john® and an Aquaterr® meter to measure soil compaction, moisture, and temperature. I also measured water depth at each core sampling site below the waterline.

Statistical Analyses

Response variables.—I quantified the following response variables during the drawdown: mean daily abundance, density (birds ha^{-1}), species richness, and Shannon-Wiener species diversity of waterbirds; mean weekly mudflat acreage (ha); mean bi-monthly plant height (cm), plant richness, percent horizontal cover of vegetation, vegetative biomass (g 0.0625-m^{-2}), belowground seed biomass (g 608.21-cm^{-3}), invertebrate density (individuals 608.21-cm^{-3}), water depth (cm), soil compaction (lbs in^{-2}), soil moisture (%), and soil temperature (°C); and vegetation biomass (g m^{-2}) and seed production (g m^{-2}) at the end of the growing season. I determined if the monthly differences existed among the above response variables, excluding end-of-year vegetation biomass and seed production. Months were chosen as the temporal unit of measurement because monthly trends in migration have been documented previously

(Helmers 1992, Twedt et al. 1998, Laux 2008), thus this unit of time has biological and management relevance. For analyses of waterbird data, I treated days within months as subsamples. Thus, I averaged total abundance, density, species richness, and species diversity among days within months for each mudflat. I calculated density by dividing total daily abundance by corresponding weekly mudflat acreages. I calculated diversity using the Shannon-Wiener algorithm (Morin 1999). Although I recorded all waterbirds using mudflats during surveys, I analyzed shorebird and waterfowl data only, because these groups likely would be impacted most by variations in mudflat characteristics. Analyses were run separately for shorebirds and waterfowl. I did not analyze waterfowl density, because they primarily used flooded portions of the mudflats, thus density estimates based on exposed mudflat acreage (as done with shorebirds) would have been inaccurate. For shorebird abundance and density tests, I excluded killdeer because they are considered resident species and dominated shorebird species composition. I sampled all remaining variables, excluding end-of-year variables, either two or four times per month, thus averaged them across weeks within months.

Temporal and spatial tests.—I used repeated measures analysis-of-variance (ANOVA) with Huynh-Feldt correction to test for differences in the aforementioned response variables among months (Montgomery 2000). If the overall ANOVA was significant, Ryan's-Q multiple comparison test was used to determine pairwise differences. I did not test for normality because sample size was large ($n \geq 9$), 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, Underwood 1997). I also calculated total abundance for each waterbird species per month and tested for differences in species composition among months using a chi-square test of homogeneity (Zar 1999). To qualitatively represent species-specific migration chronology, I constructed box plots using total weekly abundances per shorebird species. The ends of the box plot corresponded to dates that accumulated abundance equaled the 1st and 3rd quartile (i.e., 25th and 75th percentile). I analyzed all response variables separately for each year, because drawdown schedules were different between years. I also calculated percent composition of invertebrate taxa to qualitatively represent invertebrate availability. For these calculations, I used all core samples across years to derive more robust estimates of invertebrate composition.

I quantified spatial trends in the following possible habitat variables: end-of-year vegetation biomass and seed production; vegetation structure and biomass; belowground seed biomass; invertebrate abundance; and soil compaction, moisture, and temperature. For these variables, I used one-way ANOVA to test for differences among mudflat elevations (0.305-m contours). For the soil variables that were measured every 2 weeks (i.e., belowground seed biomass, invertebrate abundance, and soil compaction, moisture and temperature), I used the data that were collected from the sampling locations on the waterline. Additionally, I tested for differences in invertebrate abundance, and soil compaction, moisture, and temperature among sampling distances from the waterline (>10 m above, 10 m above, 0 m and 10 m below). Analysis of soil variables did not include the 10 m below category because these data were not collected below the waterline. The 0-m category was the average of core sampling sites at the center of the transect, and the >10-m category was the average of core sampling sites that were previously sampled. For tests with more than 1 effect, I included an interaction in the model. I performed all tests in SAS® System (SAS Institute, Cary, NC) at $\alpha = 0.05$ (Littell et al. 1991, Stokes et al. 2003).

Modeling.—I was interested in identifying important habitat characteristics that explained significant variation in shorebird and waterfowl abundance on the mudflats. All the variables that I measured, in addition to reservoir gage height (ft) and percent of the mudflat that was exposed, were designated as possible predictors of shorebird and waterfowl abundance. I averaged waterbird abundance and habitat variables for consecutive 2-week intervals. I took a categorical approach to model building and created separate models for vegetation, soil, and mudflat acreage variables. This was done because I was interested in how each of these possible components of waterbird habitat may have been associated with abundance. In addition, because variables were measured at different frequencies and times, sample size of a combined model would have reduced substantially (n = 60 combined versus n = 198 for separate models) due to the unbalanced design. Possible predictor variables for the vegetation model included plant height, richness, biomass, and percent horizontal cover. Possible soil model variables included invertebrate density, water depth, seed biomass, and soil compaction, moisture and temperature. Possible variables for the mudflat acreage model were acreage, percent exposure, and gage height. I also assigned sequential numbers to each consecutive sampling period, and included this representation of time as a possible variable in all models. I used multiple linear regression with stepwise selection in SAS® (entry and stay at $\alpha = 0.05$) to identify variables that explained significant variation in waterbird abundance (Kutner et al. 2004). Stepwise selection started with an empty model. For the final model, I presented un-standardized and standardized parameters, and variance inflation factors. The un-standardized parameters can be used by practitioners to predict mean waterbird abundance given values of the explanatory variables, and standardized parameters were used to interpret the magnitude and direction of the relationship between mean waterbird abundance and explanatory variables (Kutner et al. 2004).

I also developed multiple linear regression models to identify mudflat characteristics that were important in explaining variation in invertebrate density. Of the variables I measured, I considered the following variables could have influenced invertebrate density: soil moisture, soil temperature, soil compaction, weeks since initial and last exposure, exposure frequency, contour (i.e., elevation), and weeks (i.e., time). Weeks since initial exposure were the number of weeks between the initial exposure of the sampling site and the week that the sample was taken. Weeks since last exposure were the number of weeks between the last exposure of the sampling site and the week that the sample was taken, which often was less than the duration since initial exposure due to fluctuating water levels. Contours were an ordinal designation of relative elevation, where one was the highest 0.305-m contour and three was the lowest contour. Weeks were sequentially numbered sampling periods and were included as a representation of time. The models were initiated as an empty mode, and similar to bird models, I used stepwise selection in SAS®.

I used simple linear regression to quantify the relationship between mudflat acreage and reservoir gage height and to develop a model for TVA managers to estimate mudflat availability given water levels in Kentucky Reservoir. I averaged total acreage among mudflats and reservoir gage height for each week and combined years. I also constructed a fitted line with 95% confidence intervals to graphically illustrate the relationship.

RESULTS

Mudflat Exposure

Mudflats that I used for my study ranged in size from 9 – 78 ha (23 – 193 acres) at low pool (107.9 m [354.0 ft] MSL). In 2006, the first mudflat was exposed on 17 August, and at least 1 ha was exposed on all mudflats by 5 September (Figure 6). In 2007, initial mudflat exposure occurred prior to my first sampling date (30 July), and by 24 August, at least 1 ha was exposed on all mudflats (Figure 7). Reservoir depth at the New Johnsonville, TN, gage was a good predictor of exposed mudflat acreage (Figure 8). During both years, three 0.305-m contours became exposed on all mudflats. The mean elevations of the plots established at the midpoints of contour 1, 2, and 3 were 108.56 m (356.17 ft), 108.36 m (355.5 ft), and 108.07 m (354.55 ft) MSL, respectively.

Vegetation Response on Mudflats

Vegetation structure differed among mudflat contours during both years. In 2006, mean height ($\bar{x}$ = 3.16 cm, SD = 2), percent horizontal cover ($\bar{x}$ = 44.73, SD = 25), and richness ($\bar{x}$ = 3.14, SD = 1) were greatest in the highest mudflat contour ($F_{2,34} \geq 8.63$, $P < 0.001$; Table 1). In 2007, percent horizontal cover ($\bar{x}$ = 6.67, SD = 4) was greatest in the highest mudflat contour ($F_{1,24} = 17.15$, $P < 0.001$). I recorded a total of 22 plant species on the mudflats, including 14 species of forbs, 7 sedges and 1 grass (Appendix III). No differences in vegetation height, horizontal cover, and species richness were detected among months; although, there was a trend for all variables to increase from August – December. Due to limited vegetation growth, percent vertical cover measured using a profile board could not be analyzed either year.

Mean total vegetation biomass at the end of the growing season was 68 g m^{-2} (SD = 126) and 62 g m^{-2} (SD = 97) in 2006 and 2007, respectively, and was greatest in the highest mudflat contour both years ($F_{1,16} \geq 5.99$, $P \leq 0.03$; Figure 9). Needle spike rush (*Eleocharis acicularis*) comprised the greatest biomass, averaging 53 g m^{-2} (SD = 124) and 26 g m^{-2} (SD = 60) among contours in 2006 and 2007, respectively (Appendix IV). A total of 10 and 8 plant species reached maturity and produced seed in 2006 and 2007, respectively (Appendix V). Mean total seed production at the end of the growing season was 1.53 g m^{-2} (SD = 3.00) and 6.46 g m^{-2} (SD

= 20.05) for 2006 and 2007, respectively, and was greatest in the highest mudflat contour in 2006 ($F_{1,16}$ = 6.09, P = 0.03; Figure 9). No significant difference was detected in overall seed production among contours in 2007 ($F_{1,14}$ = 1.74, P = 0.21). Species with the highest seed production among contours were Vahl's fimbry (*Fimbristylis vahlii*; 0.39 g m^{-2}, SD = 1.66) in 2006 and valley redstem (*Ammannia coccinea*) and lowland rotala (*Rotala ramosior*; 5.70 g m^{-2}, SD = 19.37) in 2007 (Appendix V). No seed was produced either year in the lowest contour.

Belowground Seed Biomass

In 2006, mean moist-soil seed, tree seed, tuber, and cocklebur seed biomass in core samples across mudflat contours was 3.81 (SD = 1.53), 5.44 (SD = 9.24), 0.21 (SD = 0.57), and 0.17 (SD = 0.37) g m^{-2}, respectively. In 2007, mean moist-soil seed, tree seed, tuber, and cocklebur biomass was 2.51 (SD = 1.11), 0.82 (SD = 1.06), 1.79 (SD = 4.35), 0.005 (SD = 0.015) g m^{-2}. Tree seed and cocklebur seed biomass were greatest in the lowest contour in 2007 ($F_{2,54}$ = 3.72, $P \leq 0.03$; Table 2). No statistical differences were detected among contours for any seed group in 2006 ($F_{1,58} \leq 1.54$, $P \geq 0.22$), although there was a trend of decreasing biomass of moist-soil seed and tubers from the highest to lowest contour in both years (Table 2). No differences were detected among months in either year ($F_{3,46} \leq 2.93$, $P > 0.05$).

Invertebrate Response on Mudflats

Mean invertebrate density and biomass in core samples across mudflat contours and months was 2,185 individuals m^{-2} (SD = 2,753) and 3.6 g m^{-2} (SD = 9.21) in 2006. Mean invertebrate density was 847 individuals m^{-2} (SD = 1,023) and biomass was 1.5 g m^{-2} (SD =

6.91) in 2007. Chironomidae was the most commonly encountered taxa, followed by Nematoda and Oligachaeta (Figure 10).

Invertebrate density differed among mudflat contours in 2006 (Figure 11). Invertebrate density at lower contours ($\bar{x}$ = 17.01 – 17.28, SD = 5 – 8) was 2X greater than at the highest contour ($F_{2,429}$ = 4.57, P = 0.01). Differences were not detected among contours in 2007 ($F_{2,419}$ = 0.36, P = 0.70), although density trends were similar to 2006. No differences in invertebrate density were detected among months in 2006 ($F_{3,149}$ = 0.75, P = 0.49). In 2007, differences among months were detected in the ANOVA ($F_{3,135}$ = 5.16, P = 0.01), but Ryan's-Q test did not find pairwise differences.

Mean invertebrate density at sampling sites within 10 m of the waterline ($\bar{x}$ = 5.96 – 6.32, SD = 3 – 4) was 2.7 – 2.9X greater than sampling sites farther than 10 m above the waterline in 2007 ($F_{3,135}$ = 4.28, P = 0.05; Figure 12). No differences were detected in 2006 ($F_{3,145}$ = 1.79, P = 0.15); however, density trends were similar to 2007, with fewer invertebrates in the exposed mud >10 m from the waterline.

Soil Characteristics and Water Depth

Due to failures of the Aquaterr® meter during August 2006 and December 2007, these months were excluded from analysis of soil characteristics. Differences in soil compaction and temperature were detected among mudflat contours (Figure 13). Soil compaction in the highest contour ($\bar{x}$ = 29.1 – 31.7, SD = 12 – 19) was 3.1 – 8.1X greater than in the lower contours in both years ($F_{2,261} \geq 18.88$; $P < 0.001$). In 2006, temperature in the highest contour ($\bar{x}$ = 21.6, SD = 4.2) was 46 – 82% greater than in the lower contours ($F_{2,228} \geq 23.28$; $P < 0.001$). No differences in temperature were detected among contours in 2007 ($F_{2,180} \geq 0.99$, $P < 0.37$).

Soil temperature differed among months both years (Figure 14). Soil temperature decreased from September through December (25.17 °C – 7.84 °C) in 2006 ($F_{3,76}$ = 125.06; P < 0.001) and from August through November (30.74 °C – 11.63 °C) in 2007 ($F_{3,76}$ = 91.61; P < 0.001). In 2007, a month effect was detected in the ANOVA for soil compaction ($F_{3,100}$ = 4.13, P = 0.02), although Ryan's-Q multiple comparison test did not find pairwise differences. No other differences in soil moisture or compaction were detected among months ($F_{4,172} \leq 0.12$, $P \geq 0.12$; Figure 14).

Differences in soil compaction and moisture were detected among distances from the waterline (Figure 14). During both years, soil compaction at sampling sites that were farther than 10 m above the waterline ($\bar{x}$ = 25.83 – 26.88, SD = 10 – 11) was 1.69 – 2.95X greater than at sampling sites within 10 m of the waterline ($F_{2,100} \geq 5.78$, $P \leq 0.004$). Soil moisture at sampling sites within 10 m of the waterline ($\bar{x}$ = 91.77 – 93.20, SD = 3 – 5) was 5.3 – 6.8% greater than at sampling sites farther than 10 m above the waterline during both years ($F_{2,76} \geq$ 6.14, $P \leq 0.003$; Figure 14). No differences in soil temperature were detected among distances from the waterline ($F_{3,76} \leq 91.61$, $P \geq 0.69$). Mean water depth 2 m and 10 m from the waterline was 2.29 cm (SD = 1.99) and 6.61 cm (SD = 5.64), respectively.

Waterbird Use and Species Composition

A total of 182,942 birds were recorded using 9 mudflats in Kentucky Reservoir during 2006 and 2007. Representing 95 species, these birds could be divided into 4 groups: shorebirds, waterfowl, other waterbirds, and other birds. Waterfowl were the most common group, with 20 species and 59% of total abundance. I recorded 26 species of shorebirds, comprising 13% of total abundance. I also recorded 25 species of other waterbirds and 24 species of other birds (Appendix VI), each comprising 24 % and 4% of the total abundance, respectively.

Shorebirds.—Shorebird mean daily abundance in September ($\bar{x}$ = 24.07 – 52.40, SD = 24 – 51) was 2 – 12X greater than in all other months in 2006 ($F_{4,32}$ = 4.82, P = 0.027) and 3 – 10X greater than in all other months in 2007 ($F_{4,32}$ = 5.15, P = 0.017; Figure 15). However, shorebird density in August ($\bar{x}$ = 6.87, SD = 4) was 3 – 86X greater than in all other months in 2006 ($F_{4,32}$ = 13.79, P = 0.002; Figure 16). In 2007, shorebird density in August ($\bar{x}$ = 10.72, SD = 11) was 4 – 18X greater than in October, November, and December ($F_{4,32}$ = 5.32, P = 0.031). In 2006, species richness in September ($\bar{x}$ = 2.49, SD = 1) was 2 – 7X greater than in August, November, and December ($F_{4,104}$ = 4.45, P = 0.011), and species diversity in September ($\bar{x}$ = 0.64, SD = 0.03) was 2 – 6X greater than in November and December ($F_{4,104}$ = 4.61, P = 0.013; Figures 17 and 18). In 2007, species richness in September ($\bar{x}$ = 4.11, SD = 2) was 2 – 13X greater than in all other months ($F_{4,32}$ = 5.25, P = 0.008; Figure 17), and species diversity in September ($\bar{x}$ = 0.98, SD = 0.2) was 2 – 7X greater than all other months ($F_{4,32}$ = 8.70, P = 0.002; Figure 18).

Killdeer (*Charadrius vociferous*) was the most common shorebird species, constituting 45 – 61% of total shorebird species during both years. Least sandpiper (*Calidris minutilla*; 17 – 21%) and pectoral sandpiper (*Calidris melanotos*; 6 – 13%) also were common. Shorebird species composition differed among months in both years ($\chi^2_{100} \geq 4468.2$, $P < 0.001$; Figures 19 and 19). In 2006, killdeer (36 – 43%), pectoral sandpiper (12 – 23%), and least sandpiper (15 – 33%) were most common during August and September. In October, killdeer (66%) and least sandpiper (17%) were most common. In November, killdeer (71%) and dunlin (*Calidris alpina*, 15%) were most common, and killdeer (92%) were most common in December. In 2007, pectoral sandpiper (35%) and killdeer (34%) were most common in August. In September, least sandpiper (35%), killdeer (22%) and pectoral sandpiper (20%) were most common. During October and November, killdeer (50 – 77%), least sandpiper (11 – 25%), and Wilson's snipe (*Gallinago delicata*, 11 – 13%) were most common, and killdeer (76%) and least sandpiper (19%) were most common during December. No other species constituted >10% of total abundance for any month during either year (Figures 19 and 20).

Shorebird chronology.—Shorebirds were recorded using mudflats from 7 August through the last sampling week (26 December) in 2006 (Figure 21). The median cumulative abundance for 13 of the 19 species was recorded by mid-September, and the third quartile was recorded by mid-December for all species. In 2007, shorebirds were recorded from the first sampling week (1 August), through the last sampling week (24 December; Figure 22). The median cumulative abundance for 19 of the 26 species in 2007 was recorded by mid-September, and the first quartile for 15 species was recorded by early September. The third quartile for all species was recorded by late November.

Waterfowl.—Waterfowl abundance ($\bar{x}$ = 289, SD = 262) and richness ($\bar{x}$ = 3.4, SD = 2) in November was 2 – 13X greater than in August, September, and October in 2006 ($F_{4,32} \geq 6.23$, $P \geq 0.012$; Figures 23 and 24). Although overall tests were significant both years ($F_{4,104} \geq 10.6$, $P \leq 0.002$), Ryan's-Q post-hoc multiple comparison test did not detect differences in waterfowl diversity among months (Figure 25). No other differences were detected in waterfowl abundance, richness, or diversity ($F_{4,104} \leq 2.8$, $P \geq 0.07$; Figures 23 – 25).

Gadwall (*Anas strepera*) was the most common waterfowl species, constituting 34 – 35% of total waterfowl species during both years. Other commonly observed species included mallard (*A. platyrhynchos*, 29%) and green-winged teal (*A. crecca*, 15%). Waterfowl species composition differed among months in both years ($\chi^2_{72} \geq 28502.8$, $P \leq 0.001$; Figures 26 and 27). In 2006, blue-winged teal (*Anas discors*, 47 – 65%) and Canada goose (*Branta canadensis*, 20 – 40%) were most common during August and September. During October, gadwall (30%), green-winged teal (20%), mallard (18%), blue-winged teal (14%), and Canada goose (12%) were most common. During November and December, gadwall (38%), mallard (31 – 33%), and green-winged teal (18 – 19%) were most common. In 2007, blue-winged teal (65 – 78%) and Canada geese (15 – 29%) were most common during August and September. During October, green-winged teal (29%), Canada goose (17%), blue-winged teal (16%), mallard (12%), gadwall (11%), and northern pintail (11%) were most common. During November and December, gadwall (42 – 43%), mallard (28 – 43%), and green-winged teal (12 – 20%) were most common. No other species constituted >10% of total abundance for any month of either year.

<u>Waterbird and Invertebrate Models</u>

In general, the models that I constructed explained relatively little variation ($R^2 \leq 0.24$) in waterbird use (Table 3). The best performing shorebird model ($R^2 = 0.09$) had period as the explanatory variable, which was negatively related with shorebird abundance. Thus, as period increased (i.e., week progressed from August through December), shorebird abundance decreased. Other significant models include variables for mudflat acreage and soil compaction, which were positively and negatively related with shorebird abundance, respectively. The best performing waterfowl model ($R^2 = 0.25$) included water depth and period as explanatory variables – both which were positively related with waterfowl abundance. There was no evidence of collinearity in any of the models (VIF ≤ 2.9; Table 3).

Similarly, the model that I constructed for aquatic invertebrates explained very little variation in abundance (R^2 = 0.09; Table 4). The majority of this variation (8%) was explained by contour position, which was positively related with abundance. Contours were ordinally ranked from highest to lowest elevation, thus aquatic invertebrate abundance was greatest at the lowest elevation near the waterline. Soil moisture also was retained in the model but only explained 1% of the variation in invertebrate abundance.

DISCUSSION

Mudflat Area

Mudflats that I used for my study were 9 – 78 ha at the lowest extent of the drawdown, with an average size of 35 ha. Average size of mudflats in Chickamauga and Douglas Reservoirs studied by Laux (2008) was 20 ha. Thus, mudflats in Kentucky Reservoir likely provide more acreage of habitat for waterbirds than eastern TRV reservoirs, which is likely a consequence of its lower position in the TRV watershed. Although size of mudflats used by waterbirds varies considerably throughout North America (Harrington and Perry 1995), the size of TRV mudflats is comparable to other well-known migratory stopover sites in coastal (2 – 111 ha, Weber and Haig 1996, Collazo et al. 2002) and interior regions (1 – 600 ha, Skagen and Knopf 1994*b*, Anderson et al. 2000) of the United States.

During the years of my study, I recorded initial mudflat exposure between late July and early September, depending on the elevation. However, significant exposure (i.e., total mudflat area >20 ha) did not occur until the first week in September. In the eastern TRV, initial mudflat exposure occurred between 19 July and 3 August in Douglas Reservoir and in early October in Chickamauga Reservoir (Laux 2008). In southern Illinois, Elliot-Smith (2003) recorded initial mudflat exposure of Rend Lake between early July and mid-August. Thus, timing of mudflat exposure in Kentucky Reservoir was similar to other sites in the eastern United States. In mid-continental United States, it is recommended that initial mudflat exposure occurs July – September for migrating waterbirds, especially shorebirds (Rundle and Fredrickson 1981, Hands 1991, Helmers 1992).

Water level at the New Johnsonville gage was a good predictor of exposed acreage for my mudflats. Mean exposure started at 108.82 m (357.02 ft) MSL, and new mudflat area was exposed continuously through November except for when rains resulted water levels rising, which occurred twice per year during my study. The model in Figure 8 can be used to predict combined exposed acreage at my study mudflats using the water level (ft) at the New Johnsonville gage. I suspect that other mudflats in Kentucky Reservoir will be exposed similarly due to the relatively low gradient and interconnected watershed of this reservoir.

<u>Mudflat Characteristics</u>

Vegetation.—Mean vegetation structure, biomass, and seed yield differed among 0.305-m mudflat contours. Vegetation height, percent horizontal cover, biomass, and species richness at the highest contour was 2 – 33X greater and seed yield was 3100X greater than at the lowest contour. Vegetation stratification along elevation gradients has been reported in other wetland studies (Fredrickson and Reid 1988*c*, Fredrickson and Taylor 1982), and is related to the duration of soil exposure (Webb et al. 1988). Average exposure duration for the highest 2 mudflat contours was 62 and 33 days prior to the end of the growing season. Most moist-soil plants require around 70 days of growing season for seeds to germinate and plants to mature (Ahn et al. 2006, Laux 2008). Thus, it is unlikely that exposure duration was sufficient at the lower contours for substantial vegetation growth. Indeed, 99% of the seed production by mature plants was located in the highest mudflat contour.

Timing of exposure also likely affected vegetation establishment. Vegetation germinated within a week post-exposure in August, with mean horizontal coverage >30% in 2 weeks. In contrast, vegetation in plots exposed in late September and October either took over 2 weeks to germinate or germination never occurred, and horizontal coverage did not exceed 5%. These results suggest delay in the drawdown of Kentucky Reservoir would reduce vegetation establishment and seed yield on mudflats.

Across mudflat contours, I documented lower vegetation biomass in Kentucky Reservoir (62 – 68 g m^{-2}) than Laux (2008) documented in Douglas Reservoir (162 – 165 g m^{-2}) in the eastern TRV. However, mudflats in Douglas Reservoir were exposed for considerably longer duration (109 days) than in Kentucky Reservoir (42 days). Plant biomass in moist-soil wetlands that were drawn down during spring averaged 518 – 1261 g m^{-2} in Mississippi (Gray et al. 1999*c*). Thus, my results indicate that the biomass of vegetation on mudflats can be increased substantially by exposing mudflats for 3 months or more during the growing season.

Average seed production by moist-soil plants on Kentucky Reservoir mudflats was 2 – 6 g m^{-2}. These estimates were similar to those in Douglas Reservoir (3 – 10 g m^{-2}, Laux 2008), despite its earlier mudflat exposure, and probably was related to differences in species composition between reservoirs. Cocklebur comprised 59% of vegetation biomass in Douglas Reservoir. Cocklebur is considered a nuisance plants in wetlands, because it shades moist-soil plants and reduces their seed production (Reid et al. 1989). In contrast, *Eleocharis acicularis*, *Rotala ramosior*, and *Ammannia coccinea* comprised the majority of biomass in Kentucky Reservoir – all of which produce seed that are consumed by waterfowl. Thus, early exposure of mudflats in TRV Reservoirs will increase vegetation biomass but may not increase seed yield, especially in locations where there is a cocklebur seed source. Overall, seed yield on TRV mudflats were lower than estimates in moist-soil wetlands in the Southeast (12 – 121 g m^{-2}; Gray et al. 1999*c*, Kross et al. 2008).

Mean belowground seed biomass did not correspond with aboveground seed production. Tree and cocklebur seed biomass were greatest at the lowest contour, and biomass of moist-soil seed and tubers did not differ among elevations. Given that the majority of seed produced aboveground was in the highest contour, it is reasonable to hypothesize that belowground seed biomass would decrease with elevation. Even distribution of belowground seed biomass is possible if aboveground seeds that were produced became redistributed following flooding. No studies have examined the redistribution of moist-soil seeds in wetlands. Goodson et al. (2001) reported that deposition of seeds in river floodplains is dependent on a variety of factors, but often deposition rates are greater near the river channel. Thus, the biomass of tree and cocklebur seeds may have been greater at the lowest contour due to higher deposition. This inference is dependent of the assumption that moist-soil seeds are not transported as efficiently in river systems as tree and cocklebur seeds, which may be true given cocklebur and many tree seeds float (Johansson et al. 1996).

Belowground moist-soil seed biomass across contours in Kentucky Reservoir (25.1 – 38.1 kg ha^{-1}) was similar to Douglas (56.5 kg ha^{-1}) and Chickamauga Reservoirs (26.8 kg ha^{-1}) in the eastern TRV (Laux 2008). No other studies have estimated belowground seed biomass in reservoirs for comparison. However, seed biomass from core sampling in moist-soil wetlands (450 - 496 kg ha^{-1}; Reinecke et al. 1989, Kross et al. 2008) is considerably higher than TRV mudflats. Thus, mudflats may be more important sites for acquisition of other natural foods, such as aquatic invertebrates.

Invertebrates.—Benthic macroinvertebrate estimates for Kentucky Reservoir mudflats were comparable to previous studies at interior stopover sites and exceeded biomass and density thresholds (i.e., 100 individuals and 0.79 g m^{-2}) considered necessary to attract waterbirds (Eldridge 1992, Andrei et al. 2008). Mean invertebrate biomass for Kentucky Reservoir was 3.6 g m^{-2} in 2006 and 1.5 g m^{-2} in 2007. Biomass estimates from mudflats at other interior stopover sites ranged from 0.01 – 8.44 g m^{-2} (Helmers 1991, Augustin et al. 1999, Anderson and Smith 2000, Ashley et al. 2000, Elliot-Smith 2003, Andrei et al. 2008). Invertebrate biomass in Kentucky Reservoir mudflats also was comparable to managed mudflats at Cheyenne Bottoms (2.7 – 6.3 g m^{-2}), which is a migratory stopover site of hemispheric importance as designated by the Western Hemisphere Shorebird Reserve Network (Helmers 1991). Thus, my results provide evidence that western TRV mudflats support substantial biomass of aquatic invertebrates for migrating waterbirds.

Mean invertebrate density for Kentucky Reservoir (2,185 and 847 individuals m^{-2} in 2006 and 2007) was similar to some mudflat studies (i.e., 57 – 2,616 individuals m^{-2}; Davis and Smith 1998*b*, Whittington 2005, Andrei et al. 2008), while considerably less than others (i.e., 2,500 – 40,795 individuals m^{-2}; Augustin et al. 1999, Elliot-Smith 2003, Hamer et al. 2006, Furey et al. 2006). Invertebrate density at Cheyenne Bottoms was 8,888 – 11,182 individuals m^{-2}, Helmers 1991); however as mentioned earlier, biomass was similar. Differences between biomass and density estimates between Cheyenne Bottoms and Kentucky Reservoir may have been related to invertebrate size, because Chironomidae larvae comprised the majority of invertebrate abundance, thus species composition was similar. Helmers (1991) reported that chironomid length varied considerably (3 – 25 mm) within mudflats at Cheyenne Bottoms. Although I did not measure invertebrate length, it is possible that average chironomid length in Kentucky Reservoir mudflats was greater than at Cheyenne Bottoms, thereby resulting in similar biomass but lower density.

Chironomids also were most common (67%) in Douglas and Chickamauga reservoirs (J. Laux, University of Tennessee, unpublished data), suggesting that this invertebrate is the most abundant food resource for migrating waterbirds in the TRV. In a side study, I documented that chironomids were the dominant food item consumed by least sandpipers in the TRV (D. Wirwa, unpublished data). Previous studies outside the TRV have reported that chironomids are the most common invertebrate available to waterbirds in mudflats (Helmers 1991, Mihue et al. 1997, Loesch et al. 2000, Andrei et al 2008). Chironomids are considered one of the most important invertebrates for shorebirds and waterfowl, because they can occur at high biomass and contain considerable metabolizable energy (i.e., 4.2 kcal g^{-1}; Helmers 1992, Loesch et al. 2000, Baldassarre and Bolen 2006). Other common invertebrate taxa in Kentucky Reservoir mudflats included nematodes (12%) and oligachaetes (8%). Laux (University of Tennessee, unpublished data) reported that nematodes (14%) and arachnids were common in eastern TRV mudflats. Thus, TRV mudflats provide a diversity of aquatic invertebrates for migratory waterbirds.

Aquatic invertebrate densities at sampling sites within 10 m of the waterline were 1.2 – 2.9X greater than at sites over 10 m upslope of the waterline. No previous studies have directly compared spatial distribution of aquatic invertebrates in mudflats. Fewer aquatic invertebrates at higher elevations on the mudflat may have been a consequence of lower soil moisture. Average soil moisture was 92% at invertebrate sampling sites >10 m from the waterline compared to 98% within 10 m of the waterline. Most aquatic invertebrates require flooded substrate or high soil moisture to complete life cycle events (Colwell and Landrum 1993, Furey et al. 2006). In addition, soil compaction at sampling sites >10 m from the waterline was 2.5X greater than sites within 10 m of the waterline, which may have negatively impacted invertebrate abundance. These results suggest that the most suitable aquatic invertebrate foraging sites for waterbirds is within 10 m of the waterline. Given that I did not sample beyond 10 m from the waterline in the water, lower sites may provide aquatic invertebrates too if water depth does not exceed the maximum foraging depth of a waterbird species.

Aquatic invertebrate densities on the waterline were greatest at the lowest mudflat contours. Similar to trends previously described, this may be related to decreased soil compaction at lower elevations. Soil compaction at the highest contour was 3 – 8X greater than at sampling sites on the waterline at lower contours. Additionally, other microhabitat factors may have contributed to increased invertebrate densities at lower elevations, such as organic content, soil composition and dissolved oxygen (Furey et al. 2006).

Soil characteristics and water depth.—Soil moisture was lower and compaction was greater at higher mudflat elevations than lower elevations. These differences in soil characteristics among contours were likely influenced by duration of exposure. During both years, the highest mudflat contour was exposed at least 28 days prior to the lower contours. Furthermore, lower elevations were more likely to be re-inundated during slight rises in the reservoir level from rain events. Mouritsen and Jenson (1992) reported that pecking depth of shorebirds increased with soil moisture and decreased with soil compaction. Thus, it is likely that the quality of foraging habitat for shorebirds increased with decreasing distance to the waterline and decreasing elevation.

Across both years, mean water depth at 2 and 10 m below the waterline was 2.29 and 6.61 cm, respectively. Most shorebirds use water depths <10 cm and most dabbling ducks can forage efficiently in water up to 30 cm (Fredrickson and Reid 1988*a*, Helmers 1992). Thus, optimal foraging habitat for shorebirds in Kentucky Reservoir occurs within 10 m of the waterline yet likely extends farther down-slope for waterfowl.

Waterbird Use and Migration Chronology

I recorded over 23,000 shorebirds of 26 species using 9 mudflats in Kentucky Reservoir, which is 50% of the species that breed in North America (Morrison et al. 2006). This level of species richness was similar to or exceeded that of other major interior stopover sites. Twedt et al. (1998) and Short (1999) recorded 22 and 29 species, respectively, at sites within the Mississippi Alluvial Valley (MAV), and 20 – 30 species have been recorded at stopover sites in the Southern High Plains (Davis and Smith 1998*b*, Andrei et al. 2006). I also recorded several uncommon species of high conservation concern, including piping plover (*Charadrius melodus*), buff-breasted sandpiper (*Tryngites subruficollis*), Wilson's phalarope (*Phalaropus tricolor*), and ruddy turnstone (*Arenaria interpres*; Brown et al. 2001). Kentucky Reservoir mudflats also supported high shorebird abundance. I recorded 23,830 shorebirds, with several daily surveys exceeding 700 individuals. Using a 10-day turnover rate estimated by Lehnen and Krementz (2005), I estimated that approximately 3,390 – 4,786 shorebirds used these mudflats during my study. Given that these 9 mudflats represent 17% of the suitable mudflat acreage in Kentucky Reservoir, I that estimated approximately 20,000 – 28,000 shorebirds use Kentucky Reservoir annually if use of other mudflats is similar to the ones I surveyed. This level of shorebird use qualifies Kentucky Reservoir as a "Site of Regional Importance," according to the Western

Hemisphere Shorebird Reserve Network, and emphasizes the importance of Kentucky Reservoir to continental shorebird populations (WHSRN 2009).

In addition to shorebirds, I recorded over 107,000 waterfowl of 20 species, which is 36% of species that breed in North America (Bellrose 1976). Waterfowl species recorded that are believed to be in decline included lesser scaup, American black duck (*Anas rubripes*), and northern pintail. Several daily surveys exceeded 5,000 ducks and geese using Kentucky Reservoir mudflats. Additionally, I recorded 25 species of other waterbirds, including 10 species of gulls and terns (Laridae), and 9 species of wading birds (Ardeidae, Threskiornithidae, and Gruidae). Significant waterfowl use of the western TRV has previously been noted (Wiebe 1946, White and Malaher 1964, Johnson and Montalbano 1989), but its use by other waterbirds (especially shorebirds) has generally been overlooked. My results indicate that western TRV mudflats provide habitat for a diverse assemblage of migrating and wintering waterbirds – several of which are species of concern.

Shorebirds.—In general, mean shorebird abundance, richness, and diversity were greatest during September in both years, indicating shorebird use of Kentucky Reservoir peaked during this month. High shorebird use of mudflats in Kentucky Reservoir during September was likely influenced by migration chronology and habitat availability. Several studies at similar latitudes have documented peak southward migration during August and September (Smith et al. 1991, Twedt et al. 1998, Skagen et al. 1999, Andrei et al. 2006). Laux (2008) found that peak use of mudflats in the eastern TRV occurred during September when mudflats were not exposed until mid-August, but use was similar between August and September when mudflats were exposed by the end of July. In western Tennessee along the Mississippi River, Short (1999) reported abundance for 5 of the 7 most common shorebirds species peaked in August at sites managed for shorebirds. Thus, lower use of Kentucky Reservoir mudflats in August may be a consequence of less acreage exposed during this month compared to September. Mudflat acreage in September was 7.8 – 8.2X greater than in August both years (Figures 6 and 7). As a result, shorebird density in August was 2.0 – 3.3X greater than in September. Collectively, these results illustrate the importance of mudflat exposure during late summer in Kentucky Reservoir for migrating shorebirds.

From October through December, mean shorebird abundance, richness and diversity decreased by 53 – 80%, and total richness decreased from 23 species in September to 6 species in December, likely reflecting trends in migration chronology. Laux (2008) also noted total shorebird richness on eastern TRV mudflats decreased from 19 species in August and September to 9 species from October – January. Despite the decline in shorebird use, these data provide evidence that shorebirds overwinter in the TRV, and emphasize the importance of exposed mudflats later in the year as well.

Shorebird species composition differed among months, and corresponded with migration chronology. Killdeer, pectoral, least, and semipalmated sandpipers (*Calidris pusilla*) were the most common species (86% collectively) using Kentucky Reservoir mudflats. Of these species, the majority of pectoral and semipalmated sandpipers were recorded during August (30 – 49%) and September (46 – 70%), whereas least sandpipers were observed most frequently in September (53%) and October (21%). Killdeer were most common in November (28%) and December (23%). Previous studies have documented similar peak migration periods for each of these species (Smith et al. 1991, Twedt et al. 1998, Skagen et al. 1999, Andrei et al. 2006). I also recorded 9 species of high conservation concern and highly imperiled species using Kentucky Reservoir mudflats: American golden plover (*Pluvialis dominica*), buff-breasted sandpiper, piping plover, sanderling (*Calidris alba*), short-billed dowitcher (*Limnodromus griseus*), solitary sandpiper (*Tringa solitaria*), western sandpiper (*Calidris mauri*), Wilson's phalarope, and ruddy turnstone (Brown et al. 2001). All of these species were documented during August and September, and are considered early southward migrants (Smith et al. 1991, Short 1999, Skagen et al. 1999, Laux 2008). Solitary sandpiper and western sandpiper were recorded on my first day of sampling in 2007 (i.e., 30 and 31 July), illustrating the importance of early mudflat exposure. Migration chronology may be related to breeding and wintering distributions and migration distance. For example, pectoral sandpipers breed along the arctic coastal plain and winter in central and southern South America, thus this and similar species may migrate earlier to avoid decreasing ambient temperatures at higher latititudes and to allow sufficient time to reach stopover and wintering grounds. In contrast, species that winter in southern United States are commonly later migrants and breed at more southern latitudes of North America. I recorded 5 species using Kentucky Reservoir mudflats in December: Wilson's snipe, killdeer, long-billed dowitcher (*Limnodromus scolopaceus*), least sandpiper, and pectoral sandpiper. Killdeer, least sandpiper and Wilson's snipe were the most abundant (99%), indicating these species likely overwintered in Kentucky Reservoir. Laux (2008) also reported killdeer, least sandpipers, and Wilson's snipe using eastern TRV mudflats in December and January. Least sandpipers breed in the sub-arctic regions of North America and are known to winter in mid-continental United States.

Waterfowl.—Waterfowl mean abundance, richness, and diversity increased from August through November and declined in December. Most waterfowl species arrive in the TRV during October – December (Reid et al. 1989, Benedict and Hepp 2000). Laux (2008) recorded 12 of 16 waterfowl species in October or later. In Kentucky Reservoir, total waterfowl abundance increased by 4.3 – 5.3X from October to November during both years, followed by a 28 – 41% decrease in abundance from November to December. This decrease may have been related to an increase in the availability of flooded agricultural fields on the Tennessee National Wildlife Refuge or at Tennessee Wildlife Resources Agency Wildlife Management Areas that were nearby (e.g., Big Sandy Wildlife Management Area). Additionally, given that the Tennessee waterfowl hunting season opens in late November, and 6 of our 9 mudflats were open to hunting, the decrease in waterfowl use during December may have been due to disturbance from hunting activities. For example, in 2007, mean daily abundance at mudflats open to hunting decreased by 65% from November to December, whereas mean daily abundance at mudflats within the refuge boundary decreased by only 7%. These differences in surrounding disturbance among mudflats were likely the source of substantial variation in waterfowl use, which also may have contributed to the lack of differences detected by statistical tests with some comparisons.

Waterfowl species recorded during August were a combination of resident and migratory species. Most common resident species were Canada goose (33%), wood duck (*Aix sponsa*, 9%), and mallard (4%), and the most common migrant was blue-winged teal (53%). Baar et al. (2008) also documented peak migration of blue-winged teal during August in the Southern High Plains of Texas. Green-winged teal (3%), gadwall (1%), northern pintail (1%), and northern shoveler (*Anas clypeata*, 1%) were recorded arriving in September, which also is consistent with previous migration chronology research (Minser 1968, Bellrose 1976, Baar et al. 2008). During November and December, mallard, gadwall, and green-winged teal were the most common species (91% collectively), with gadwall most common (40%). Although mallards have been reported as the most common migratory waterfowl species in the Mississippi Flyway (Reinecke et al. 1989, Pearse et al. 2008), gadwalls are known to use permanent wetlands more than other dabbling ducks (Oring 1964, Paulus 1982). Within Tennessee National Wildlife Refuge during my study, gadwalls comprised 23% of total waterfowl abundance using Kentucky Reservoir compared to 4% abundance within managed moist-soil impoundments measured during bi-monthly aerial surveys (R. Wheat, USFWS, unpublished data). Previous studies have reported gadwall as one of the most common waterfowl species using riverine reservoirs (McKnight and Hepp 1998, Benedict and Hepp 2000). Gadwall also was the most common species using lakes and marshes of the central coastal region of Louisiana (Chabreck et al. 1989). Thus, Kentucky Reservoir mudflats are important habitats for migratory gadwall as well as a diversity of other waterfowl species.

Waterbird and Invertebrate Models

The shorebird models that I developed explained very little variation (i.e., 4 – 8%) in relative abundance. Three variables were retained in the final models: mudflat acreage, soil compaction, and period. Shorebird abundance and mudflat acreage were positively related, suggesting shorebirds may be attracted to larger mudflats. Taylor et al. (1993) also documented greater shorebird use of larger mudflats in American Falls Reservoir, which may be a result of greater likelihood of detection or lower predation rates. Shorebird abundance was negatively related with soil compaction. Fewer aquatic invertebrates and decreased probing efficiency may have been mechanisms driving this relationship (Mouritsen and Jenson 1992, Bolduc and Afton 2004). Period (i.e., number of consecutive weeks from the beginning to the end of sampling) was negatively related with shorebird abundance, which was a consequence of migration chronology. Shorebird abundance in Kentucky Reservoir was greatest during August and September, and decreased thereafter.

The waterfowl models explained slightly more variation (i.e., 15 – 25%) in abundance than shorebird models. The model that explained the greatest variation in waterfowl abundance included water depth and period as explanatory variables. These variables were positively related with waterfowl abundance, suggesting waterfowl tended to use mudflats with steeper slopes. The relationship with depth also may have been confounded by protection from waterfowl hunting. Waterfowl abundance was greatest at mudflats within Tennessee National Wildlife Refuge, which tended to have steeper slopes than other non-refuge mudflats (9.8 vs. 4.4-cm depth 10 m below the waterline). Similar to the shorebird models, the relationship of period was related to migration chronology, with more waterfowl using mudflats from October – December than in August or September.

Of the 2 variables retained in the invertebrate model, contour position explained the most variation (15%) in density. Contour position was positively related with invertebrate density. Contours were ranked in order from highest to lowest elevation, thus invertebrate density was greatest in the lowest contour. As discussed previously, invertebrate density probably was lower in higher contours because soil moisture was lower and compaction was higher, which may have reduced suitability for aquatic invertebrates.

Overall, the low amount of variation explained by models was likely attributed partially to the high variability in waterbird abundance and invertebrate densities across mudflats. Also, I constructed multiple regression models, which capture linear relationships between dependent and explanatory variables. However, exploratory analysis of temporal trends showed cases of non-linear relationships and possible lag effects among variables. Thus, I am collaborating with Dr. William Seaver in the Department of Statistics at the University of Tennessee to develop non-linear time-series models that may be able to explain more variation in waterbird abundance.

Another factor that may have contributed to low variation explained by waterbird models is that soil, vegetation and aquatic invertebrate explanatory variables were measured along standardized transects that were not always positioned near locations where waterbirds were using the mudflats. Although these transects allowed accurate measurement of these variables along mudflat contours, transect conditions may not have been an accurate representation of conditions at sites where waterbirds were located. For invertebrate models, all predictor variables were measured at sampling sites, thus other microhabitat factors that were not measured (e.g., organic content, soil composition, and dissolved oxygen) may have been more important. More research may be needed to identify important microhabitat factors influencing the use of mudflats by waterbirds and the spatial distribution of aquatic invertebrates.

Despite the low amount of variation in waterbird abundance explained by the multiple regression models that I constructed, there were several spatial and temporal trends that were detected by ANOVA models that may have impacted waterbird use. Thus, in the the next section, I included a general discussion on how vegetation establishment and aquatic invertebrate abundance on Kentucky Reservoir mudflats may have affected waterbird use.

Possible Impacts of Vegetation and Invertebrates on Waterbird Use of Mudflats

Vegetation can impact waterbird use of wetlands (Rundle and Fredrickson 1981, Baldassarre and Bolen 2006). While some species of shorebirds commonly use moderately vegetated mudflats (e.g., Wilson's snipe and Yellowlegs [*Tringa spp.*]; Helmers 1992), most species prefer mudflats containing <25% horizontal cover of vegetation (Meeks 1969, Colwell and Oring 1988, Helmers 1993, Short 1999). In Kentucky Reservoir, vegetation establishment below the highest mudflat contour was minimal. By the end of the growing season, vegetative cover in the second 0.305-m contour was ≤15 %, and vegetation height was ≤1.75 cm. Vegetation did not germinate in the lowest contour. Therefore, vegetation on mudflats did not limit shorebird use in Kentucky Reservoir.

Most species of waterfowl are attracted to vegetated wetlands (Baldassarre and Bolen 2006, Stafford et al. 2007). Several waterfowl species browse recently germinated vegetation (Craven 1984; Fredrickson and Reid 1988*b*). Canada geese, green and blue-winged teal, and American wigeon were observed grazing vegetation shoots on Kentucky Reservoir mudflats (D. Wirwa, personal observation). Vegetation in the highest mudflat contour produced seed but probably is of little value to waterfowl within years unless the mudflat re-floods. Re-flooding occurred approximately 2X each year in Kentucky Reservoir. During these events, waterfowl responded immediately to the newly flooded vegetation (D. Wirwa, personal observation). Several studies have reported immediate foraging of waterfowl in recently inundated habitats (Reinecke et al. 1988, Reinecke et al. 1989, Heitmeyer 2006).

Aquatic invertebrates are an important food item for many species of waterbirds (Colwell and Landrum 1993, Laubhan and Gammonley 2000). Waterfowl consume invertebrates during migration as an energy source and to acquire essential nutrients and amino acids (Baldassarre and Bolen 2006). Many shorebirds feed almost exclusively on invertebrates (Baldassarre and Fischer 1984, Skagen and Oman 1996), and food availability during migration may be a primary limiting factor of shorebird populations (Loesch et al. 2000, Skagen 2006). Given the low density of seed in core samples, it is likely that waterfowl foraging in the shallowly flooded mudflats of Kentucky Reservoir are acquiring aquatic invertebrates. My results suggest that aquatic invertebrates are a significant food resource on western TRV mudflats, thus their availability may be important to sustaining waterbird populations that migrate through the region.

MANAGEMENT IMPLICATIONS

Reservoirs associated with river systems in the interior United States can provide important mudflat and shallow-water habitat for migrating and wintering waterbirds during drawdown. Kentucky Reservoir mudflats provided migrating and wintering habitat for 26 species of shorebirds and 20 species of waterfowl. Food resource densities were comparable with other important stopover sites in the interior United States. Aquatic invertebrate and seed biomass estimates indicate that Kentucky Reservoir mudflats provide on average 5,480 shorebird energy-days (SED) ha^{-1} and 553 duck energy-days (DED) ha^{-1}. Biologists can multiply these values by corresponding mudflat acreage and divide by the number of anticipated days of use to estimate the number of shorebirds or waterfowl that could be energetically sustained (see Reinecke et al. 1989 and Loesch et al. 2000 for details). However, biologists should be aware that total SEDs and DEDs for a mudflat are not available continuously. My results indicate that suitable habitat for shorebirds most likely occurs within a 20-m band centered on the waterline, which on average was 23% of the total mudflat area available at any given time during the drawdown. Suitable waterfowl habitat probably extends farther than 10 m into the water (e.g., 20 m) because they can forage deeper, but at the same time, few waterfowl species will probe exposed soil for seeds or aquatic invertebrates unlike shorebirds. Thus, I recommend that for more realistic estimates of SEDs or DEDs at a certain time during a drawdown, the SED and DED averages provided above are multiplied by available acreage (i.e., 20 m $\times$ length of the waterline associated with a mudflat).

Timing of the drawdown in Kentucky Reservoir had a significant influence on waterbird use by impacting mudflat exposure, vegetation establishment and seed production, and invertebrate availability. Waterbirds in Kentucky Reservoir used mudflats as they were exposed. Under the current drawdown schedule, very little mudflat acreage (<10 ha) is exposed on the 9 mudflats that I studied during August (Figures 6 and 7). Exposed mudflat area increased 8X from August to September, which corresponded with a 3-fold increase in mean shorebird abundance. Using a 10-day turnover rate of shorebird populations (Lehnen and Krementz 2005) and total abundance estimated during my study, I estimated that 1,214 – 2,084 shorebirds use these 9 mudflats during September and 365 – 421 shorebirds use the mudflats in August. Thus, if similar mudflat acreage was exposed during August, these mudflats could support at least an additional 849 – 1,663 shorebirds during August. This inference is contingent on similar numbers of shorebirds migrating through the TRV in August and September, which data from Laux (2008) support. Further, exposure of mudflats during August is important for several shorebird species of conservation concern (e.g., buff-breasted sandpiper, piping plover, and Wilson's phalarope) that I documented.

Using SEDs that I estimated and a 20-m band of suitable habitat on the mudflats that I studied, approximately 2,593 – 2,658 SEDs are available to shorebirds during September. Total shorebird use on the 9 study mudflats in September was 1,214 – 2,084 shorebirds which did not exceed available SEDs, thus these mudflats appear to provide sufficient energetic resources to sustain shorebirds populations during this month under the current drawdown schedule. This probably is the case for other suitable mudflats in Kentucky Reservoir. However, only 498 – 730 SEDs are available on the 9 mudflats in August. Thus, if a similar number of shorebirds migrate through the TRV in August as in September (Laux 2008), available SEDs on Kentucky

Reservoir mudflats is 2 – 3X lower than what is necessary to energetically support these birds. To compensate for this deficit, an additional 74 ha (or 83 ha total) should be exposed by mid-August on these mudflats, and a total of 488 ha exposed in Kentucky Reservoir to support migrating shorebird populations in August. These results also provide evidence that delaying the drawdown in Kentucky Reservoir will negatively affect shorebird populations migrating through the western TRV.

Based on these results, if waterbird conservation is a goal of Kentucky Reservoir operations, I recommend a drawdown schedule that results in initial mudflat exposure by 1 August, which is earlier than currently planned (i.e., existing operations result in initial exposure by 15 August; Figure 3, 8). Tennessee Valley Authority can use the 9 mudflats that I studied for drawdown guidance, which become exposed when the water level at the New Johnsonville gage is 108.81 m (357 ft) MSL or lower (Figure 8). Based on the information provided in the preceding paragraph, I recommend that 83 ha of mudflats are exposed on these mudflats by 15 August. Using the model that I developed in Figure 8, this will occur when the water level at the New Johnsonville gage is 108.43 m (355.74 ft) MSL, which may require adjustment to the existing guide curve (Figure 3). This adjustment to reservoir operation should result in sufficient mudflat habitat exposed during August to energetically support shorebird populations migrating through the western TRV. Lastly, throughout the drawdown, I recommend that water levels are drawn down slowly (<4 cm day^{-1}) to allow continuous exposure of new mudflats. The current drawdown for Kentucky Reservoir occurs at this rate. Operators of other reservoirs at similar latitudes (36°N) in the interior United States that are interested in providing habitat for migratory waterbirds should consider a similar drawdown schedule.

Future research efforts should be directed towards identifying additional riverine reservoirs in the interior United States that provide habitat migrating and wintering waterbirds. Overall, mudflats associated with river systems have been overlooked as important sites for migratory waterbirds. The results from my study and Laux (2008) indicate that TRV mudflats are an important stopover site for thousands of migratory shorebirds and waterfowl. As such, I recommend that the TRV be considered in habitat objectives of the United States Shorebird Conservation Plan and the North American Waterfowl Management Plan. I also estimated that over 20,000 shorebirds use Kentucky Reservoir mudflats during fall migration, thus this system of mudflats should be designated as a "Site of Regional Importance," by the Western Hemisphere Shorebird Reserve Network (WHSRN 2009).

CHAPTER III

WATERBIRD ACTIVITIES ON MUDFLATS IN THE TENNESSEE RIVER VALLEY

INTRODUCTION

Analysis of avian activities is fundamental to understanding their life history and the importance of various habitats (Paulus 1988, Dubowy 1996, Davis and Smith 1998*a*). For migratory species, activities at stopover and wintering sites can be different than during other periods of the annual cycle (Recher and Recher 1969). For example, during the breeding season, many avian species are engaged in courtship, nest building, and parental care activities (Gibson 1978). However, during migration, avifauna spend a large percentage of their time acquiring food resources to replenish lipid reserves depleted during long-distance flights (Paulus 1988, Davis and Smith 1998*a*). This is particularly true for many waterbirds that may migrate thousands of kilometers between breeding and wintering sites (Skagen 2006). Several species of waterbirds also initiate courtship and establish pair bonds at migratory stopovers (Bellrose 1976, Quinlan and Baldassarre 1984). Understanding trends in life-cycle activities among waterbird species during migration and winter will help in identifying critical habitats and will provide guidance to biologists interested in managing habitats for these species (Paulus 1988, Andrei et al. 2007).

Waterbirds use a variety of wetland types during migration and winter. Shorebirds frequently use shallowly-flooded wetlands with very little vegetation cover (Helmers 1992). On the other hand, waterfowl commonly use herbaceous wetlands, flooded forests, and reservoirs (Johnson and Montalbano 1989, Reid et al. 1989). Other waterbirds, such as herons and egrets, may use a combination of forested wetlands and deepwater habitats (Willard 1977, DuBowy

1996). Despite the wealth of information on waterbird use in wetlands, there are very few studies that have examined the use of mudflats by these birds (Johnson and Rohwer 2000, Andrei et al. 2007). Given that waterbird densities on mudflats can be substantial (e.g., 100 shorebirds m^{-2}, Mawhinney et al. 1993), it is important to build a more thorough understanding of life-cycle activities associated with these habitats and determine if activities differ among species.

Most studies on waterbird use of mudflats have focused on coastal or depressional wetlands (e.g., Burger et al. 1979, Quinlan and Baldassarre 1984, Johnson and Rohwer 2000). Only a handful of studies have quantified waterbird-use activities on mudflats associated with riverine systems (Turnbull 1985, White 1994, Elliot-Smith 2003). Coastal and depressional wetlands can differ substantially from riverine wetlands in terms of habitat connectivity. Due to their linear shape, riverine wetlands typically cover a smaller percentage of the landscape compared to other wetland types. For example, depressional playa and prairie pothole wetlands cover around 2% and 6 – 12% of the Southern High Plains and Great Plains landscapes, respectively (Haukos and Smith 1994, Beeri and Phillips 2007). In comparison, mudflats and shallowly flooded wetlands associated with the Tennessee River Valley cover approximately 0.1% of the landscape (T. Henry, Tennessee Valley Authority, unpublished data). Thus, migratory waterbirds that use riverine mudflats may be required to fly farther distances between suitable stopover sites causing them to spend more time feeding compared to those that migrate between coastal or depressional wetlands. Further, density of available food resources on mudflats may differ between these wetland types (Chapter II), which could influence time dedicated to various life-cycle activities. Research is needed quantifying waterbird activities on riverine mudflats to determine if they function similarly to mudflats associated with other wetland types.

For shorebirds, the types of activities may differ based on average migration distance. Laux (2008) found that shorebirds migrating longer distances spent 2.0 – 2.2X more time feeding than short-distance migrants. Similarly, Andrei et al. (2007) reported arctic-nesting least sandpipers (*Calidris minutilla*) spent more time feeding in the Southern High Plains and less time resting than American avocets (*Recurvirostra americana*), which breed in the United States. Activity budgets can be used with species composition data to help biologists target management strategies for waterbird species of greatest concern. Also, given that activities of waterbirds change seasonally (Davis and Smith 1998*a*), documenting temporal trends in activity budgets is important to help direct management strategies.

The Tennessee River Valley (TRV) is an ideal system to quantify waterbird activities on mudflats because the Tennessee Valley Authority (TVA) lowers water levels annually among 49 interconnected reservoirs, resulting in thousands of hectares of exposed mudflats (Chapter II). Waterbird use of TRV mudflats can be substantial, perhaps because they are located at mid-latitude in North America between the Mississippi and Atlantic Flyways (Figure 1). Laux (2008) estimated that waterbird use of TRV mudflats may be as high as in the Mississippi Alluvial Valley. In Chapter II, I documented 70 species of waterbirds using mudflats in Kentucky Reservoir in the western TRV. Information on waterbird activities on TRV mudflats will improve our understanding of their functional role and importance to migrating and wintering waterbirds in North America.

Thus, the goal of my study was to quantify waterbird activities on riverine mudflats. My research objectives were to: 1) quantify species-specific differences in waterbird activities on TRV mudflats in Kentucky Reservoir, 2) determine if activity budgets differed among months, 3) determine if activity budgets differed among short-, intermediate-, and long-distance migrant shorebirds, and 4) qualitatively compare my results to previous studies in other river and wetland systems. These results will be combined with Laux (2008) for publication as a comprehensive assessment of the functionality of TRV mudflats in meeting waterbird life-cycle needs.

METHODS

Species-specific activities were quantified at 9 mudflats in Kentucky Reservoir from 31 July – 30 December 2006 and from 30 July – 29 December 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 mudflats. Scan sampling was conducted on a randomly selected subsample of individuals ($n \leq 5$ per species) for up to 4 distinct flocks on each mudflat. This was done by aligning the scope with the center of the flock, and recording the instantaneous activity of the first five birds observed (Altmann 1974). Focal sampling was performed by selecting 2 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 durations of their activities were recorded.

Recorded waterbird activities included foraging, preening, inactive, alert, sleeping, antagonistic interaction, courtship, walking, stretching, flying, and swimming. Activities were combined into general categories post-hoc to simplify analyses and facilitate interpretation and comparisons with other studies. Combined activity categories included foraging, locomotion (flying, swimming and walking), maintenance (preening and stretching), resting (inactive and sleeping), alert, antagonistic, and courtship (waterfowl only), similar to previous studies (e.g., Paulus 1988, DuBowy 1996, Davis and Smith 1998*a*).

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 Kentucky Reservoir consisted of 5 short-distance, 15 intermediate-distance and 6 long-distance migrants (Skagen and Knopf 1993; Table 5). All wetland-dependent bird species observed other than shorebirds and waterfowl were placed into an "other waterbirds" category (Appendix VI). This category consisted of 14 species (indicated parenthetically) in the following families: Ardeidae (5), Gruidae (1), Laridae (5), Pelecanidae (1), Podicipedidae (1), and Rallidae (1).

Statistical Analysis

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 = 1,829 shorebirds, n = 1,562 waterfowl, and n = 1,237 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 expended per activity during the one-minute surveys. Differences in average percent time expended were tested among species, months, and activities using an analysis-of-variance (ANOVA). For tests among months, I used repeated measures ANOVA. If the overall ANOVA was significant, Ryan's-Q multiple comparison 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, Underwood 1997). All statistical analyses were performed using the SAS® system (SAS Institute, Cary, NC) 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 shorebird migrants ($\chi^2_{10} = 535.8$, $P < 0.001$). Feeding was the most common activity observed for long- and intermediate-distance migrants, comprising 76 and 71% of observations, respectively, but only comprised 37% of observations for short-distance migrants (Figure 28). In contrast, resting was the most common for short-distance migrants, comprising 39% of total observations but was only a minor component of observations for intermediate- and long-distance migrants (6% and 3%, respectively). Maintenance and locomotion were observed at similar rates among migration groups (7 – 14%), and alert behavior was uncommon (0.5 – 1%). Antagonistic behavior was observed for long- (1%) and intermediate- (0.3%) distance migrants but was uncommon (Figure 28).

Percent occurrence of activities also differed among shorebird species ($\chi^2_{70} = 550.3$, $P < 0.001$). All shorebirds were observed feeding more than any other activity, excluding killdeer (*Charadrius vociferous*), which was observed resting (44%) most often (Figure 29). Resting also was relatively common for lesser (*Tringa flavipes*) and greater yellowlegs (*Tringa melanoleuca*, 27 – 30%). Feeding was most common for short-billed dowitchers (*Limnodromus scolopaceus*), long-billed dowitchers (*L. griseus*) and Wilson's snipe (*Gallinago delicata*, 81 – 85%). Greater yellowlegs exhibited alert behavior (4.55%) most often, but this activity was uncommon (≤1%) for all other shorebirds. Dunlin (*Calidris alpine*, 28%) and spotted sandpipers (*Actitis macularia*, 33%) were observed engaged in locomotion more often than any other shorebird; locomotion was observed ≤18% for all other shorebirds. Semipalmated sandpipers (*Calidris pusilla*) were engaged in body maintenance (21%) more than any other shorebird. Antagonistic behavior was only recorded for pectoral sandpipers (*C. melanotos*, 0.9%) and least sandpipers (0.5%, Figure 29).

Waterfowl.—Feeding (62%) and locomotion (17%) were the most common activities for waterfowl using mudflats. The occurrence of maintenance (10%) and resting (11%) were similar. Antagonistic and alert behaviors rarely occurred for waterfowl (0.1%), and courtship behavior was not recorded. Percent occurrence of activities differed among waterfowl species (χ^2_{50} = 236.5, $P < 0.001$). Gadwalls (*Anas strepera*, 77%) were observed feeding more than other species, while Canada geese (*Branta Canadensis*, 35%) were observed feeding least often (Figure 30). Locomotion was observed for all waterfowl species except redheads (*Aythya americana*), and ranged from 7% for blue-winged teal (*Anas discors*) to 27% for wood ducks (*Aix sponsa*). Resting and maintenance were observed for all waterfowl except buffleheads (*Bucephala albeola*), ranging from 3% for gadwall to 33% for redheads. Alert behavior was only observed for Canada geese but was minimal (1%). The only species observed exhibiting antagonistic behavior were green-winged teal (*Anas crecca*, 0.5%) and mallards (*A. platyrhynchos*, 0.3%; Figure 30).

Other waterbirds.—Resting (45%) and maintenance (27%) were the most common activities of other waterbirds using mudflats. Feeding (13%) and locomotion (14%) occurred at similar rates, and alert behavior (0.7%) was rarely observed. Percent occurrence of activities differed among waterbird species (χ^2_{52} = 199.1, P < 0.001). Yellow-crowned night-herons (*Nyctanassa violacea*) and Caspian terns (*Sterna caspia*) were observed resting most often (80%), while pied-billed grebes (*Podilymbus podiceps,* 7%) were observed resting least often (Figure 31). Pied-billed grebes (50%) and American coots (*Fulica americana*, 32%) were engaged in locomotion more than other waterbirds, whereas terns and gulls that were using mudflats were observed in locomotion least often (0 – 15%). Maintenance was most often observed for herring gulls (*Larus argentatus*, 62%). Great blue herons (*Ardea herodias*, 2%) and great egrets (*A. alba*; 2%) were the only waterbirds that were seen exhibiting alert behavior (Figure 31).

Focal 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 variable is continuous (i.e., 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., Ryan's-Q 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 during 1-minute activity budgets differed among activities for short-, intermediate-, and long-distance migrants differed among activities ($F_{5,2352} \geq 255.3$, P <

0.001). Intermediate- and long-distance migrants spent significantly more time feeding than any other activity ($F_{5,768} \geq 365.3$, $P < 0.001$), whereas short-distance migrants spent significantly more time resting than any other activity ($F_{5,2352} = 255.3$, $P < 0.001$; Table 6). Time spent engaged in feeding, antagonistic, locomotion, and resting activities also differed among short-, intermediate-, and long-distance migrants ($F_{2,951} \geq 6.0$, $P \leq 0.003$). Time spent feeding by intermediate-distance migrants was 73% greater than short-distance migrants, and time spent feeding by long-distance migrants was 22% greater than intermediate-distance migrants ($F_{2,951} = 101.1$, $P < 0.001$). Time spent engaged in antagonistic behavior for intermediate- and long-distance migrants was 9 – 11X greater than for short-distance migrants ($F_{2,951} = 7.2$, $P < 0.001$). Locomotion for short- and intermediate-distance migrants was 43 – 65% greater than for long-distance migrants ($F_{2,951} = 6.0$, $P = 0.003$). Time spent resting by intermediate-distance migrants was 2.3X greater than for long-distance migrants, and time spent resting by short-distance migrants was 4X greater than for intermediate-distance migrants ($F_{2,951} = 185.6$, $P < 0.001$; Table 6).

For each shorebird species (excluding western sandpipers, *Calidris mauri*), percent time among activities differed ($F_{5,54} = 9.7$, $P < 0.001$). Additionally, time spent engaged in feeding, antagonistic, locomotion, and resting activities differed among shorebird species ($F_{15,932} = 2.36$, $P \leq 0.002$). All species spent significantly more time feeding than any other activity ($F_{5,54} = 9.7$, $P < 0.001$), except for killdeer and black-bellied plovers (*Pluvialis squatarola*, Table 7). Killdeer and black-bellied plovers spent 27 and 28% of their time feeding, respectively, while all other species spent at least 45% of their time feeding. Killdeer and black-bellied plovers spent significantly more time resting than any other species ($F_{15,932} = 34.67$, $P < 0.001$), except semipalmated plovers (*Charadrius semipalmatus*) and Wilson's snipe. Greater yellowlegs spent significantly more time engaged in locomotion than semipalmated sandpipers, Wilson's snipe, western sandpipers, white-rumped sandpipers (*Calidris fuscicollis*), and short-billed dowitchers ($F_{15,933}$ = 6.7, P < 0.001). Differences for antagonistic behaviors were detected among species ($F_{15,932}$ = 2.4, $P \leq 0.002$), but Ryan's-Q test did not detect any pairwise differences. No differences in maintenance or alert behaviors were detected among species ($F_{15,932} \geq 1.5$, $P \geq$ 0.10; Table 7).

Within months, the amount of time differed among activities ($F_{5,672} \geq 70.8$, P < 0.001). During August – November, shorebirds spent significantly more time feeding than all other activities ($F_{5,1086} \geq 101.6$, P < 0.001; Table 8). During December, shorebirds spent significantly more time resting and feeding than other activities ($F_{5,672}$ = 70.8, P < 0.001). The amount of time spent engaged in feeding, antagonistic, locomotion, and resting activities also differed among months ($F_{4,944} \geq 5.4$, P < 0.001). Time spent feeding in August and September was 42 – 84% greater than in October, November, and December ($F_{4,943}$ = 25.7, P < 0.001). Time spent engaged in antagonistic behavior in August was 2.1 – 7.3X greater than in September and October, and antagonistic behavior was not recorded in November and December ($F_{4,943}$ = 7.7, P < 0.001). Time spent in locomotion in December was 44 – 65% greater than in September and August ($F_{4,944}$ = 5.4, P < 0.001). Time spent resting in December also was 37 – 48% greater than in November and October, and time spent resting in November and October was 2 – 2.8X greater than in September and August ($F_{4,943}$ = 28.7, P < 0.001). No differences were detected among months for alert or maintenance behaviors ($F_{4,943}$ = 1.4, $P \geq 0.23$; Table 8).

Waterfowl.—Differences in percent time were detected among activities for each waterfowl species ($F_{5,84} \geq 5.1$, P < 0.001). All waterfowl species (except Canada geese and American black ducks [*Anas rubripes*]) spent significantly more time feeding than all other activities ($F_{5,186} \geq 10.2$, $P < 0.001$; Table 9). Canada geese spent the majority of their time resting and feeding ($F_{5,372} = 16.8$, $P < 0.001$), and American black ducks spent the majority of their time engaged in feeding, locomotion, and resting behaviors ($F_{5,84} = 5.1$, $P < 0.001$). Additionally, differences in percent time spent in feeding, locomotion, and resting behaviors were detected among waterfowl species ($F_{11,761} \geq 3.3$, $P < 0.001$). Blue-winged teal spent 1.7 – 2.4X more time feeding than wood ducks, American black ducks, mallards, and Canada geese ($F_{9,748} = 9.4$, $P < 0.001$). American black ducks spent 4.3X more time engaging in locomotion than blue-winged teal ($F_{11,761} = 3.3$, $P \leq 0.001$). Canada geese spent 2.1 – 7.4X more time resting than all other species except northern pintails (*A. acuta*) and mallards. Canada geese, northern pintails, and mallards spent 5.2 – 7.4X more time resting than blue-winged teal ($F_{11,761} = 6.7$, $P < 0.001$). No other differences were detected among waterfowl species ($F_{11,761} \leq 6.7$, $P \geq 0.87$; Table 9).

Mean percent time differed among activities for each month ($F_{5,600} = 42.0$, $P < 0.001$). During all 5 months, time spent feeding was ≥2.8X greater than any other activity ($F_{5,600} \geq 42.0$, $P < 0.001$; Table 10). Time engaged in resting, locomotion, and maintenance averaged 16%, 14% and 12%, respectively, across all months. Time engaged in alert and antagonistic behaviors averaged 0.6% and 0.1%, respectively. Additionally, percent time engaged in locomotion and maintenance differed among months ($F_{4,775} \geq 3.0$, $P \leq 0.02$). Time spent engaged in locomotion in August, October, November, and December was 2.9 – 4.3X greater than in September ($F_{4,775} = 4.2$, $P = 0.002$). Time spent engaged in maintenance activities in August was 2.4X greater than in December ($F_{4,775} = 3.0$, $P = 0.02$; Table 10).

Other waterbirds.—Percent time differed among activities for all species of waterbirds ($F_{5,66} \geq 3.4$, $P < 0.001$). All species in Laridae, except herring gulls, spent significantly more time resting than any other activity ($F_{5,18} \geq 14.3$, $P < 0.001$; Table 11). Herring gulls spent significantly more time engaged in maintenance than all other activities ($F_{5,78} = 12.5$, $P < 0.001$). Similarly, all species in Ardeidae, except yellow-crowned night-herons, spent significantly more time resting than all other activities ($F_{5,96} \geq 8.8$, $P < 0.001$). Yellow-crowned night-herons spent more time in locomotion and resting than other activities ($F_{5,30} \geq 6.0$, $P < 0.001$). Additionally, differences in time spent engaged in feeding, maintenance, and resting behaviors were detected among species ($F_{12,572} \geq 4.3$, $P < 0.001$). American coots spent ≥3.3X more time feeding than all species in Laridae and most species in Ardeidae ($F_{12,572} = 4.6$, $P < 0.001$). Herring gulls spent ≥4.9X more time engaged in maintenance than all other waterbirds except American white pelicans (*Pelicanus erythrorhynchos*), Bonaparte's gulls (*Larus philadelphia*), ring-billed gulls (*Larus delawarensis*), and American coots ($F_{12,572} = 7.4$, $P < 0.001$). Forster's terns (*Sterna forsteri*) spent ≥2.9X more time resting than herring gulls, American white pelicans, and American coots ($F_{12,572} = 9.5$, $P < 0.001$). Differences in time spent in locomotion were detected among waterbird species by ANOVA ($F_{12,572} = 4.3$, $P < 0.001$), but Ryan's-Q test did not reveal any pairwise differences. No differences in alert and antagonistic behaviors were detected among waterbird species ($F_{12,572} = 0.3$, $P \geq 0.10$; Table 11).

Mean percent time differed among activities for each month ($F_{5,216} \geq 38.4$, $P < 0.001$). Time spent resting was at least 83% greater than all other activities for all 5 months ($F_{5,216} \geq 38.4$, $P < 0.001$; Table 12). During August and September, more time was spent engaged in locomotion than feeding, maintenance, alert, and antagonistic behaviors ($F_{5,300} \geq 50.8$, $P < 0.001$). During October, more time was spent engaged in locomotion than alert and antagonistic behaviors ($F_{5,216} = 38.4$, $P < 0.001$). Percent time also differed among months for locomotion and resting behaviors ($F_{4,230} \geq 4.4$, $P < 0.001$). Percent time engaged in locomotion was greater in August and September than in November and December ($F_{4,230}$ = 4.4, P < 0.001), whereas percent time resting was greater in November and December than in August and September ($F_{4,230}$ = 9.6, P < 0.001; Table 12).

DISCUSSION

Shorebirds

Feeding (46 – 98%) was the most common activity of shorebirds using riverine mudflats in Kentucky Reservoir. These results are similar to those documented on mudflats in other river systems in the eastern United States. Laux (2008) found that feeding (42 – 99.5%) was the predominant activity for 12 of 15 shorebird species on mudflats in the eastern TRV, and Elliot-Smith (2003) reported that shorebirds fed 78% of the time on mudflats in Rend Lake, which is a reservoir associated with the Big Muddy River in southern Illinois, USA. Additionally, feeding was the most common shorebird activity (41 – 80%) during fall migration on mudflats in the Prairie Pothole Region (DeLeon and Smith 1999) and Southern High Plains (Davis and Smith 1998*a*, Kostecke and Smith 2003, Andrei et al. 2007). Shorebirds likely spend the majority of their time foraging during fall migration to replenish depleted energy reserves (Skagen 2006). Davis and Smith (1998*b*) found that shorebirds fed almost exclusively on benthic macroinvertebrates during fall migration. Benthic macroinvertebrates contain considerable metabolizable energy (1.1 – 10.0 kcal/g, Baldassarre and Bolen 2006). In Chapter II, I reported that invertebrate density (847 – 2185 invertebrates m^{-2}) and biomass (1.5 – 3.6 g m^{-2}) in Kentucky Reservoir mudflats were similar to those reported at well-known stopover sites in the Great Plains (i.e., 689 invertebrates m^{-2}, 1.2 g m^{-2} [Southern High Plains, Davis and Smith 1998*b*], 8,888 – 11,182 invertebrates m^{-2}, 1.7 – 6.3 g m^{-2} [Cheyenne Bottoms, Helmers 1991]).

Thus, mudflats in the western TRV likely function as important foraging sites for migratory shorebirds.

Shorebirds also spent considerable time engaged in resting (14%) and locomotion (14%). Laux (2008) reported similar results for resting (17%) and locomotion (13%) in the eastern TRV. Similar rates of resting and locomotion also were reported on mudflats in the Great Plains (2 – 40% [locomotion], 1 - 42% [resting]; Davis and Smith 1998*a*, Deleon and Smith 1999, Andrei et al. 2007). Resting is a critical component of restoration of energy reserves necessary to continue migration (Skagen and Knopf 1993, Andrei 2007), and research has suggested that the inability for shorebirds to spend adequate time resting may contribute to long-term population declines (Pfister et al. 1992). Time spent engaged in locomotion probably was associated with searching for prey items (Beauchamp 2006). Thus, TRV mudflats also are important resting sites for migratory shorebirds.

Time spent engaged in activities differed among shorebird species and were primarily driven by differences in average migration distance. On Kentucky Reservoir mudflats, long-distance migrants spent 22% more time feeding than intermediate-distance migrants, and intermediate-distance migrants spent 73% more time feeding than short-distance migrants. Similar trends were documented on mudflats in the eastern TRV, Illinois, and Great Plains (Davis and Smith 1998*a*, DeLeon and Smith 1999, Elliot-Smith 2003, Andrei et al. 2007, Laux 2008). Several authors have noted there is usually a positive relationship between migration distance and time spent foraging probably due to increased energy demands associated with farther flight (Morrison et al. 1984, Myers et al. 1987, Skagen and Knopf 1993). My results support this hypothesis and emphasize the importance of western TRV mudflats in helping meet energy needs of long-distance migratory shorebirds.

Activity patterns also differed among months. Time spent feeding decreased significantly from August – December, whereas time spent resting increased during the same time period. These results could reflect different energy needs between peak migration and winter. In Chapter II, I documented that most shorebirds migrated through the western TRV during August and September, while most species documented during October – December likely overwintered in Kentucky Reservoir. Species composition and average migration distance also may have impacted these results, because more long-distance migrants were documented in August and September. Laux (2008) also recorded the majority of long-distance migratory shorebirds during August and September in the eastern TRV. Although no studies have directly examined differences in activities through fall migration, research on long-distance migrants indicated a high necessity to acquire energy-rich foods at stopover sites during fall migration (Page and Middleton 1972, Skagen and Knopf 1993). These results emphasize the importance of TRV mudflats being exposed in August and September during peak migration of long-distance migrants (Chapter II). Presumably, shorebird species that overwinter on western TRV mudflats spend more time resting because they tend to be short-distance migrants. These species also may rest more to conserve energy and reduce heat loss (Smith and Prince 1973).

Time spent engaged in antagonistic activities was greater in August than all other months. Aggressive behavior of shorebirds during migration is typically associated with conspecific interactions among foraging individuals and increases with shorebird density (Recher and Recher 1969, Burger et al. 1979). In Chapter II, I documented that shorebird density was greatest during August because mudflat area was much lower during this month than during subsequent months. Davis and Smith (1998*a*) and DeLeon and Smith (1999) also documented an increase in aggressive encounters with shorebird density. Thus, competition for food resources on TRV mudflats likely is greatest during August when mudflat area is low and shorebird abundance is high. These results emphasize the importance of making large mudflats available in August.

Waterfowl

Most waterfowl spent more time feeding (32 – 78%) than any other activity in shallow-water areas associated with western TRV mudflats. Previous studies also have documented feeding as the predominant activity of waterfowl associated with mudflats during migration and winter (Quinlan and Baldassarre 1984, White 1994, Benedict and Hepp 2000, Laux 2008). Acquiring energy- and protein-rich foods is a priority for waterfowl during this portion of their annual cycle due to nutritional demands of migration, thermoregulation, courtship, and feather replacement (Fredrickson and Reid 1988*a*, Reid et al. 1989). In Chapter II, I documented that aquatic invertebrate densities associated with mudflats were comparable with other wetland types; however, seed densities were lower. Although I did not collect waterfowl to analyze diet composition, I hypothesize that waterfowl likely are using western TRV mudflats to acquire aquatic invertebrates instead of seed. No studies have examined diet composition of migrating and wintering waterfowl using interior mudflats; however, several studies have documented large percentages of invertebrates consumed by waterfowl in coastal mudflats (100%) and interior vegetated wetlands (38%) during winter (Euliss and Harris 1987, Gaston 1992). Additionally, aquatic plants (e.g., *Myriophyllum spicatum*) and algae (e.g., *Chara* spp.) may contribute to waterfowl diets on TRV mudflats (Johnson and Montalbano 1989, Benedict and Hepp 2000). Thus, TRV mudflats are important foraging sites for migrating and wintering waterfowl.

Feeding (62%) and locomotion (17%) were observed more often on Kentucky Reservoir mudflats than other wetland types (e.g., moist-soil wetlands; Paulus 1988, Rave and Cordes 1993, White 1994). Additionally, waterfowl in Kentucky Reservoir were observed resting (10%) less often than in managed wetlands (Tamisier 1976, Paulus 1988). These differences may have been related to differences in food densities and size of food items. In Chapter II, I reported that seed densities in Kentucky Reservoir mudflats were 13 – 20X lower than in moist-soil wetlands in the Mississippi Alluvial Valley (Kross et al. 2008), which may result in a need to forage more often. Also, although aquatic invertebrate biomass estimates were similar to other wetlands used by waterbirds (Gray et al. 1999*c*, Manley et al. 2004, Andrei et al. 2008), the most common invertebrate in Kentucky Reservoir mudflats was Chironomidae larvae (Chapter II), which are much smaller (<0.9 mg) than invertebrates commonly found in managed moist-soil wetlands (e.g., Gastropoda and Decapoda, [>2.0 mg]; Gray et al. 1999*c*, Anderson et al. 2000). Thus, available food resources in Kentucky Reservoir mudflats may have required more foraging and searching time by waterfowl in order to meet nutritional demands. Additionally, the higher percentage of time engaged in feeding and locomotion may be at least partially related to differences in diurnal sampling periods. My surveys were conducted within 5 hours after sunrise, whereas surveys in several other studies (Tamisier 1976, Paulus 1982, Rave and Cordes 1993) were conducted throughout the day. Feeding and locomotion are more common during crepuscular periods, and resting is more common mid-day (Quinlan and Baldassarre 1984, Rave and Baldassarre 1989, LeSchack 1993, Rave and Cordes 1993).

Courtship activities were not recorded on Kentucky Reservoir mudflats. Although it is likely that subtle displays may have been overlooked, previous research has documented greater courtship behavior in vegetated habitats that provide more isolation than open habitats such as reservoirs (Turnbull 1995). Laux (2008) also documented low occurrence (<2%) of courtship activities on mudflats in the eastern TRV. Quinlan and Baldassarre (1984) reported that courtship of green-winged teal was significantly greater during February and March than during September – January in the Southern High Plains. Thus, the period of time that I sampled may have preceded peak courtship activities.

Intensively managed moist-soil wetlands and agriculture within Tennessee National Wildlife Refuge were in close proximity (<1 km – 8.75 km) to my survey sites. It has been suggested that if high quality foraging habitats are available near open water habitats, such as riverine mudflats in Kentucky Reservoir, the open water sites would primarily function as a loafing or resting area (Tamisier 1976, Rave and Cordes 1993, White 1994, Laux 2008). In general, my results suggest otherwise, and indicate that mudflats can be important foraging sites for waterfowl. White (1994) performed a study comparing habitat use of American black ducks in managed moist-soil wetlands on Tennessee National Wildlife Refuge and mudflats in Kentucky Reservoir and found that feeding was more common in moist-soil wetlands (i.e., 53% versus 37% for mudflats). I also found that American black ducks foraged less on Kentucky Reservoir mudflats (44%) compared to most other waterfowl species. Thus, black ducks may acquire food resources from other wetland types or agricultural areas more than other waterfowl species in the western TRV.

Blue-winged teal (78%), green-winged teal (67%) and gadwalls (64%) spent more time feeding and less time resting (5%, 8%, and 11%, respectively) than several other species. In contrast, Canada geese spent most of their time resting (35%) on mudflats. Differences in foraging time are likely due to differences in food habits, metabolic rates, and migration patterns (Kaminski and Prince 1981, Quinlan and Baldassarre 1984, Miller 1984, Fredrickson and

Heitmeyer 1988). Teal are considered foraging specialist that consume smaller food items than most other waterfowl species and have a high proportion of aquatic invertebrates in their diets (Euliss and Harris 1987, Anderson et al. 2000, Johnson and Rohwer 2000). Smaller food items contain less energy per gram, which necessitates greater foraging time (Baldassarre and Bolen 2006). Thus, the combination of high chironomid larval densities and the preference of teal for aquatic invertebrates (Anderson et al. 2000) may have contributed to high foraging rates of teal on TRV mudflats. Additionally, teal migrate longer distances and have higher metabolic rates than other species, hence require more time foraging to meet energetic requirements (Bellrose 1976). Similarly, gadwalls consume large proportions of aquatic plants and invertebrates relatively low in nutritional value, thus require increased foraging time (Benedict and Hepp 2000, Baldassarre and Bolen 2006). In contrast, Canada geese primarily consume agricultural seeds (Gates et al. 2001), which contain high energy and were abundant in harvested and unharvested fields on the Tennessee National Wildlife Refuge (Baldassarre and Bolen 2006; M. Foster, University of Tennessee, unpublished data). I often observed Canada geese roosting on mudflats and making flights to agriculture fields to feed. Occurrence of feeding by Canada geese on mudflats was primarily restricted to browsing vegetation. These results collectively illustrate differences in the functional importance of Kentucky Reservoir mudflats to different waterfowl species.

The amount of time spent engaged in activities on mudflats differed among months, with a general trend that waterfowl spent more time feeding during September – December than in August. In Chapter II, I discussed that waterfowl use of Kentucky Reservoir mudflats in August was dominated by resident species. Energy needs of resident waterfowl species is typically less than migratory species, because the former has not experienced long-distance flight (Williams et al. 1999). Time spent engaged in locomotion was lowest during September but this was driven by the high numbers of blue-winged teal, which spent little time engaged in locomotion (6%) and most of their time feeding (Chapter II). Waterfowl spent the least amount of time engaged in maintenance activities during December. Occurrence of body maintenance activities may be related to molting events (Tamisier 1976). Quinlan and Baldassarre (1984) reported most body maintenance activities occurred during September – October, which probably was associated with the pre-alternate molt. These results further emphasize that waterfowl use mudflats in the western TRV for a variety of reasons, with the prevalence of activities changing among months and associated with various life-cycle activities or possibly changes in ambient temperature.

Other Waterbirds

Although few significant differences among species were detected, several trends in activity patterns were apparent for all other waterbirds observed using Kentucky Reservoir mudflats. All species of Ardeidae (herons and egrets) spent the majority of their time resting (46 – 82%). However, it is important to note that only the time spent probing or capturing prey was recorded as feeding, and all periods of inactivity were recorded as resting. Thus, it is likely that during periods of inactivity or locomotion, many of these birds were searching for prey. Among Ardeidae species, little blue herons (*Egretta caerulea*) and yellow-crowned night-herons generally spent more time feeding (14 – 16%) and less time resting (50 – 55%) than other species. Other studies have documented that smaller herons and egrets generally are more active foragers than larger birds (DuBowy 1996), but this is dependent on a variety of factors including prey size, foraging tactics, and habitat (Kushlan 1976, Willard 1977, Ramo and Busto 1993). For example, I found that great egrets spent the most time engaged in locomotion (33%) and the least resting (46%). Great egrets were the second largest Ardeidae species recorded, but they feed on smaller prey items than most other species and more commonly forage in open water, which requires more active foraging (Kushlan 1976).

Most species of Laridae (gulls and terns) spent the majority of their time resting (33 – 95%) or engaged in maintenance activities (5 – 56%). Previous studies reported that gulls commonly use mudflats for resting, loafing, and body maintenance during migration (Welham 1987, Burger 1988, Laux 2008). Welham (1987) and Burger (1988) also noted that mudflats were important foraging areas for gulls. Bonaparte's gulls, herring gulls and ring-billed gulls spent 9 – 13% of their time feeding, suggesting Kentucky Reservoir mudflats provided foraging opportunities for these birds. Tern species (i.e., Forster's and Caspian) were not recorded engaged in feeding or locomotion because these species feed exclusively while flying or diving into the water, and I did not monitor flying birds during activity budgets. Thus, Kentucky Reservoir mudflats were important sites for resting and body maintenance for most species of Laridae but also provided foraging opportunities for some species.

I also documented use of Kentucky Reservoir mudflats by American white pelicans and American coots. Large numbers of American white pelicans have been recorded using wetlands in western Tennessee in the last decade (Tennessee Important Bird Areas Program 2009; R. Wheat, USFWS, unpublished data). In Kentucky Reservoir, pelicans spent the majority of their time engaged in maintenance (42%) and resting (36%), but also spent considerable time feeding (20%). King and Werner (2001) reported American white pelicans spent 28% of their time foraging and 72% loafing in wetlands in Mississippi. American coot use of TRV reservoirs has been documented previously (McKnight and Hepp 1998, Benedict and Hepp 2000, Laux 2008). Coots spent significantly more time feeding (42%) than most other waterbird species. Aquatic vegetation and algae (e.g., *Chara*, *Najas*, *Myriophyllum*) have been reported as primary food resources consumed by coots in the TRV (McKnight and Hepp 1998, Benedict and Hepp 2000), and these plants were abundant in shallow water areas associated with Kentucky Reservoir mudflats (D. Wirwa, personal observation).

Differences in activity patterns also differed among months across waterbird species. Time spent engaged in locomotion decreased and time spent resting increased from August – December, which probably reflected a change in the species composition of the waterbird community. Most species of Ardeidae migrated south of Kentucky Reservoir by late October, whereas many Laridae species did not arrive until October and were recorded through December (Chapter II). As discussed, Ardeidae species generally spent more time feeding than Laridae species. Additionally, lower ambient temperature results in increased heat loss in waterbirds (Smith and Prince 1973). Thus, increased resting activity may be associated with attempts to conserve energy during colder months. Presumably, birds that are resting lose less heat convectively than those that are actively moving (Smith and Prince 1973).

MANAGEMENT IMPLICATIONS

Foraging was the most common activity of waterbirds using Kentucky Reservoir mudflats, providing evidence that TRV mudflats are important stopover and refueling sites for migratory waterbirds. Aggressive interactions among shorebirds were greatest during August when mudflat acreage was lowest. Thus, I recommend that Kentucky Reservoir drawdowns be planned to expose mudflats (New Johnsonville gage height <108.81 m [357 ft] MSL, Figure 8) by early August to reduce competitive interactions and increase per-capita food resources among individual shorebirds. Use of mudflats by long-distance migratory shorebirds also was greatest during August, several which are species of conservation concern, and further emphasizing the importance of mudflat exposure during late summer. Resting was the second most common activity on mudflats, with some groups of birds (e.g., wading birds and Canada geese) devoting considerable time. Prevalence of resting increased from August – December, and was related with changes in species composition and decreases in ambient temperature. These results collectivity demonstrate the multiple functions of Kentucky Reservoir mudflats, and the importance of exposed mudflats in August for waterbirds.

Kentucky Reservoir mudflats also provide an additional natural habitat component to Tennessee National Wildlife Refuge, thus help contribute to regional biodiversity. My results also highlight the importance of mudflats associated with rivers and reservoirs. Given the low landscape coverage of riverine mudflats in the United States, conserving these habitats and planning the timing of drawdowns in riverine reservoirs so they coincide with migration will help conserve continental populations of waterbirds.

Future research should investigate food habits of waterbirds using Kentucky Reservoir mudflats to determine food item preference and temporal changes in food habits. Research also should quantify daily flight patterns between Tennessee NWR impoundments and reservoir mudflats. These studies are necessary to formulate additional inferences on the functional role of Kentucky Reservoir mudflats and the interrelationship with Tennessee NWR in meeting life-cycle requirements of migratory waterbirds.

CHAPTER IV

EXECUTIVE SUMMARY

The Tennessee River Valley (TRV) is the fifth largest watershed in the nation, encompassing 106,190 km^2 in 7 southeastern states (Figure 1, Tennessee Valley Authority 2004), and an important annual migratory stopover and wintering location for thousands of North American shorebirds and waterfowl (Brown et al. 2001, USFWS 2005, Laux 2008). Prior to 1933, the Tennessee River fluctuated naturally according to basin physiography and seasonal precipitation (Tennessee Valley Authority 2004). There are now 9 main-stem reservoirs and 40 tributary reservoirs in the TRV that are owned and operated by Tennessee Valley Authority (TVA). Tennessee Valley Authority manages water levels in each reservoir, with the primary goals of facilitating navigation, producing hydroelectric power, cooling nuclear reactors, and preventing floods (TVA 2004). During fall drawdown of TRV reservoirs, extensive acreage of mudflats is exposed that provides habitat for migrating waterbirds (TVA 2004, Smith 2006, Laux 2008).

Kentucky Reservoir is the lowermost and largest among the TRV reservoirs. Due to its size and close proximity to the Mississippi Alluvial Valley, this reservoir provides habitat for the greatest abundance and diversity of migratory waterbirds among TRV reservoirs. Prior to 1980, TVA initiated drawdown of these reservoirs on 15 June, resulting in exposed mudflats from mid-July – September (TVA 2004). However, in 1980, TVA changed the reservoir operation schedule to initiate drawdown on 1 July, which delayed mudflat exposure. Currently, Kentucky Reservoir elevation is maintained at 109.4 m (359 ft) MSL from April through 5 July and gradually lowered to 107.9 m (354 ft) MSL by December, where it remains at winter pool through March.

On 19 May 2004, the TVA Board of Directors implemented a new operations policy for the drawdown of TRV reservoirs, called the Reservoir Operation Study (ROS), which took effect on 1 June 2004 (TVA 2004). The new policy resulted in delay of the historic drawdown schedule for 35 of the 49 reservoirs, with a primary goal of increasing late-summer recreational opportunities. The drawdown schedule for Kentucky Reservoir was not changed because of concerns raised about the potential increase in flood risk and possible degradation of natural resources (TVA 2004). In particular, shorebirds could be negatively influenced by a delayed drawdown, because mudflat stopover sites would be inundated during peak migration. In addition, waterfowl use of mudflats may decline if later drawdown results in reduced growing season and insufficient temperature for seed germination and moist-soil plant production (TVA 2004). Thus, the **goal of my research** was to determine the influences of the existing drawdown in Kentucky Reservoir on: (1) mudflat availability, (2) waterbird use of mudflats, 3) food resource densities, and 4) other habitat factors that potentially could influence waterbird use.

I quantified waterbird use on 9 mudflats located in Kentucky Reservoir that were deemed by TVA as suitable migratory stopover sites based on previous surveys (T. H. Henry, TVA, unpublished data). Relative abundance, density and activities of shorebirds, waterfowl, and other waterbirds (e.g., herons, gulls, terns) were recorded from August – December 2006 and 2007. I also quantified temporal availability of mudflats and developed a model to predict relative mudflat acreage using reservoir elevation at the New Johnsonville gage (Figure 8). I measured a variety of characteristics of mudflats including soil moisture, temperature and compaction, vegetation growth, aboveground seed production, biomass of seed and aquatic invertebrates in core samples, and water depth near the waterline. These characteristics were related to waterbird use and compared among 0.305-m (1-ft) contours as Kentucky Reservoir was drawn down.

Collectively, my results confirm conclusions made by Laux (2008) that TRV mudflats are important habitats for resident and migratory waterbirds. In particular, mudflat exposure during August was critical for use by several long-distance migratory shorebirds that are currently in decline. Use of mudflats from October – December was dominated by short-distance migratory shorebirds and waterfowl. Below I discuss my overall findings in Chapters II and III, and provide some recommendations on managing water levels in Kentucky Reservoir for migratory waterbirds.

I recorded 26 species of shorebirds using Kentucky Reservoir mudflats, which is 50% of the species that breed in North America (Chapter II). Shorebird richness in Kentucky Reservoir exceeded that of several other regional interior stopover sites: northwestern Arkansas (S = 23), Mississippi Alluvial Valley (S = 22), and upper Mississippi Valley (S = 21), and was comparable to some internationally recognized stopover sites: Quivira National Wildlife Refuge in central Kansas (S = 29), and playa (S = 20 – 22) and saline (S = 28) lakes in Texas (Reid et al. 1983, Smith et al. 1991, Skagen and Knopf 1994*a*, Davis and Smith 1998*b*, Twedt et al. 1998, Andrei et al. 2006). Kentucky Reservoir mudflats also supported high shorebird abundance, with several daily surveys on the 9 mudflats that I studied exceeding 700 shorebirds (Chapter II). Using a 10-day turnover rate estimated by Lehnen and Krementz (2005), I estimated that approximately 3,390 – 4,786 shorebirds used the 9 mudflats from August – December. Assuming these mudflats are representative of other Kentucky Reservoir mudflats, I estimated approximately 20,000 – 28,000 shorebirds use Kentucky Reservoir annually during fall migration (Chapter II). This level of use qualifies Kentucky Reservoir mudflats as a “Site of Regional Importance” in the Western Hemisphere Shorebird Reserve Network (WHSRN 2009). Thus, in support of Laux (2008), I recommend that TRV mudflats be designated as a “WHSRN

Site of Regional Importance." These results collectively illustrate the biological value of Kentucky Reservoir mudflats for migrating shorebirds.

Of the shorebird species I documented, 88% have shown evidence of population decline in North America, and 35% are listed as species of high conservation concern or highly imperiled due to significant population declines (Howe et al. 1989, Morrison et al. 1994, Brown et al 2001). Most notably, I recorded the following species of high conservation concern using mudflats in Kentucky Reservoir: American golden plover (*Pluvialis dominica*), buff-breasted sandpiper (*Tryngites subruficollis*), sanderling (*Calidris alba*), short-billed dowitcher (*Limnodromus griseus*), solitary sandpiper (*Tringa solitaria*), western sandpiper (*Calidris mauri*), Wilson's phalarope (*Phalaropus tricolor*), and ruddy turnstone (*Arenaria interpres*, Chapter II). Additionally, I recorded the federally listed piping plover (*Charadrius melodus*, Chapter II), which is considered highly imperiled (Brown et al. 2001). Thus, mudflats in Kentucky Reservoir provided habitat for several species of concern for which habitat protection is a conservation priority (Brown et al. 2001, Potter et al. 2007).

Results that I presented in Chapter III revealed that feeding was the most common activity (46 – 98%) of shorebirds using mudflats in Kentucky Reservoir. The ability of shorebirds to meet energy requirements during migration is critical to their survival (Morrison 1984, Myers et al. 1987, Skagen and Knopf 1993), and these results illustrate the importance of Kentucky Reservoir mudflats in providing necessary food resources. My results also indicated that foraging time varied among species, with long-distance migrants spending 22 – 73% more time feeding than short-distance migrants (Chapter III). Thus, energy demands of long-distance migrants are likely greater than short-distance migrants.

I documented a total of 107,851 waterfowl of 20 species using Kentucky Reservoir mudflats (Chapter II). Peak waterfowl abundance in Kentucky Reservoir occurred in November, with several daily surveys exceeding 5,000 birds using the 9 study mudflats. Further, I recorded 10 species of waterfowl using Kentucky Reservoir during August and September, with use dominated (53 – 73%) by blue-winged teal (Chapter II). Thus, Kentucky Reservoir mudflats served as important habitats for early and late migrating waterfowl species.

Most waterfowl spent more time feeding (32 – 78%) than any other activity in Kentucky Reservoir (Chapter III). Waterfowl species that spent considerable time feeding on mudflats included American wigeon (*Anas Americana*, 57%), blue-winged teal (*Anas discors*, 78%), gadwall (*Anas strepera*, 64%), green-winged teal (*Anas crecca*, 68%), and northern pintail (*Anas acuta*, 57%). In contrast, Canada geese (*Branta canadensis*) spent 2.1 – 7.4X more time resting than most other species. Mallards (*Anas platyrhynchos*), American black ducks (*Anas rubripes*), and northern pintails also spent considerable time engaged in resting (7 – 25%) and maintenance behaviors (9 – 23%, Chapter III). Thus, Kentucky Reservoir mudflats and associated shallow waters provided foraging and resting habitat for waterfowl.

I also recorded 25 species of other waterbirds using Kentucky Reservoir mudflats, including 10 species of gulls and terns (Laridae), and 9 species of wading birds (Ardeidae, Threskiornithidae, and Gruidae; Chapter II). Results from Chapter III indicated that these waterbirds spent the majority of their time resting (15 – 95%). Thus, Kentucky Reservoir mudflats provided habitat for a diversity of waterbird species that utilized these habitats to meet various life-cycle needs.

Food resources available to shorebirds and waterfowl in Kentucky Reservoir mudflats included aquatic invertebrates and moist-soil seeds in the substrate. In Chapter II, I estimated 1.5

– 3.6 g m^{-2} of invertebrates and 2.5 – 3.8 g m^{-2} of belowground moist-soil seeds. Additionally, seed-producing vegetation at higher elevations was available to waterfowl during re-flooding caused by rain events. Mean seed yield in the highest 0.305-m contour was 15.3 – 64.6 kg ha^{-1} but was minimal at lower contours. Using the equation provided by Loesch et al. (2000) for calculation of shorebird energy-days (SEDs) and my estimates of invertebrate mass, I estimated that Kentucky Reservoir mudflats provide 5,480 SEDs ha^{-1}. Similarly, using the equation provided by Reinecke et al. (1989) for calculation of duck energy-days (DEDs), I estimated that 553 DEDs ha^{-1} are available on Kentucky Reservoir mudflats (Chapter II). These values can be multiplied by exposed mudflat acreage and divided by the anticipated duration of use to estimate the number of shorebirds or waterfowl that could be energetically sustained. These results provide evidence that substantial food resources are available for waterbirds on Kentucky Reservoir mudflats.

In Chapter II, I demonstrated that initial exposure of the 9 mudflats that I studied occurred when the reservoir elevation was 108.82 m (357 ft) MSL at the New Johnsonville gage (Figure 8). Therefore, according to the current drawdown schedule (Figure 3), most mudflats in Kentucky Reservoir are inundated until mid-August, thus are unavailable to migratory waterbirds. During my study, the actual drawdown varied between years due to the drought in Tennessee in 2007. In 2006, initial mudflat exposure occurred in mid-August in accordance with the drawdown schedule. In 2007, initial mudflat exposure of several mudflats occurred prior to my first sampling date of 30 July. Subsequent to initial mudflat exposure, reservoir elevation generally followed the guide curve (Figure 3), and mudflat area increased through November (Figures 6 and 7). The model that I present in Figure 8 can be used to predict mudflat acreage on the 9 mudflats that I studied (Chapter II). Given that the topographic gradient of Kentucky

Reservoir is relatively low, exposure of these mudflats should be similar to other mudflats in Kentucky Reservoir.

Results in Chapter II indicated that shorebird use of Kentucky Reservoir was influenced by mudflat availability and migration chronology. Shorebird use peaked during September – mean abundance, richness, and diversity during September were greater (≥58%) than all other months. However, mean density was greatest during August when mudflat acreage was minimal (Figures 6 and 7). Given that peak shorebird migration through the mid-continental United States occurs July – mid-September (Smith et al. 1991, Twedt et al. 1998, Skagen et al. 1999, Andrei et al. 2006), mudflat availability for shorebirds in Kentucky Reservoir is limiting during July and August in a typical drawdown year. Using my estimates of shorebird use in 2007 when mudflats were exposed 1 – 15 August, over 1,000 shorebirds of 11 species would not have used the 9 study mudflats if they were flooded during this time. Moreover, if the drawdown schedule was delayed such that initial mudflat exposure occurred on 1 September, I estimated that 2,580 shorebirds of 22 species would have been forced to overfly these mudflats. Further, of the 9 species of high conservation concern that I documented, 7 were recorded during August. Collectively, these results demonstrate the importance of mudflat exposure during late summer in Kentucky Reservoir for migrating shorebirds. Thus, any delay in mudflat exposure will negatively impact shorebirds populations migrating through the TRV. In addition, planned initial exposure of mudflats on 1 August should be considered if shorebird conservation is an objective of Kentucky Reservoir operation. Additional justification for a 1 August exposure of mudflats is provided on pages 29 – 31 and 42 – 43 in Chapter II, and in the second to last paragraph of this chapter.

Mudflat vegetation in Kentucky Reservoir has been described as pioneer plant species that are capable of completing their life cycle in the shortened growing season between the drawdown and frost (Webb et al. 1988). In support, my results from Chapter II indicated that timing and duration of mudflat exposure govern the extent of vegetation establishment, structure, and seed production. Average exposure duration for the 2 highest 0.305-m mudflat contours was 62 and 33 days prior to the end of the growing season. Exposure duration affected vegetation establishment. Vegetation height, species richness, percent horizontal cover, plant biomass, and seed yield decreased (≥2X) from the highest to the lowest 0.305-m (1-ft) contour. My results also indicated that the timing of exposure influenced vegetation establishment. For example, vegetation germinated on mudflats within 1 week post-exposure in August, and mean horizontal coverage was >30% within 2 weeks. In contrast, vegetation took over 2 weeks to germinate or never germinated when mudflats were exposed in late September or October, and horizontal coverage did not exceed 5%. Notably, over 99% of mudflat seed yield was produced in the highest 0.305-m contour, further illustrating the impacts of duration and timing of exposure (Chapter II). Thus, delay in the drawdown schedule of Kentucky Reservoir would substantially reduce vegetation establishment and seed production.

Based on my results, vegetation establishment did not limit shorebird use, primarily because newly exposed mudflats became available throughout the drawdown period, excluding when water levels rose during rain events. Conceivably, vegetation could occlude shorebird use if mudflats became exposed in August and reservoir levels remained stagnant. Shorebirds prefer mudflats with <25% vegetative cover (Helmers 1992). This emphasizes the importance of a gradual drawdown through fall, which is consistent with the existing schedule (Figure 8). Establishment of moist-soil vegetation on upper contours of mudflats is valuable, because these plants produce seed for waterfowl (Fredrickson and Taylor 1982). Seed production in upper contours is unavailable to waterfowl unless these elevations become re-flooded during rain events. Mudflats in Kentucky Reservoir re-flooded approximately 2X each year. During these events, waterfowl responded immediately to the newly flooded vegetation and were observed foraging (Chapter II).

In Chapter II, I documented that as the water receded, mudflats dried, became more compact, and invertebrate densities decreased. Invertebrate density and soil moisture increased and soil compaction decreased by 5 – 190% within 10 m of the waterline. Mean water depth at 2 and 10 m below the waterline was 2.29 and 6.61 cm, respectively. Given that shorebirds use water depths <10 cm and most dabbling ducks can forage efficiently in water up to 30 cm (Fredrickson and Reid 1988*a*, Helmers 1992), suitable foraging habitat for shorebirds in Kentucky Reservoir most likely occurs within 10 m of the waterline yet likely extends farther downslope for waterfowl. These results underscore the importance of a slow and continuous drawdown to optimize the availability of suitable foraging habitat for shorebirds and other waterbirds.

Although I did not measure effects of drawdown rate, this was likely an additional important factor that influenced invertebrate availability and vegetation establishment (Rundle and Fredrickson 1981, Hands et al. 1991, Eldridge 1992). The drawdown schedule for Kentucky Reservoir calls for a 1.5-m (5-ft) decrease in elevation from 5 July through November, which is equivalent to a drawdown rate of approximately 1 cm day^{-1}. This drawdown rate is similar to recommended rates for managed impoundments for migratory waterbirds (2 – 4 cm day^{-1}; Rundle and Fredrickson 1981, Hands et al. 1991). Laux (2008) speculated that rapid drawdown of Douglas Reservoir in the eastern TRV (6.5 – 7.2 cm day^{-1}) resulted in rapid drying and decreased suitability of mudflats for waterbirds. In Kentucky Reservoir, the drawdown rate appeared to provide quality foraging habitat for waterbirds because it was slow enough to create ideal soil conditions for foraging and maximize invertebrate availability, yet fast enough to continuously expose new mudflats and avoid extensive vegetation establishment that would limit shorebird use. Therefore, I recommend maintaining the current drawdown rate.

Shorebird conservation has become an increasing concern for the U.S. Fish and Wildlife Service as well as many state agencies and conservation organizations (Brown et al. 2001). Consequently, cooperative goals and objectives established in the U.S. Shorebird Conservation Plan outline the need to identify and enhance existing shorebird stopover sites to increase and sustain current continental populations. Results from this study indicate that if shorebird conservation is an objective of the TVA Kentucky Reservoir operations, mudflats should be exposed by 1 August to provide habitat for long-distance migratory shorebirds of high conservation concern. This will occur when water level at the New Johnsonville gage is <108.81 m (357 ft) MSL (Figure 8). In Chapter II (pages 44 – 47), I also provided justification for why earlier exposure of mudflats is necessary based on mudflat acreage, food resource density, and shorebird use. Under the current drawdown schedule, I estimated approximately 2,593 – 2,658 SEDs are available to shorebirds on the 9 study mudflats during September, which is sufficient to energetically support migrating shorebirds. However, mudflat acreage is 8X lower in August and no mudflats will be exposed prior to 15 August under the current operations guide (Figures 3, 8), resulting in a deficit in available SEDs in August. I estimated that a total of 87 ha of mudflats should be exposed on the 9 mudflats that I studied and 488 ha exposed throughout Kentucky Reservoir by 15 August to energetically support migrating shorebirds (Chapter II). This acreage goal can be accomplished by lowering water levels to 108.43 m (355.74 ft) MSL at the New Johnsonville gage (Figure 8). Mudflat exposure during early August also would result in over 70 days of exposure for vegetation establishment and seed production at the highest mudflat contour, which will benefit waterfowl and other waterbirds.

This study and Laux (2008) demonstrated the biological value of TRV mudflats as stopover sites for late-summer and fall migrating waterbirds. Although the majority of TRV mudflats were anthropogenically created during reservoir construction, these habitats now function as critical stopover and wintering sites for thousands of North American waterbirds. The availability of these habitats via planned reservoir drawdowns is vital considering that over 50% of the wetlands in the conterminous United States have been destroyed and many waterbird populations are experiencing precipitous declines. Results compiled over 4 years of data collection during this study and Laux (2008) provide justification that waterbird use of TRV mudflats should be considered in the management of TVA reservoirs.

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APPENDICES

APPENDIX I

TABLES AND FIGURES

Table 1. Mean vegetation height (cm), species richness, and percent horizontal cover within 0.305-m mudflat contours in Kentucky Reservoir from August – November 2006 and 2007, Tennessee River Valley.

		Contour 1[a]		Contour 2[b]		Contour 3	
Variable[c]	Year	$\bar{x}$ [d]	SE	$\bar{x}$	SE	$\bar{x}$	SE
HT	2006	3.16 A	0.53	1.37 B	0.37	0 B	0
	2007	6.67 A	1.30	1.46 A	0.44	FL	FL
HC	2006	44.73 A	8.34	5.77 B	2.00	0 B	0
	2007	64.68 A	6.77	12.39 B	6.27	FL	FL
RICH	2006	3.14 A	0.47	1.19 B	0.26	0 C	0
	2007	3.61 A	0.50	2.14 A	0.55	FL	FL

[a]Contour 1 = 108.56 m (356.17 ft) MSL, contour 2 = 108.36 m (355.5 ft) MSL, and contour 3 = 108.07 m (354.55 ft) MSL.

[b]FL = Vegetation plots were flooded during sampling.

[c]HT = height, HC = percent horizontal cover, and RICH = species richness.

[d]Means within rows followed by unlike letters are different ($P \leq 0.05$).

Table 2. Mean belowground biomass (g) of 4 seed types in core samples (608.21-cm^3) taken within 0.305-m mudflat contours in Kentucky Reservoir during 2006 and 2007, Tennessee River Valley.

		Contour 1[a]		Contour 2		Contour 3	
Seed	Year	$\bar{x}$ [b]	SE	$\bar{x}$	SE	$\bar{x}$	SE
Moist-Soil	2006	0.029 A	0.005	0.024 A	0.003	0.023 A	0.004
Tree		0.040 A	0.035	0.015 A	0.006	0.033 A	0.013
Tubers		0.006 A	0.006	<0.001 A	<0.001	<0.001 A	<0.001
Cocklebur		0 A	0	0.001 A	<0.001	0.002 A	0.002
Moist-Soil	2007	0.015 A	0.004	0.015 A	0.002	0.011 A	0.002
Tree		0.003 A	0.002	0.005 A	0.001	0.014 B	0.007
Tubers		0.013 A	0.013	0.002 A	0.001	0.002 A	0.001
Cocklebur		0 A	0	0 A	0	<0.001 B	<0.001

[a]Contour 1 = 108.56 m (356.17 ft) MSL, contour 2 = 108.36 m (355.5 ft) MSL, and contour 3 = 108.07 m (354.55 ft) MSL.

[b]Means within rows followed by unlike letters are different ($P \leq 0.05$).

Table 3. Final models with variables that explained significant variation in habitat use by waterbirds in Kentucky Reservoir, from August – December 2006 and 2007, Tennessee River Valley.

			Estimates					
Waterbirds	Model[a]	Variable	Un-standardized	Standardized	*t*-value	*P*-value	Partial R^2	VIF[b]
Shorebird	Area	Intercept	1.06	0	7.08	<0.001	NA	0
		acreage	0.01	0.20	2.93	0.004	0.04	1.00
	Substrate	Intercept	1.82	0	11.36	<0.001	NA	0
		comp	-0.01	-0.20	-2.37	0.019	0.04	1.00
	Vegetation	Intercept	4.33	0	4.34	<0.001	NA	0.00
		period	-0.47	-0.30	-2.53	0.014	0.09	1.00
Waterfowl	Area	Intercept	-441.12	0	-3.30	0.001	NA	0.00
		acreage	0.16	0.32	3.57	0.001	0.02	1.81
		gage	7.70	0.37	3.27	0.001	0.05	2.92
		period	2.38	0.43	4.60	<0.001	0.09	1.99
	Substrate	Intercept	-9.81	2.53	-3.88	<0.001	NA	0
		depth	0.91	0.21	4.35	<0.001	0.14	1.09
		period	2.10	0.35	5.98	<0.001	0.11	1.09
	Vegetation	Intercept	-5.43	0	-1.95	0.056	NA	0
		height	0.43	0.34	2.84	0.006	0.07	1.05
		period	1.32	0.33	2.76	0.008	0.10	1.05

[a]Acreage = ha of exposed mudflat, comp = soil compaction (lbs in^{-2}), period = 2-week intervals numbered 1 – 11 from August – December, gage = reservoir gage height, depth = water depth (cm), and height = vegetation height (cm).

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

Table 4. Final models with variables that explained significant variation in invertebrate abundance in mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

Model[a]	Estimates		*t*-value	*P*-value	Partial R^2	VIF[b]
	Un-standardized	Standardized				
Intercept	-12.97	5.86	-2.21	0.027	NA	0
Contour	4.66	0.65	7.17	<0.001	0.08	1.1
Moisture	0.14	0.06	2.16	0.031	0.01	1.1

[a]Contour = mudflat contours numbered 1 – 3 where 1 = highest and 3 = lowest 0.305-m contour; moisture = percent soil moisture measured using an Aquaterr® TEMP-300 digital soil moisture and temperature meter.

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

Table 5. Classification of observed shorebirds based on average migration distance (Skagen and Knopf 1993) using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

Species	Migration Distance	Average Distance (km)
American avocet	Short	2,100
piping plover		3,000
killdeer		3,400
willet		3,600
Wilson's snipe		3,900
spotted sandpiper	Intermediate	6,300
dunlin		6,300
short-billed dowitcher		6,400
greater yellowlegs		6,700
long-billed dowitcher		8,900
black-bellied plover		8,900
least sandpiper		9,100
semipalmated plover		9,400
semipalmated sandpiper		9,500
western sandpiper		9,500
lesser yellowlegs		9,700
solitary sandpiper		9,800
Wilson's phalarope		10,100
ruddy turnstone		11,000
sanderling		11,400
American golden-plover	Long	14,800
stilt sandpiper		15,000
pectoral sandpiper		16,500
Baird's sandpiper		16,700
buff-breasted sandpiper		16,800
white-rumped sandpiper		17,200

[a]Short = <3,900 km, Intermediate = 6,300 – 12,400 km, Long = >14,800 km.

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

Table 6. Diurnal activity budgets of long-, intermediate-, and short-distance migrant shorebirds observed using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

	Migration Distance[a]					
	Long (n = 129)		Intermediate (n = 432)		Short (n = 393)	
Behavior	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE
Alert	0.33 Ad	0.19	0.44 Ad	1.69	1.34 Ae	0.43
Antagonistic	0.09 Ad	0.04	0.11 Ad	0.02	0.01 Be	0.01
Feeding	76.56 Aa	2.73	62.94 Ba	1.69	36.28 Cb	1.61
Locomotion	10.73 Bb	1.40	17.73 Ab	1.14	15.34 Ac	0.90
Maintenance	7.64 Abc	1.99	8.81 Ac	1.13	6.79 Ad	1.09
Resting	4.43 Cdc	1.02	10.2 Bc	1.00	40.29 Aa	1.59

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

[b]Means represent percentage of time expended during 1-minute focal surveys.

[c]Means within rows followed by unlike upper-case letters and means within columns followed by unlike lower-case letters are different by analysis-of-variance and Ryan's-Q multiple comparison test ($P \leq 0.05$).

Table 7. Diurnal activity budgets of shorebird species observed using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

		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
BBPL	8	0 Ca	0.0	0.3 Ca	0.3	27.8 Bd	4.4	28.8 Bab	5.6	0 Cb	0.0	43.3 Aa	5.5
DUNL	47	0.1 Da	0.1	0 Da	0.0	59.8 Aabcd	5.2	19.3 BCabcd	3.9	6.2 CDb	2.5	13.9 Bb	3.9
GRYE	35	1.3 Ca	1.3	0.1 Ca	0.1	45.7 Acd	4.8	31.8 Ba	4.0	8.4 Cb	4.1	12.5 Cb	3.3
KILL	291	1.4 Ea	0.6	0 Ea	0.0	27.0 Bd	1.3	18.9 Cabcd	1.1	6.5 Db	1.3	46.3 Aa	1.6
LESA	198	0.5 Da	0.3	0.1 Da	0.0	64.3 Aabcd	2.7	16.3 Babcd	1.8	10.2 Cb	1.9	7.3 Cb	1.4
LEYE	26	0.9 Ca	0.9	0 Ca	0.0	67.8 Aabc	5.4	23.9 Babcd	5.6	3.9 Cb	1.6	3.5 Cb	1.4
PESA	110	0.4 Da	0.2	0.1 Da	0.0	76.8 Aabc	2.9	11.3 Babcd	1.6	7.5 BCb	2.2	3.9 CDb	1.0
SBDO	10	0 Ba	0.0	0.2 Ba	0.2	66.8 Aabc	13.7	0.8 Bd	0.6	21.4 Bab	11.5	10.8 Bb	9.9
SEPL	34	0.5 Da	0.5	0.1 Da	0.1	47.0 Abcd	4.7	17.1 BCabcd	2.8	8.8 CDb	3.8	25.9 Bab	3.3
SESA	37	0 Ba	0.0	0.3 Ba	0.1	84.8 Aab	3.4	7.0 Bbcd	1.7	2.8 Bb	1.6	4.9 Bb	2.0
SOSA	13	0 Ba	0.0	0 Ba	0.0	64.2 Aabcd	10.0	10.0 Babcd	3.8	13.5 Bb	8.4	12.3 Bb	8.0
SPSA	17	0.1 Ca	0.1	0 Ca	0.0	64.8 Aabcd	6.5	26.2 Babc	5.1	7.2 Cb	4.8	4.4 Cb	2.9
STSA	12	0 Ba	0.0	0 Ba	0.0	79.5 Aabc	8.3	8.5 Babcd	3.1	6.7 Bb	4.1	5.3 Bb	5.2
WESA	4	0 Aa	0.0	0 Aa	0.0	47.0 Abcd	27.3	3.0 Acd	3.0	43.5 Aa	25.7	6.5 Ab	6.5
WISN	102	1.1 Ca	0.6	0 Ca	0.0	62.9 Aabcd	4.0	5.2 Cbcd	1.2	7.7 Cb	2.2	23.3 Bab	3.5
WRSA	4	0 Ba	0.0	0 Ba	0.0	98.0 Aa	2.0	2.0 Bcd	2.0	0 Bb	0.0	0 Bb	0.0

[a]BBPL = black-bellied plover (*Pluvialis squatarola*), DUNL = dunlin (*Calidris alpina*), GRYE = greater yellowlegs (*Tringa melanoleuca*), KILL = killdeer (*Charadrius vociferus*), LESA = least sandpiper (*Calidris minutilla*), LEYE = lesser yellowlegs

Table 7 (continued).

(*Tringa flavipes*), PESA = pectoral sandpiper (*Calidris melanotos*), 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 macularia*), STSA = stilt sandpiper (*Calidris himantopus*), WESA = western sandpiper (*Calidris mauri*), WISN = Wilson's snipe (*Gallinago delicata*), and WRSA = white-rumped sandpiper (*Calidris fuscicollis*).

[b]Means represent percentage of time expended during 1-minute focal surveys.

[c]Means within rows with unlike upper-case letters are different, and means within columns with unlike lower-case letters are different by analysis-of-variance and Ryan's-Q multiple comparison test ($P \leq 0.05$).

Table 8. Diurnal activity budgets of shorebirds among months in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

	August		September		October		November		December	
Behavior	$\bar{x}$ [a,b]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	67.95 Aa	2.68	64.21 Aa	2.09	44.89 Ba	2.35	45.14 Ba	2.69	37.03 Ba	3.07
Alert	0.34 Ad	0.31	0.92 Ac	0.29	0.5 Ae	0.27	1.64 Ade	0.81	0.34 Ac	0.2
Antagonistic	0.2 Ad	0.06	0.1 Bc	0.03	0.03 Be	0.02	0 Be	0	0 Bc	0
Locomotion	13.76 BCb	1.37	11.96 Cb	0.97	18.58 ABc	1.58	17.41 ABCc	1.61	19.8 Ab	2.28
Maintenance	7.76 Ac	1.91	9.26 Ab	1.4	8.9 Ad	1.64	6.68 Ad	1.59	3.59 Ac	1.55
Resting	10.22 Cbc	1.74	13.18 Cb	1.31	26.63 Bb	2.12	28.6 Bb	2.31	39.29 Aa	3.31

[a]Means represent percentage of time expended during 1-minute focal surveys.

[b]Means within rows followed by unlike upper-case letters and means within columns followed by unlike lower-case letters are different by analysis-of-variance and Ryan's-Q multiple comparison test ($P \leq 0.05$).

Table 9. Diurnal activity budgets of waterfowl species observed using mudflats in Kentucky Reservoir from August – September 2006 and 2007, Tennessee River Valley.

		Behavior											
		Alert		Antagonistic		Feeding		Locomotion		Maintenance		Resting	
Species[a]	*n*	$\bar{x}$ [b,c]	SE	Mean	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
ABDU	15	0 Ba	0.00	0 Ba	0.00	44.93 Abc	11.67	24.93 ABa	9.63	23.2 ABa	10.38	6.93 Bbc	5.46
AMWI	63	0.89 Da	0.44	0.03 Da	0.03	56.70 Aabc	5.06	19.02 Bab	3.77	7.1 Cdab	2.10	16.25 BCbc	3.90
BWTE	74	0 Ca	0.00	0.24 Ca	0.08	78.38 Aa	4.11	5.84 BCb	1.89	11.41 Bab	3.35	4.70 BCc	2.00
CAGO	63	1.49 Ca	0.94	0 Ca	0.00	32.06 Abc	4.97	18.51 Bab	3.70	14.76 Bab	3.60	34.76 Aa	5.00
GADW	160	0.80 Ca	0.50	0.15 Ca	0.05	63.74 Aab	3.12	14.59 Bab	2.09	9.21 Bab	1.89	11.29 Bbc	2.02
GWTE	125	0.61 Ca	0.26	0.08 Ca	0.04	67.39 Aab	3.61	15.94 Bab	2.59	8.18 Cab	2.02	7.81 Cbc	1.89
MALL	150	1.27 Da	0.67	0.07 Da	0.03	41.37 Abc	3.32	20.32 BCab	2.51	12.84 Cab	2.20	24.27 Bab	2.93
NOPI	48	0.17 Ca	0.17	0.04 Ca	0.04	56.50 Aabc	6.14	8.67 Cab	2.52	9.29 Cab	3.31	25.33 Bab	4.94
NSHO	28	0.43 Ca	0.43	0 Ca	0.00	60.0 Aab	7.45	21.21 Bab	5.39	4.64 BCb	2.44	13.71 BCbc	6.10
WODU	32	0 Ca	0.00	0.06 Ca	0.06	46.00 Abc	7.85	18.06 BCab	5.78	21.13 Bab	6.70	14.81 BCbc	5.48

[a]ABDU = American black duck (*Anas rubripes*), AMWI = American wigeon (*Anas americana*), BWTE = blue-winged teal (*Anas discors*), CAGO = Canada goose (*Branta canadensis*), GADW = gadwall (*Anas strepera*), GWTE = green-winged teal (*Anas crecca*), MALL = mallard (*Anas platyrhychos*), NOPI = northern pintail (*Anas acuta*), NSHO = northern shoveler (*Anas clypeata*), and WODU = wood duck (*Aix sponsa*).

[b]Means represent percentage of time expended during 1-minute focal surveys.

[c]Means within rows with unlike upper-case letters are different, and means within columns with unlike lower-case letters are different by analysis-of-variance and Ryan's-Q multiple comparison test ($P \leq 0.05$).

Table 10. Diurnal activity budgets of waterfowl among months in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

	August		September		October		November		December	
Behavior	$\bar{x}$ [a,b]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	50.75 Aa	4.51	66.87 Aa	5.42	58.75 Aa	4.02	54.64 Aa	2.49	56.53 Aa	2.65
Alert	0.16 Ac	0.11	0.43 Ac	0.25	0.79 Ac	0.79	0.72 Ac	0.35	0.99 Ad	0.34
Antagonistic	0.1 Ac	0.04	0.2 Ac	0.08	0.04 Ac	0.03	0.08 Ac	0.03	0.08 Ad	0.03
Locomotion	13.76 Ab	2.78	4.8 Bbc	1.72	16.04 Ab	2.58	17.15 Ab	1.74	20.59 Ab	1.97
Maintenance	16.12 Ab	3.16	13.37 ABc	3.74	11.43 ABb	2.73	11.55 ABb	1.58	6.74 Bc	1.26
Resting	18.1 Ab	3.33	15.67 Ab	4.25	13.67 Ab	2.87	16.16 Ab	1.83	15.07 Ab	1.88

[a]Means represent percentage of time expended during 1-minute focal surveys.

[b]Means within rows followed by unlike upper-case letters and means within columns followed by unlike lower-case letters are different by analysis-of-variance and Ryan's-Q multiple comparison test ($P \leq 0.05$).

Table 11. Diurnal activity budgets of other waterbird[a] species observed using mudflats in Kentucky Reservoir from August – September 2006 and 2007, Tennessee River Valley.

			Behavior											
			Alert		Antagonistic		Feeding		Locomotion		Maintenance		Resting	
Family	Species[b]	*n*	$\bar{x}$ [c,d]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ardeidae	GBHE	109	0.68 Ca	0.68	0 Ca	0	2.81 Cc	1.28	11.58 Ba	2.57	3.28 Cbc	1.19	81.63 Aab	3.04
	GREG	88	0.61 Da	0.55	0.05 Da	0.03	10.41 Cbc	2.04	32.73 Ba	3.51	9.7 Cbc	2.51	46.39 Aabc	3.67
	GRHE	13	0 Ba	0	0 Ba	0	0 Bc	0	9.08 Ba	4.44	9.85 Bbc	7.29	81.08 Aab	7.61
	LBHE	17	0 Ba	0	0.12 Ba	0.12	14.24 Babc	5.27	24.47 Ba	7.9	11.53 Bbc	6.37	49.65 Aabc	10.28
	YCHH	6	0 Ba	0	0 Ba	0	16.33 Babc	7.4	28.67 ABa	15.61	0 Bc	0	55 Aabc	13.71
Laridae	BOGU	83	0.1 Da	0.1	0.02 Da	0.02	12.67 Cbc	2.83	12.96 Ca	3.03	27.52 Babc	4.26	46.92 Aabc	4.69
	FOTE	8	0 Ba	0	0 Ba	0	0 Bc	0	0 Ba	0	5.25 Bbc	3.48	94.75 Aa	3.48
	FRGU	4	0 Ba	0	0 Ba	0	0 Bc	0	11.5 Ba	11.5	5.5 Bbc	5.5	83 Aab	17
	HERG	14	0 Ca	0	0 Ca	0	9.14 Cbc	5.94	2.14 Ca	2.14	56.29 Aa	10.98	32.43 Bbc	9.61
	RBGU	22	0.03 Da	0.03	0.01 Da	0.01	11.46 Cbc	1.64	15.64 Ca	1.81	23.59 Babc	2.51	49.42 Aabc	2.86
Pelicanidae	AWPE	24	0 Ca	0	0 Ca	0	19.5 Cabc	6.7	7.92 Cca	3.2	42.08 Bab	9.05	35.5 Ac	7.64
Podicipedidae	PBGR	5	0 Ba	0	0 Ba	0	37.2 ABab	16.85	7.6 Ba	4.92	3.2 Bbc	1.96	52 Aabc	18.7
Rallidae	AMCO	12	0 Ba	0	0 Ba	0	42 Aa	13.11	19 ABa	30.94	24 Ababc	10.91	15 Abc	8.49

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

[b]AMCO = American coot (*Fulica americana*), AWPE = American white pelican (*Pelicanus erythrorhynchos*), BOGU = Bonaparte's gull (*Larus philadelphia*), FOTE = Forster's tern (*Sterna forsteri*), FRGU = Franklin's gull (*Larus pipixcan*), GBHE = great blue heron (*Ardea herodias*), GREG = great egret (*Ardea alba*), GRHE = green heron (*Butorides virescens*),

Table 11 (continued).

HERG = herring gull (*Larus argentatus*), LBHE = little blue heron (*Egretta caerulea*), PBGR = pied-billed grebe (*Podilymbus podiceps*), RBGU = ring-billed gull (*Larus delawarensis*), and YCNH = yellow-crowned night-heron (*Nyctanassa violacea*).

[c]Means represent percentage of time expended during 1-minute focal surveys.

[d]Means within rows followed by unlike upper-case letters and means within columns followed by unlike lower-case letters are different by analysis-of-variance and Ryan's-Q multiple comparison test ($P \leq 0.05$).

Table 12. Diurnal activity budgets of other waterbirds[a] among months in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

	August		September		October		November		December	
Behavior	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	7.45 Ac	1.7	9.41 Ac	2.81	7.84 Abc	3.21	8.53 Ab	4.52	3.56 Ab	2.53
Alert	1.01 Ac	0.96	0.04 Ac	0.04	1.3 Ac	1.3	0 Ab	0	0 Ab	0
Antagonistic	0.03 Ac	0.03	0 Ac	0	0.11 Ac	0.08	0 Ab	0	0 Ab	0
Locomotion	28.88 Ab	4.06	28.94 Ab	4.19	17.89 ABb	4.82	9.59 Bb	4.26	4.44 Bb	2.76
Maintenance	9.77 Ac	2.77	5.8 Ac	2.31	9.89 Abc	4.02	2.76 Ab	1.77	0.78 Ab	0.78
Resting	52.86 Ca	4.39	55.61 Ca	5.07	62.97 BCa	5.95	79.06 Aba	6.07	91.22 Aa	3.76

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

[b]Means represent percentage of time expended during 1-minute focal surveys.

[c]Means within rows followed by unlike upper-case letters and means within columns followed by unlike lower-case letters are different by analysis-of-variance and Ryan's-Q multiple comparison test ($P \leq 0.05$).

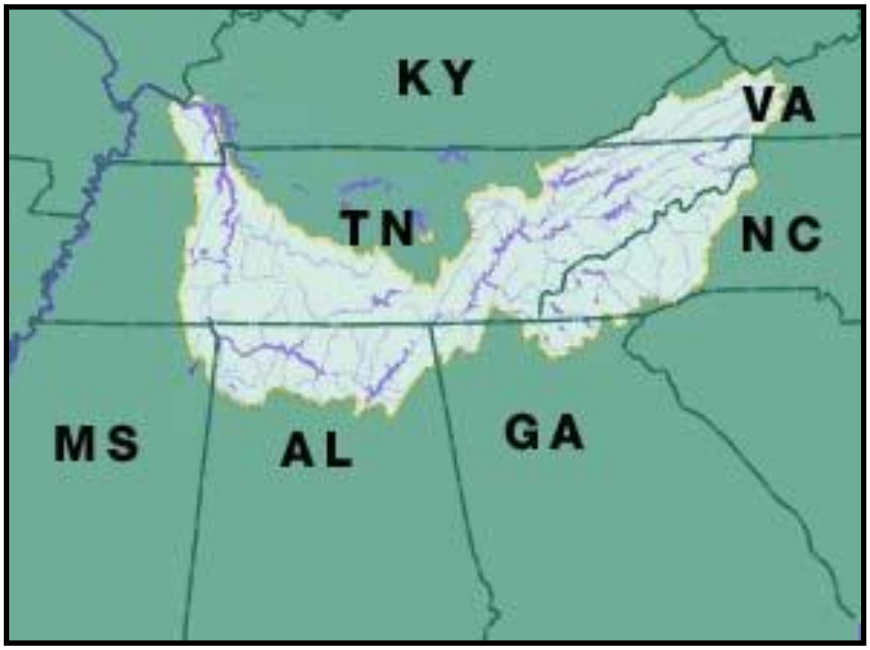

Figure 1. Location of the Tennessee River Valley in the southeastern United States.

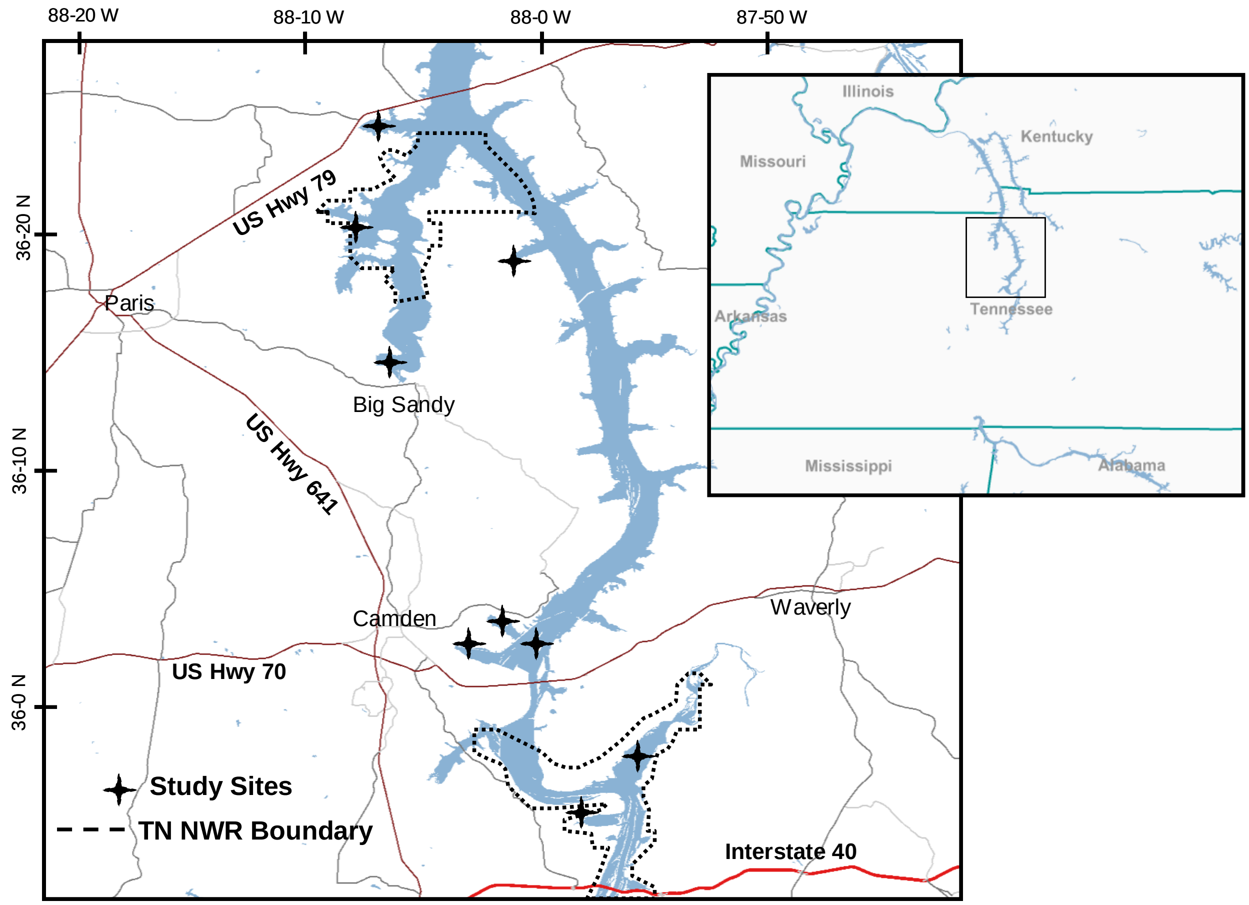

Figure 2. Location of study mudflats and Tennessee National Wildlife Refuge (TN NWR) along Kentucky Reservoir, Tennessee River Valley, USA.

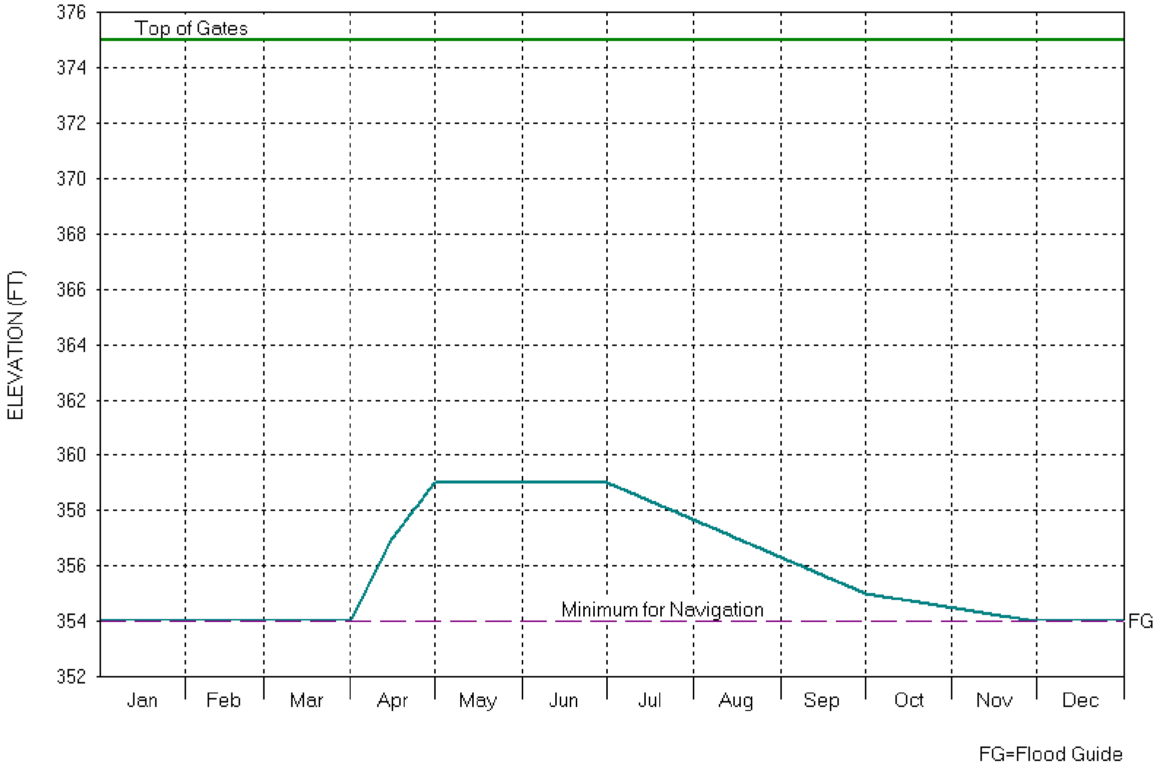

Figure 3. Tennessee Valley Authority operating guide for Kentucky Reservoir (Tennessee Valley Authority 2008).

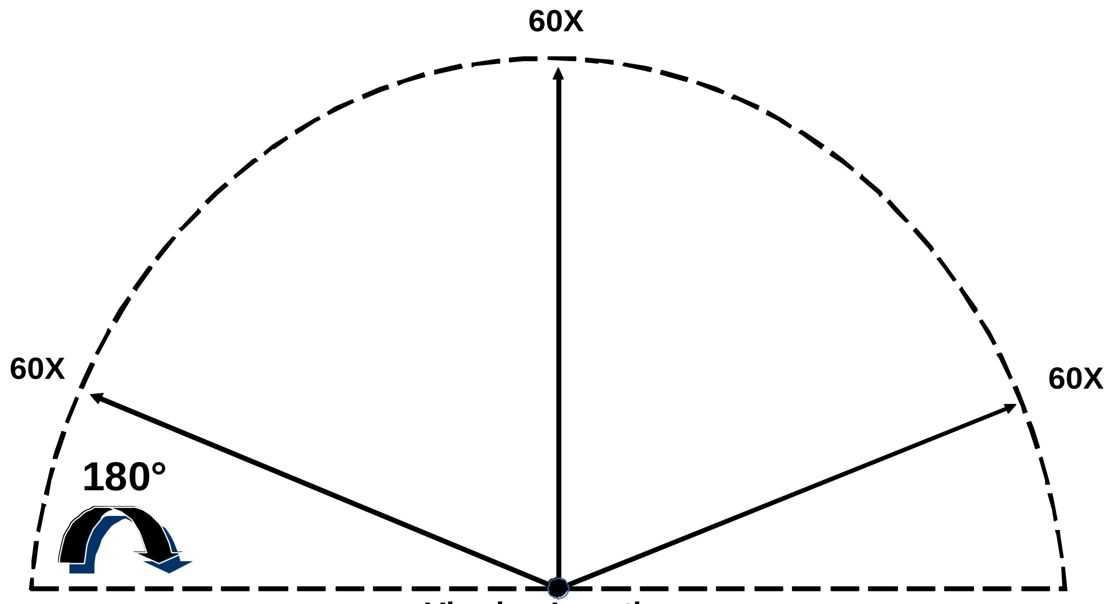

Figure 4. Waterbird survey design schematic at a permanent viewing location at each mudflat.

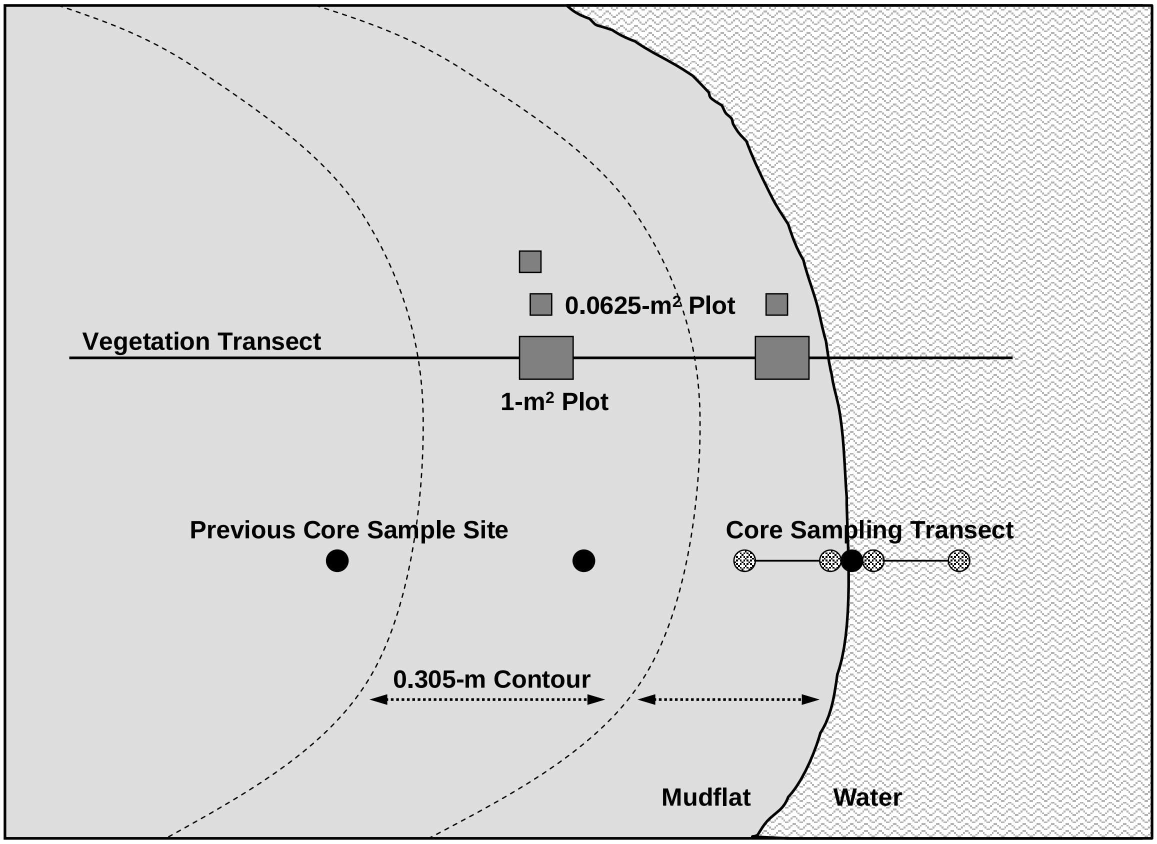

Figure 5. Schematic of vegetation and core sampling transects positioned on a typical mudflat.

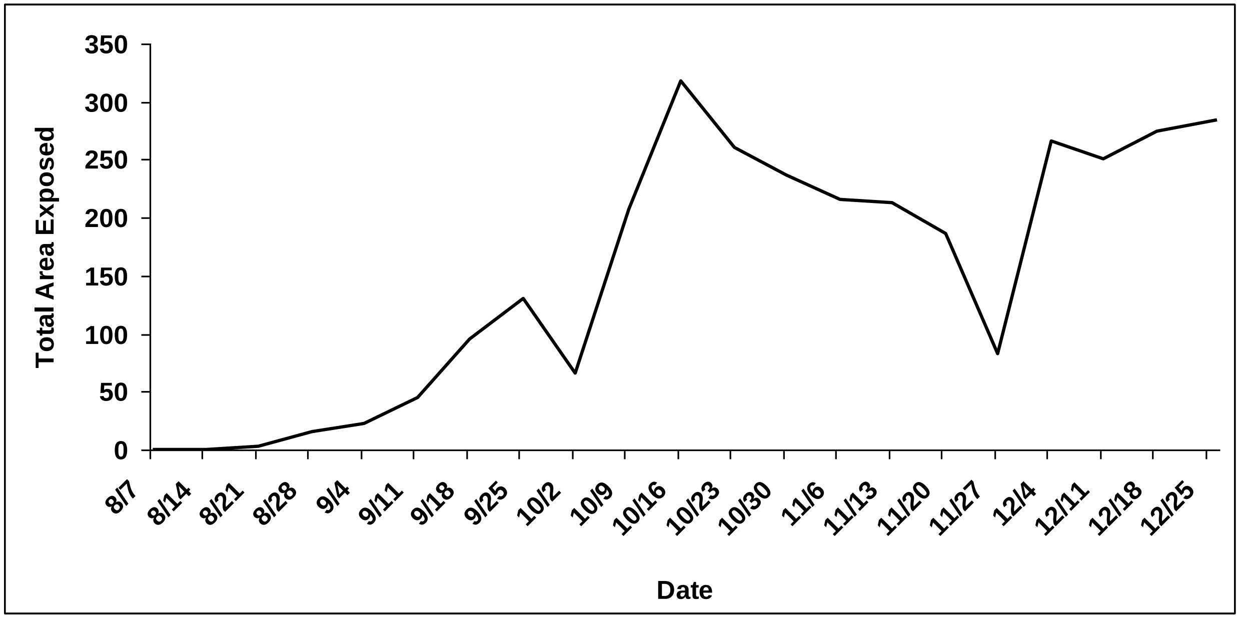

Figure 6. Total area of mudflats (ha) exposed on 9 mudflats in Kentucky Reservoir from August – December 2006, Tennessee River Valley.

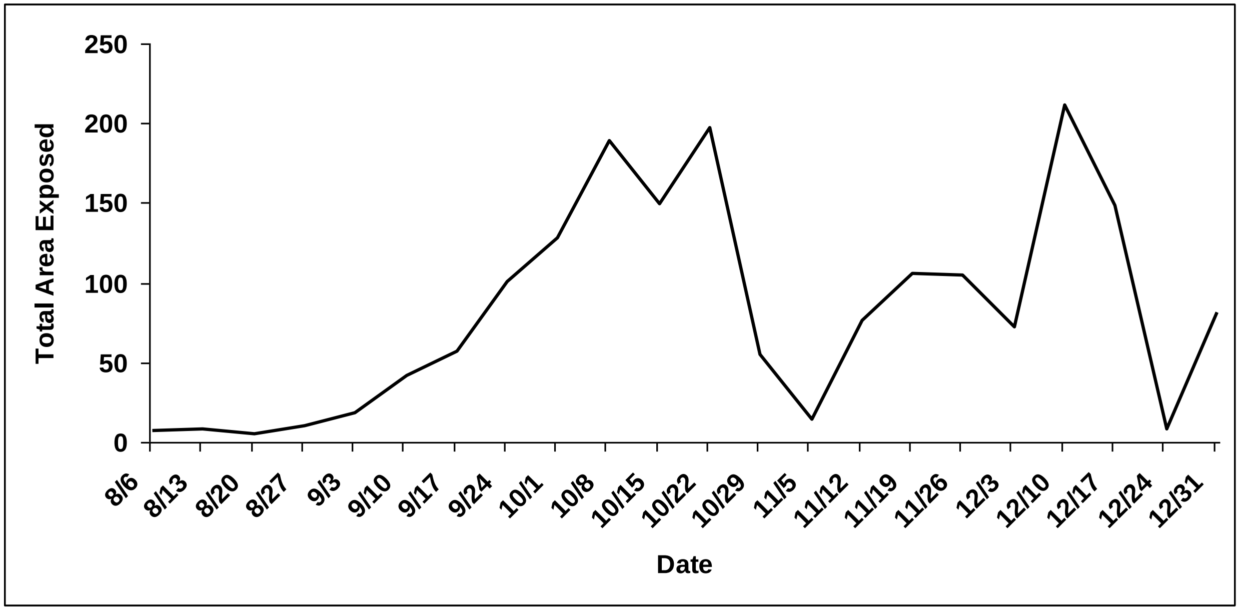

Figure 7. Total area of mudflats (ha) exposed on 9 mudflats in Kentucky Reservoir from August – December 2007, Tennessee River Valley.

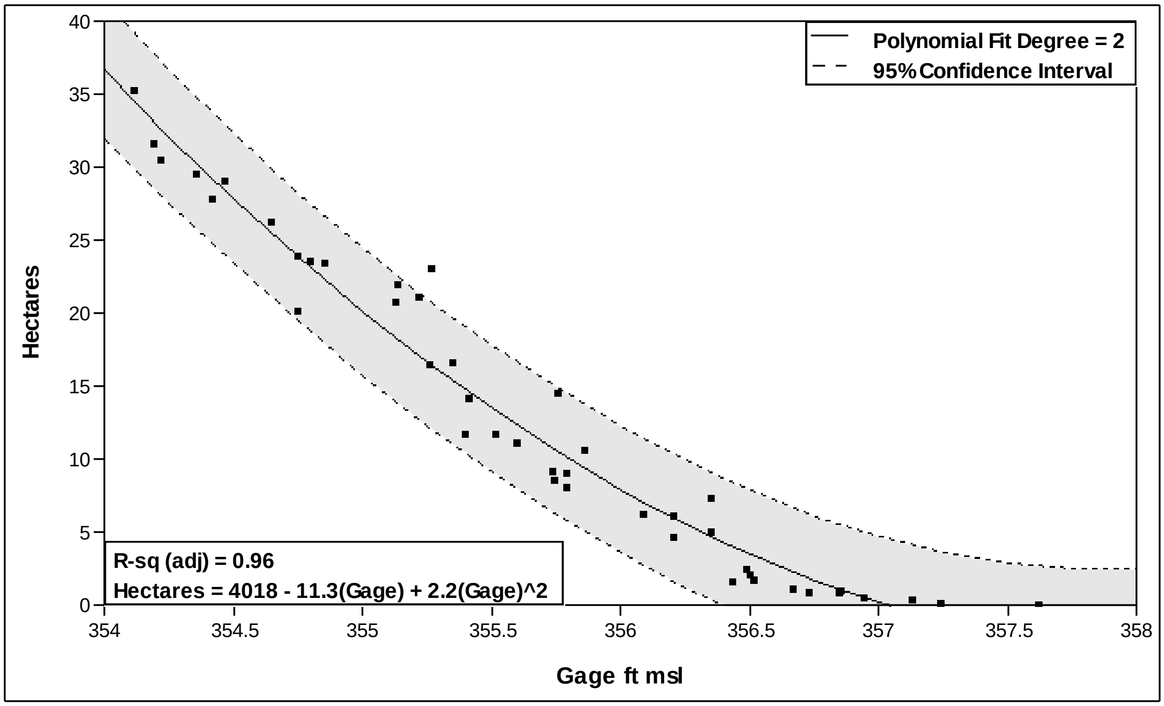

Figure 8. Model and fitted regression line relating exposed mudflat area (ha) with Kentucky Reservoir gage height (TVA, New Johnsonville Gage) from August – December 2006 and 2007, Tennessee River Valley.

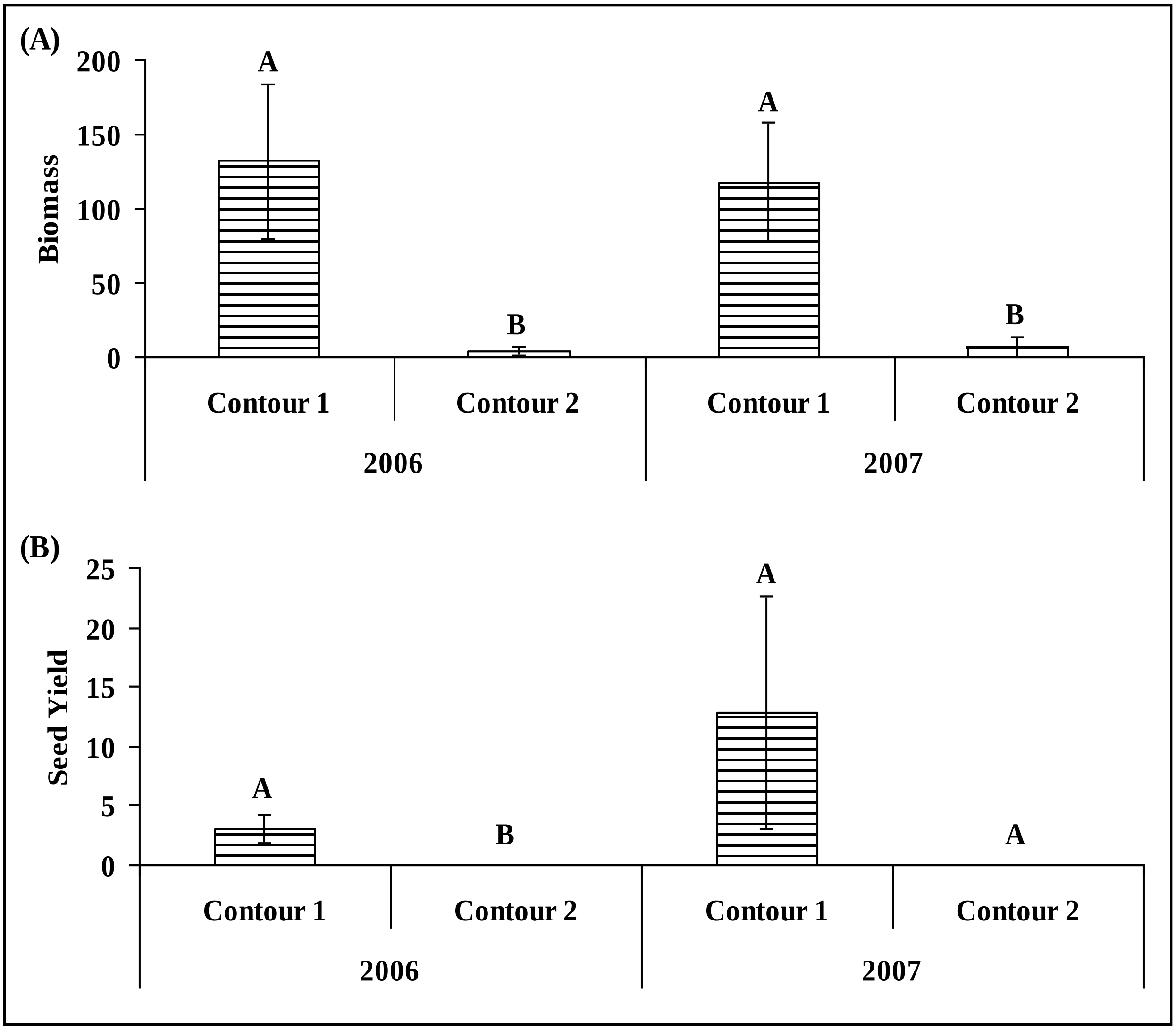

Figure 9. Mean vegetation biomass (A; g m^{-2}) and seed yield (B; g m^{-2}) among mudflat contours in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Contour 1 = 108.56 m (356.17 ft) MSL, contour 2 = 108.36 m (355.5 ft) MSL, and contour 3 = 108.07 m (354.55 ft) MSL. Bars with unlike letter within years are different ($P \leq 0.05$).

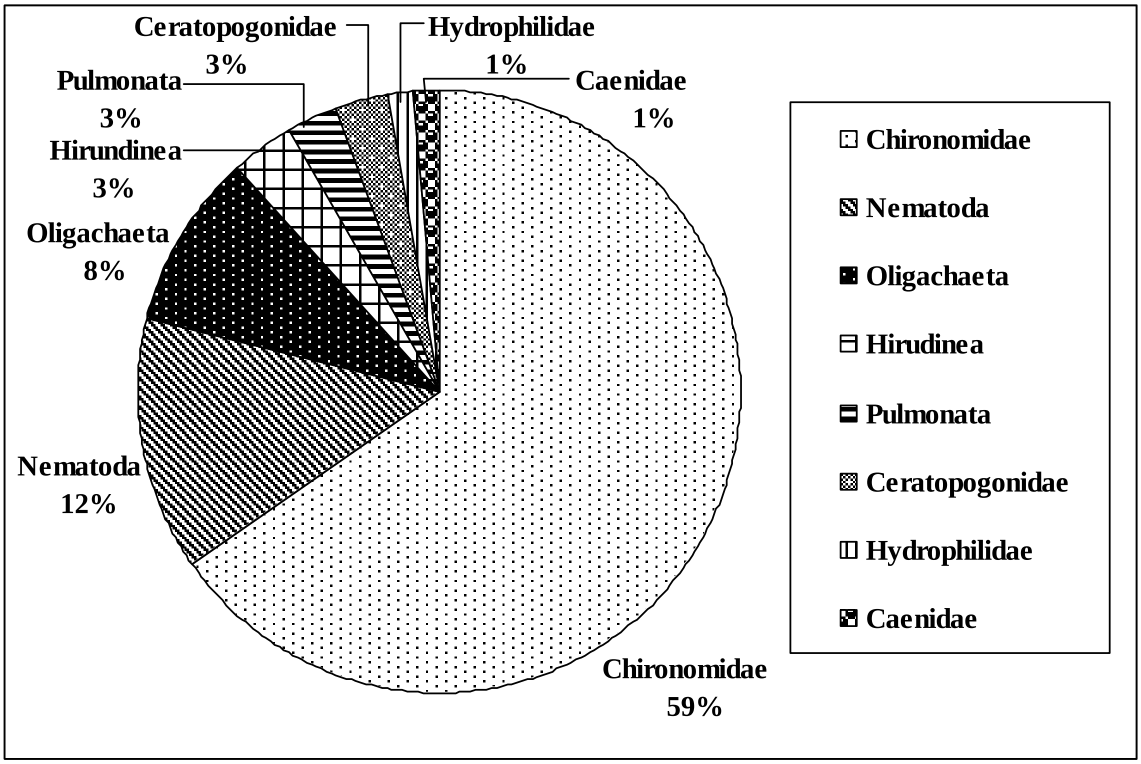

Figure 10. Percent composition of invertebrates sampled in mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. The listed taxa collectively comprise >90% of total invertebrates sampled.

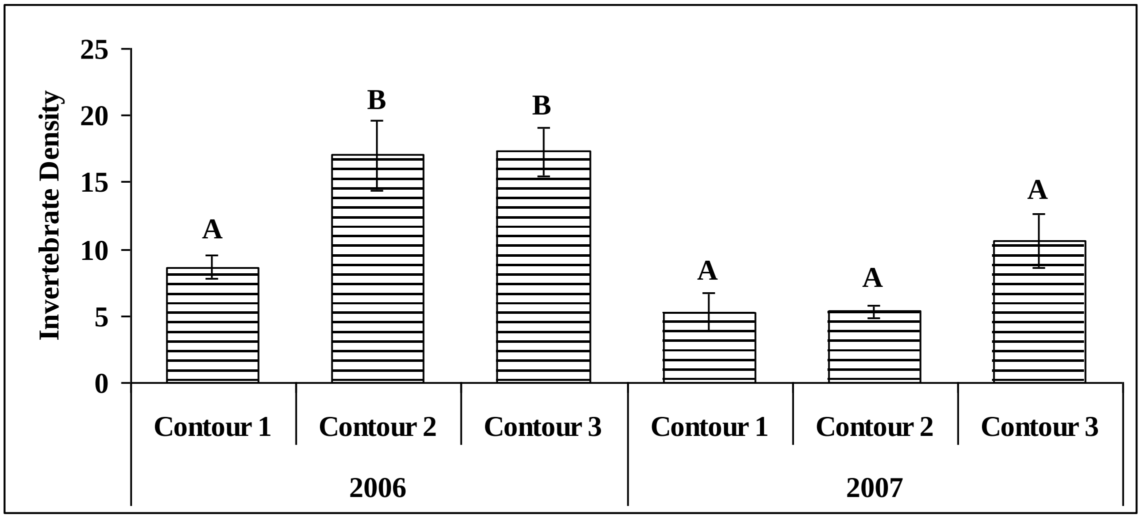

Figure 11. Mean density of invertebrates (individuals per 608.21 cm^3) among mudflat contours in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Contour 1 = 108.56 m (356.17 ft) MSL, Contour 2 = 108.36 m (355.5 ft) MSL, and Contour 3 = 108.07 m (354.55 ft) MSL. Bars with unlike letter within years are different ($P \leq 0.05$).

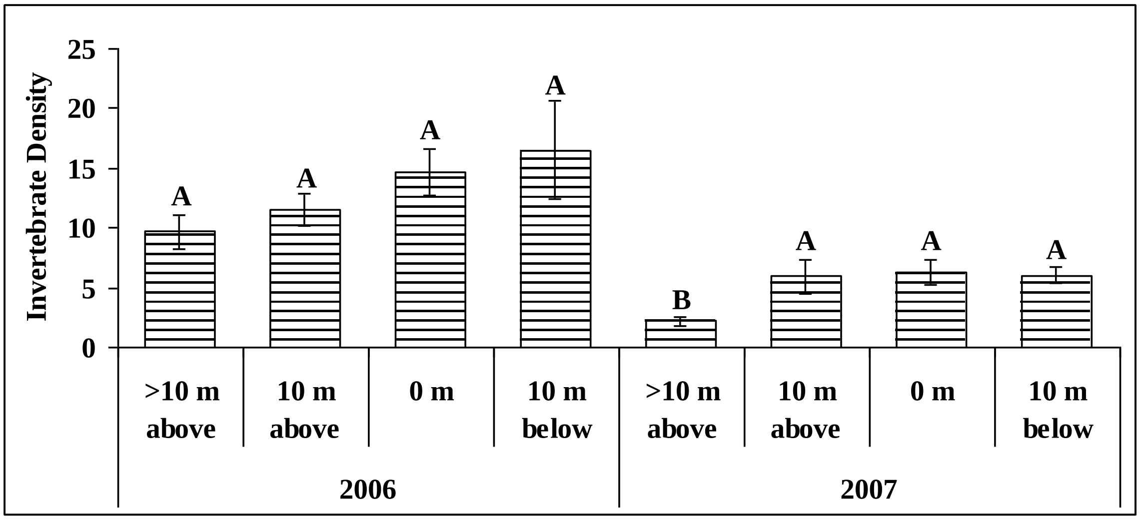

Figure 12. Mean density of invertebrates (individuals 608.21 cm^{-3}) among mudflat locations relative to the waterline (0 m) in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Bars with unlike letters within years are different ($P \leq 0.05$).

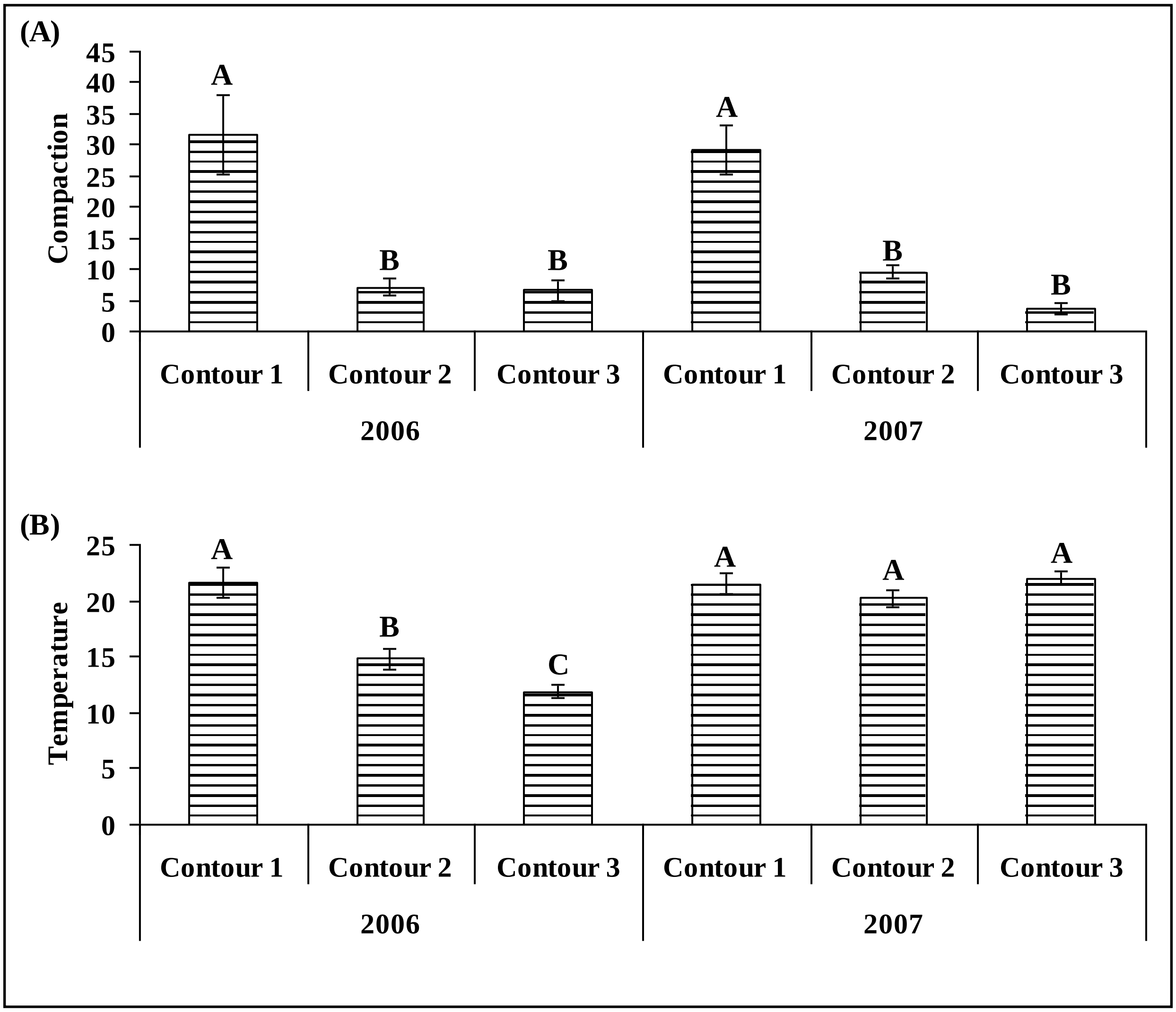

Figure 13. Mean soil compaction (A; lbs in^{-2}) and mean temperature (B; °C) among mudflat contours in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Contour 1 = 108.56 m (356.17 ft) MSL, contour 2 = 108.36 m (355.5 ft) MSL, and contour 3 = 108.07 m (354.55 ft) MSL. Bars with unlike letter within years are different ($P \leq 0.05$).

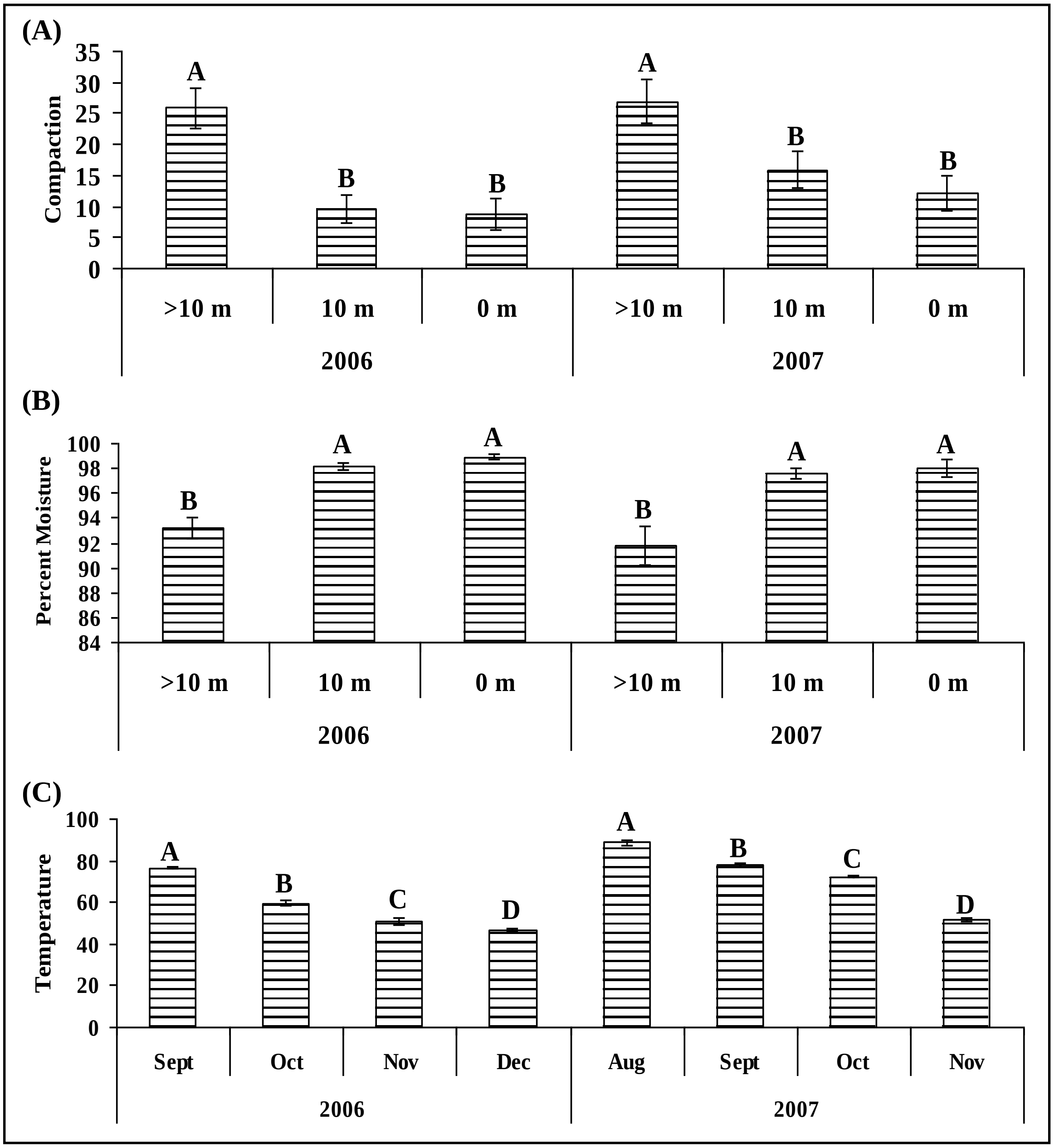

Figure 14. Mean soil compaction (A; lbs in^{-2}) and percent moisture (B) among mudflat locations relative to the waterline (0 m), and mean soil temperature (C; °C) among months in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Bars with unlike letters within years are different ($P \leq 0.05$).

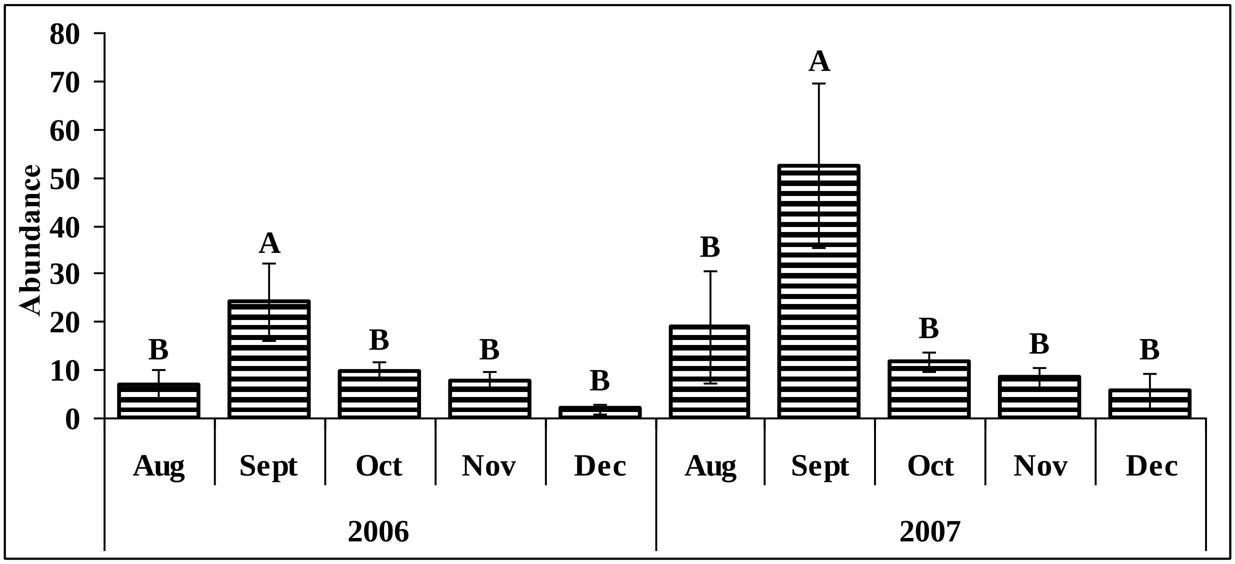

Figure 15. Mean daily abundance of shorebirds (excluding killdeer, *Charadrius vociferus*) using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Bars with unlike letters within years are different ($P \leq 0.05$).

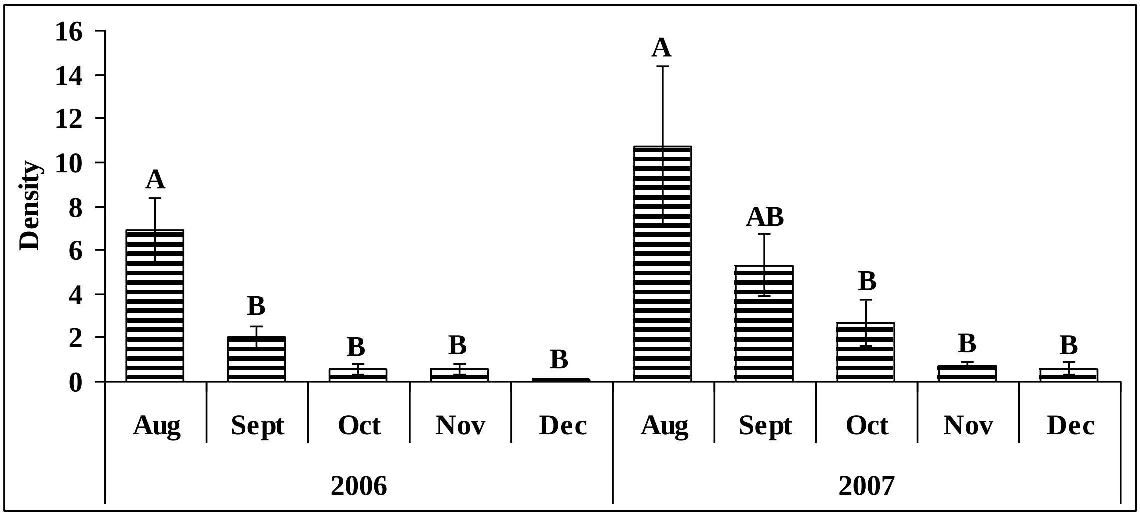

Figure 16. Mean shorebird density (individuals per ha; excluding killdeer, *Charadrius vociferus*) using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Bars with unlike letters within years are different ($P \leq 0.05$).

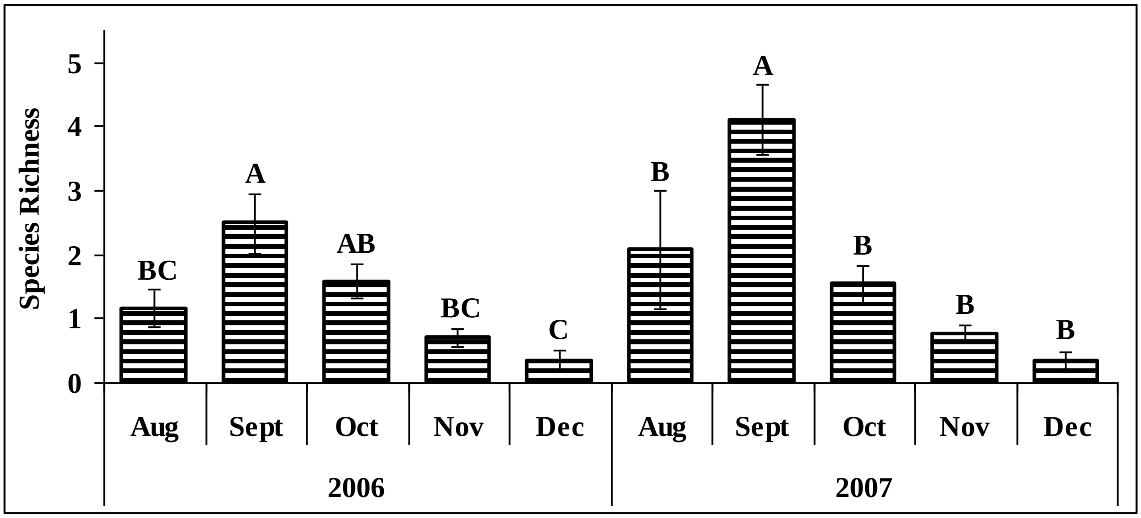

Figure 17. Mean species richness of shorebirds using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Bars with unlike letters within years are different ($P \leq 0.05$).

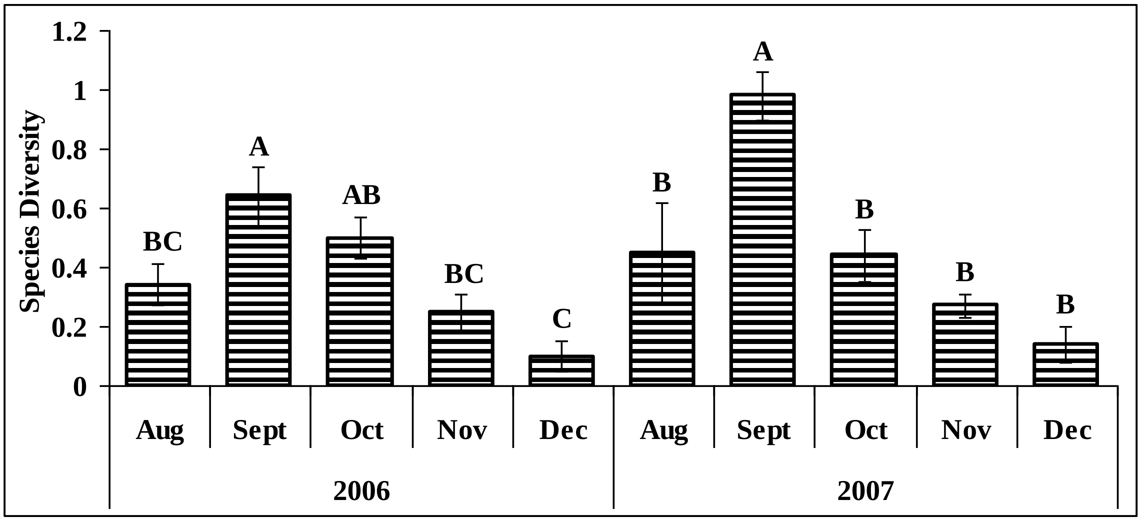

Figure 18. Mean species diversity (Shannon-Wiener index) of shorebirds using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Bars with unlike letters within years are different ($P \leq 0.05$).

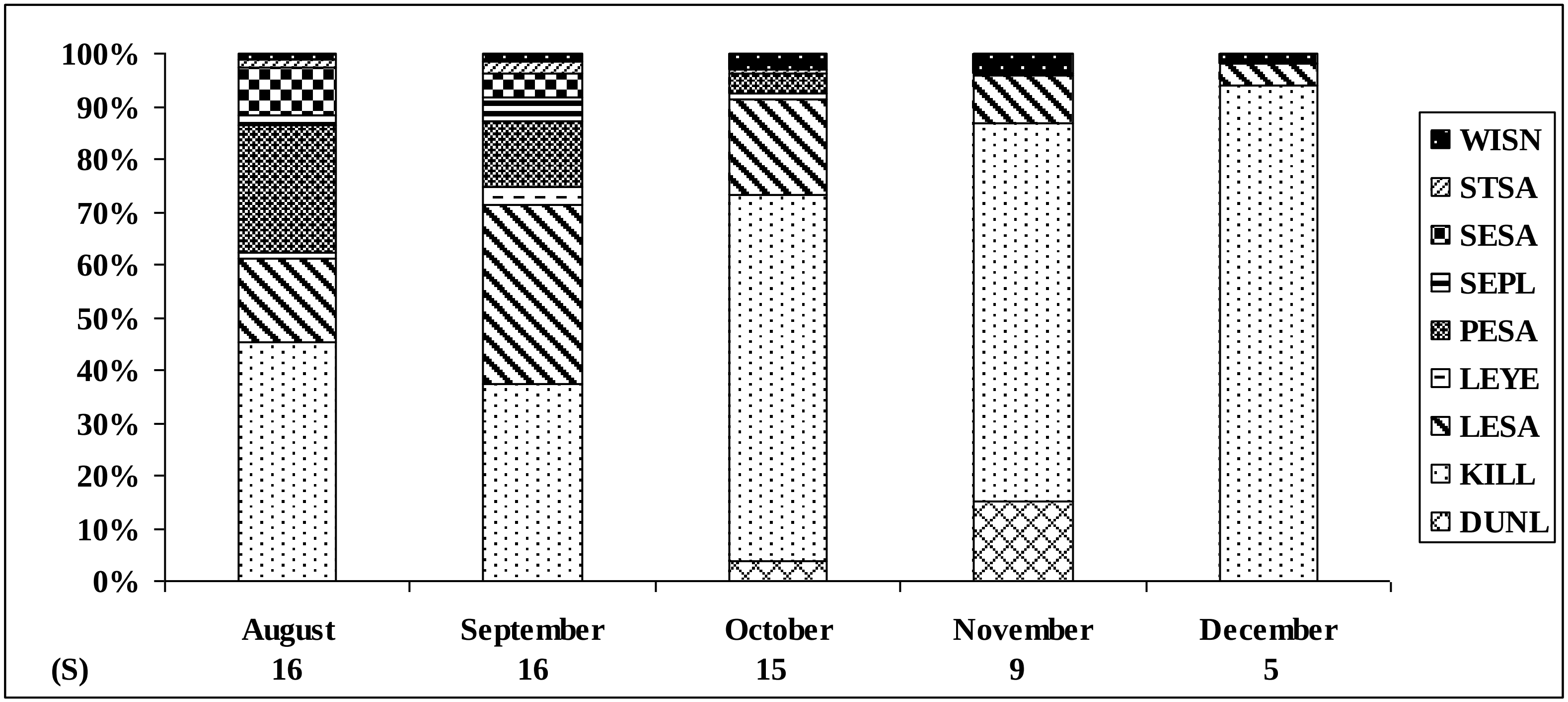

Figure 19. Species composition and total richness (*S*) of shorebirds using mudflats in Kentucky Reservoir from August – December 2006, Tennessee River Valley. The species listed comprised ≥1% for any month and collectively comprised >95% of total shorebird abundance. DUNL = dunlin (*Calidris alpina*), KILL = killdeer (*Charadrius vociferus*), LESA = least sandpiper (*Calidris minutilla*), LEYE = lesser yellowlegs (*Tringa flavipes*), PESA = pectoral sandpiper (*Calidris melanotos*), SEPL = semipalmated plover (*Charadrius semipalmatus*), SESA = semipalmated sandpiper (*Calidris pusilla*), STSA = stilt sandpiper (*Calidris himantopus*), and WISN = Wilson's snipe (*Gallinago delicata*).

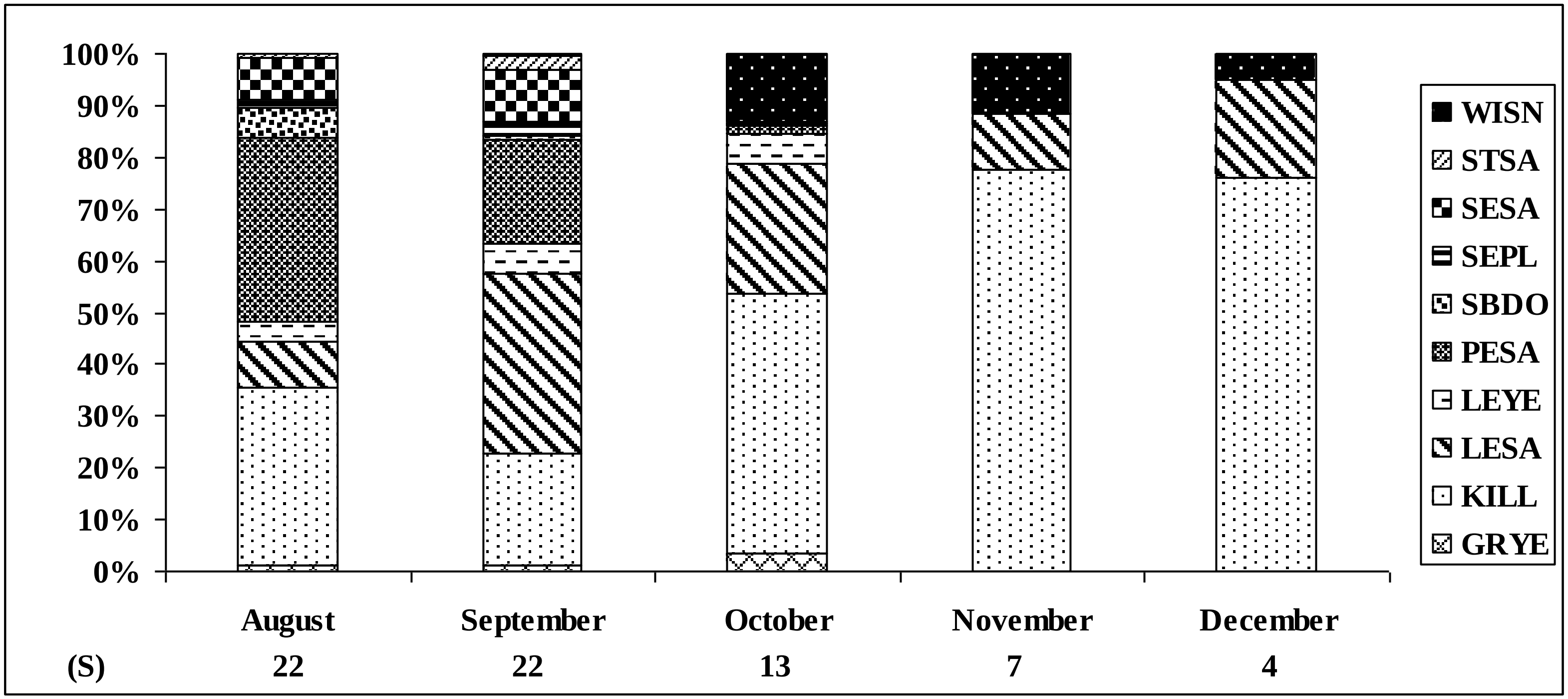

Figure 20. Species composition and total richness (*S*) of shorebirds using mudflats in Kentucky Reservoir from August – December 2007, Tennessee River Valley. The species listed comprised ≥1% for any month and collectively comprised >95% of total shorebird abundance. GRYE = greater yellowlegs (*Tringa melanoleuca*), KILL = killdeer (*Charadrius vociferus*), LESA = least sandpiper (*Calidris minutilla*), LEYE = lesser yellowlegs (*Tringa flavipes*), PESA = pectoral sandpiper (*Calidris melanotos*), SBDO = short-billed dowitcher (*Limnodromus griseus*), SEPL = semipalmated plover (*Charadrius semipalmatus*), SESA = semipalmated sandpiper (*Calidris pusilla*), STSA = stilt sandpiper (*Calidris himantopus*), and WISN = Wilson's snipe (*Gallinago delicata*).

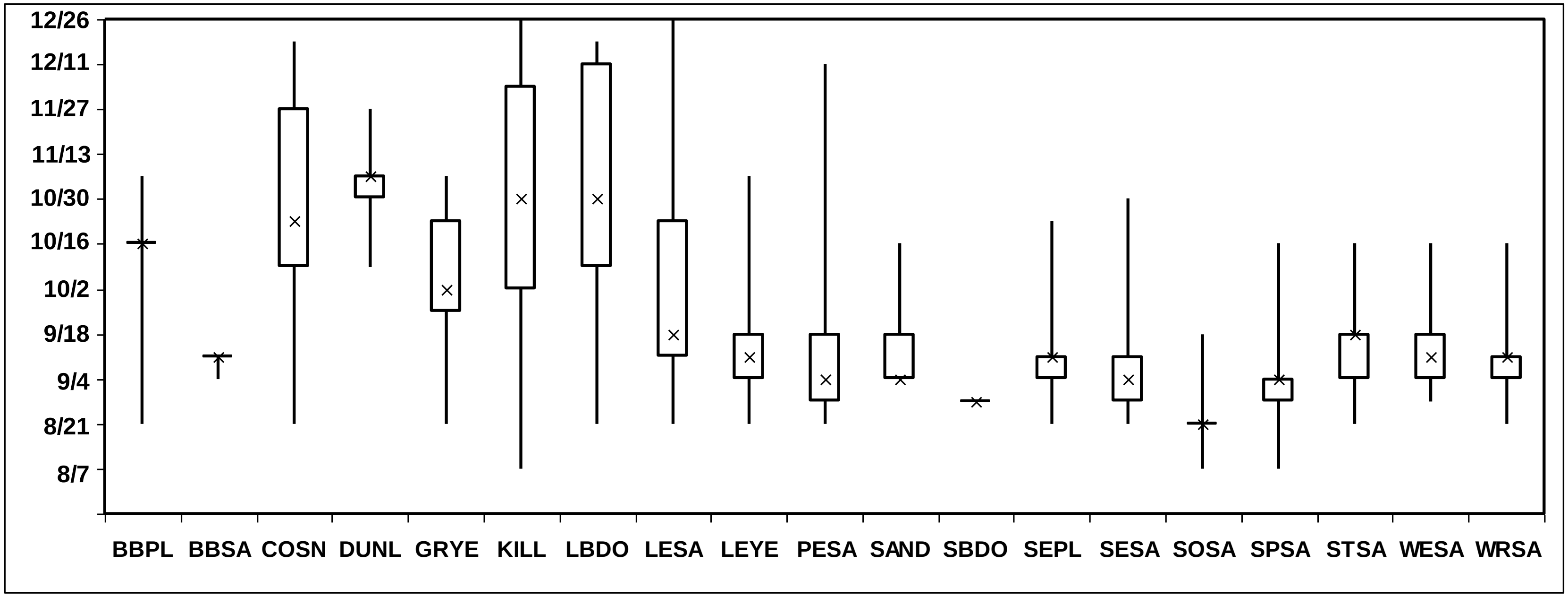

Figure 21. Species-specific migration chronology of shorebirds in Kentucky Reservoir from August – December 2006, Tennessee River Valley. The ends of the box plot correspond to dates that accumulated abundance equals the 1st and 3rd quartile (i.e., 25th and 75th percentile). X corresponds to the date that accumulated abundance equals 50% of the birds of that species was recorded. The line corresponds to the duration that 100% of all birds of that species was recorded.

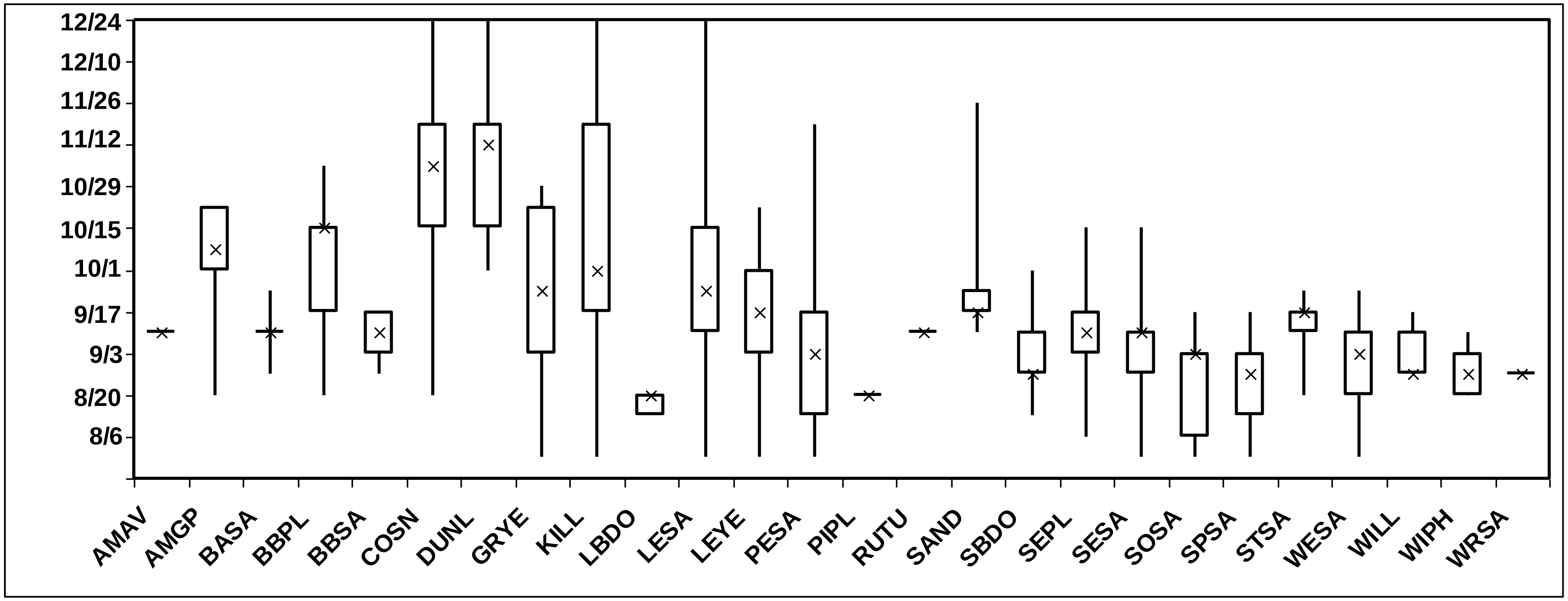

Figure 22. Species-specific migration chronology of shorebirds in Kentucky Reservoir from August – December 2007, Tennessee River Valley. The ends of the box plot correspond to dates that accumulated abundance equals the 1st and 3rd quartile (i.e., 25th and 75th percentile). X corresponds to the date that accumulated abundance equals 50% of the birds of that species was recorded. The line corresponds to the duration that 100% of all birds of that species was recorded.

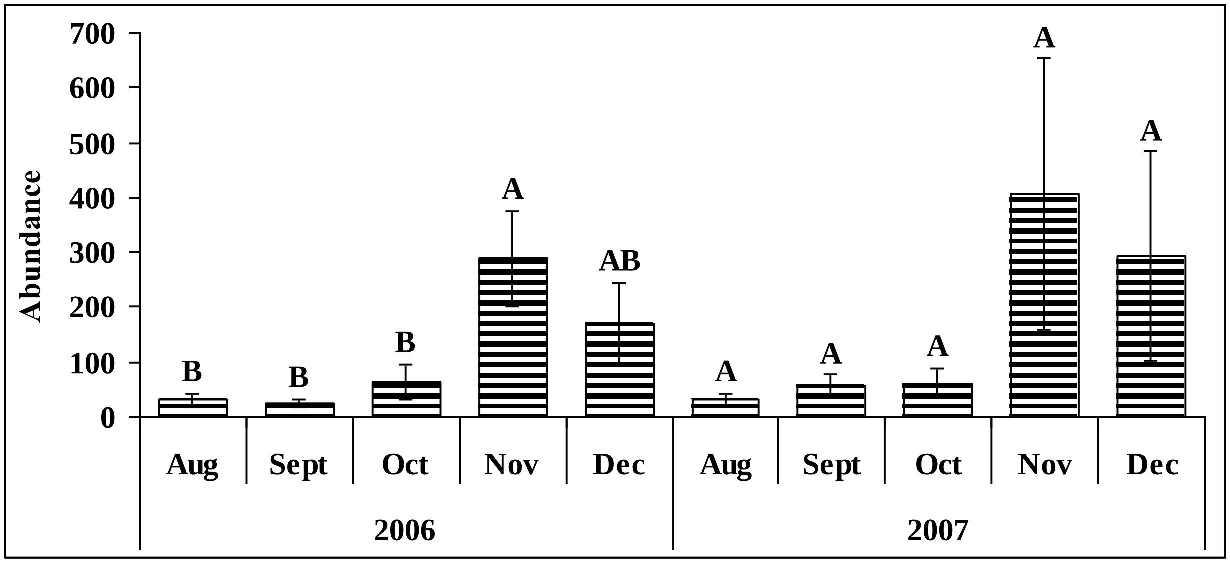

Figure 23. Mean daily abundance of waterfowl using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Bars with unlike letters within years are different ($P \leq 0.05$).

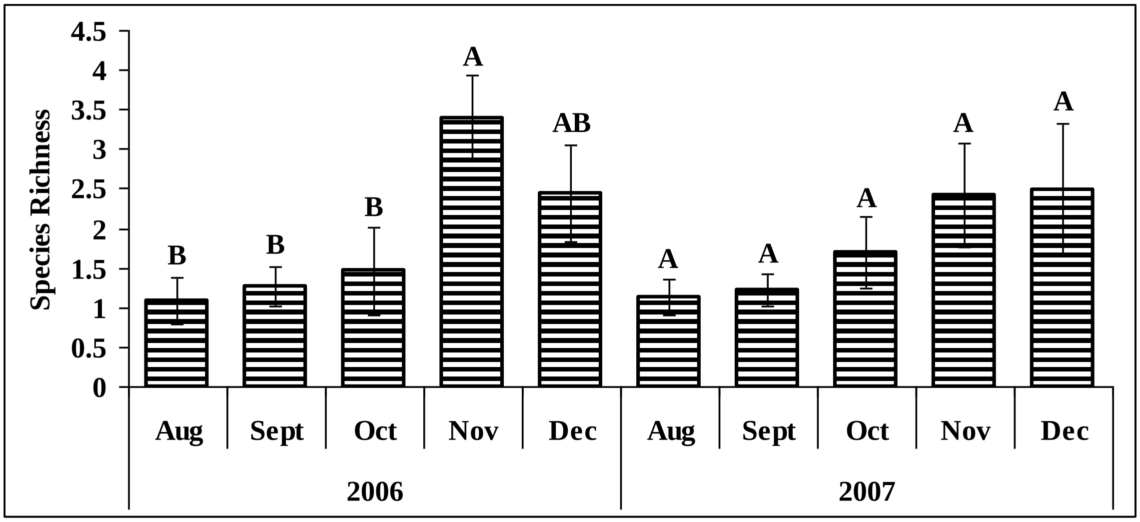

Figure 24. Mean species richness of waterfowl using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Bars with unlike letters within years are different ($P \leq 0.05$).

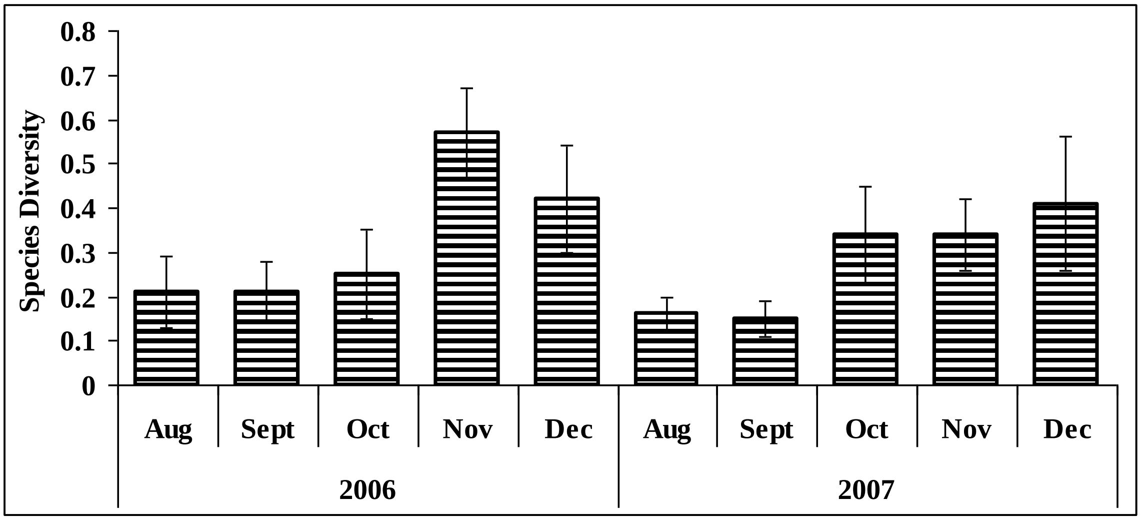

Figure 25. Mean species diversity of waterfowl using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. No differences were detected among months ($P > 0.05$) by Ryan's-Q multiple comparison test.

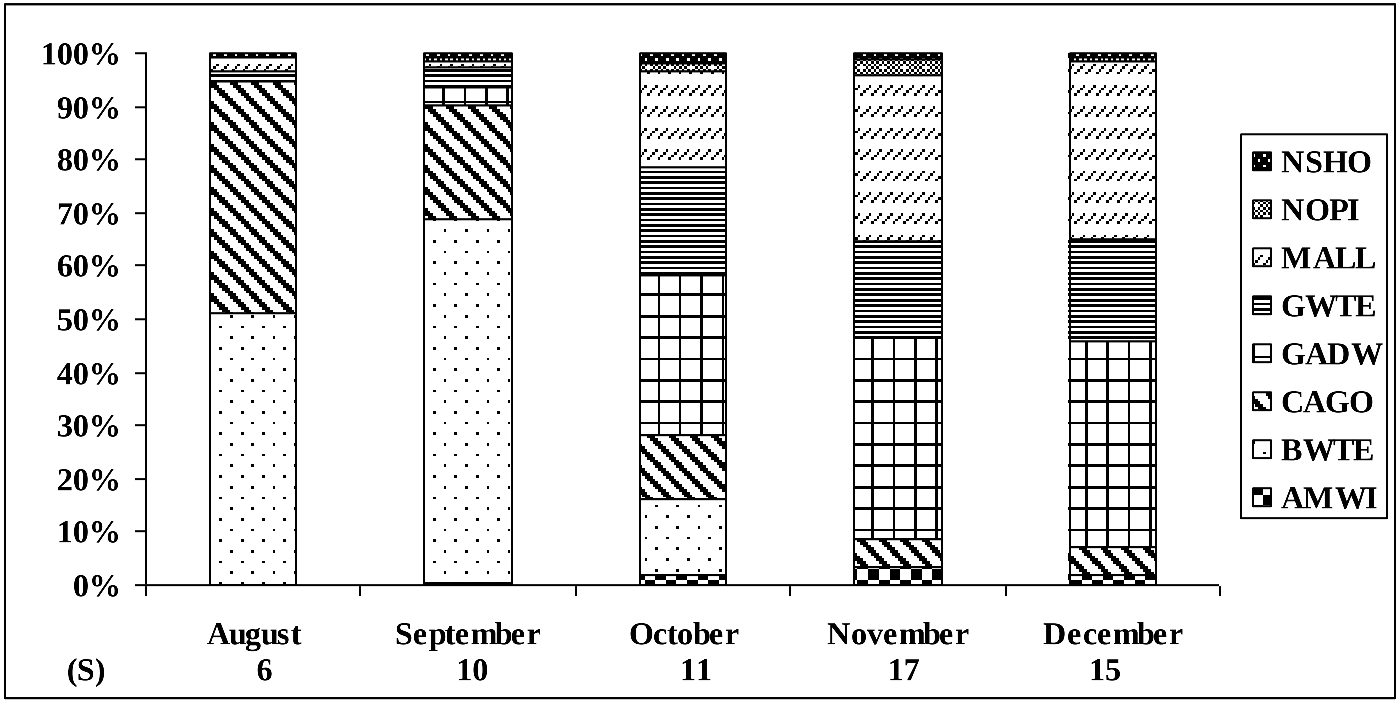

Figure 26. Species composition and total richness (*S*) of waterfowl using mudflats in Kentucky Reservoir from August – December 2006, Tennessee River Valley. The species listed comprised ≥1% for any month and collectively comprised >90% of total waterfowl abundance. AMWI = American wigeon (Anas *americana*), BWTE = blue-winged teal (*Anas discors*), CAGO = Canada goose (*Branta canadensis*), GADW = gadwall (*Anas strepera*), GWTE = green-winged teal (*Anas crecca*), MALL = mallard (*Anas platyrhynchos*), and NOPI = northern pintail (*Anas acuta*).

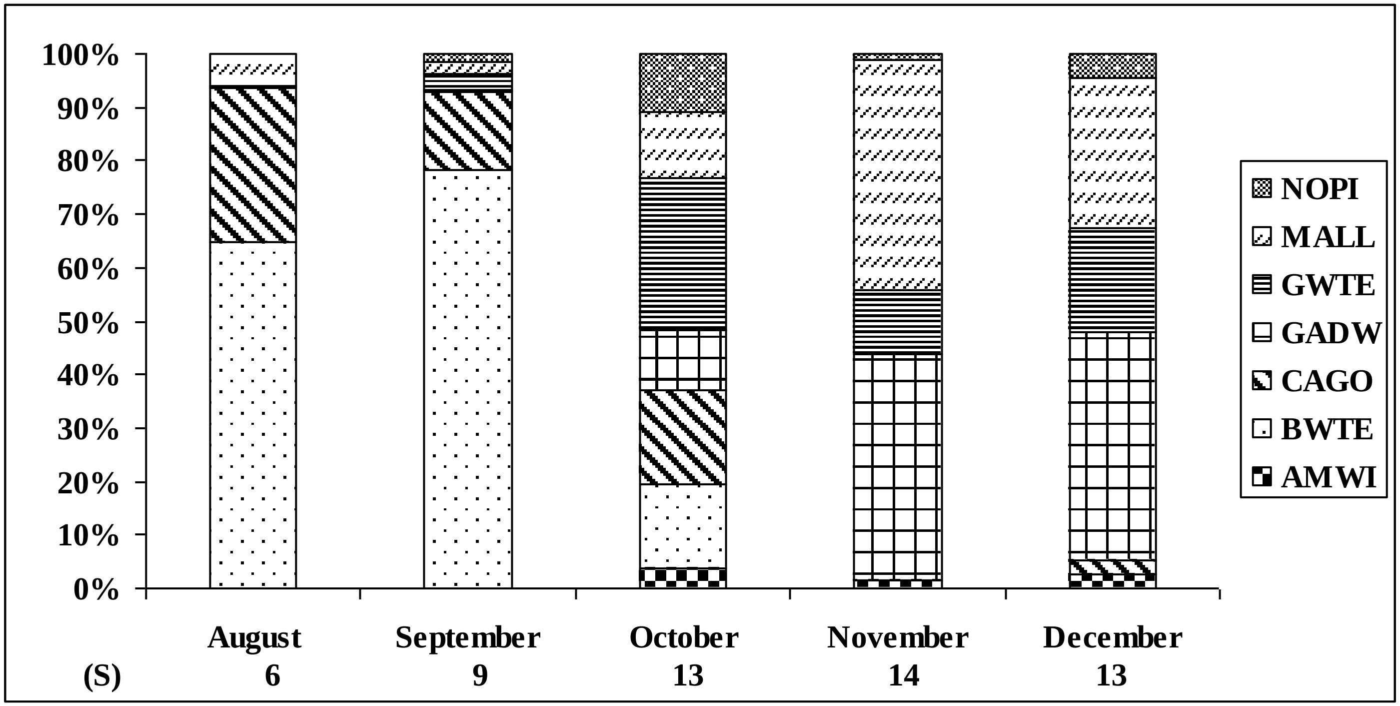

Figure 27. Species composition and total richness (*S*) of waterfowl using mudflats in Kentucky Reservoir from August – December 2007, Tennessee River Valley. The species listed comprised ≥1% for any month and collectively comprised >90% of total waterfowl abundance. AMWI = American wigeon (Anas *americana*), BWTE = blue-winged teal (*Anas discors*), CAGO = Canada goose (*Branta canadensis*), GADW = gadwall (*Anas strepera*), GWTE = green-winged teal (*Anas crecca*), MALL = mallard (*Anas platyrhynchos*), and NOPI = northern pintail (*Anas acuta*).

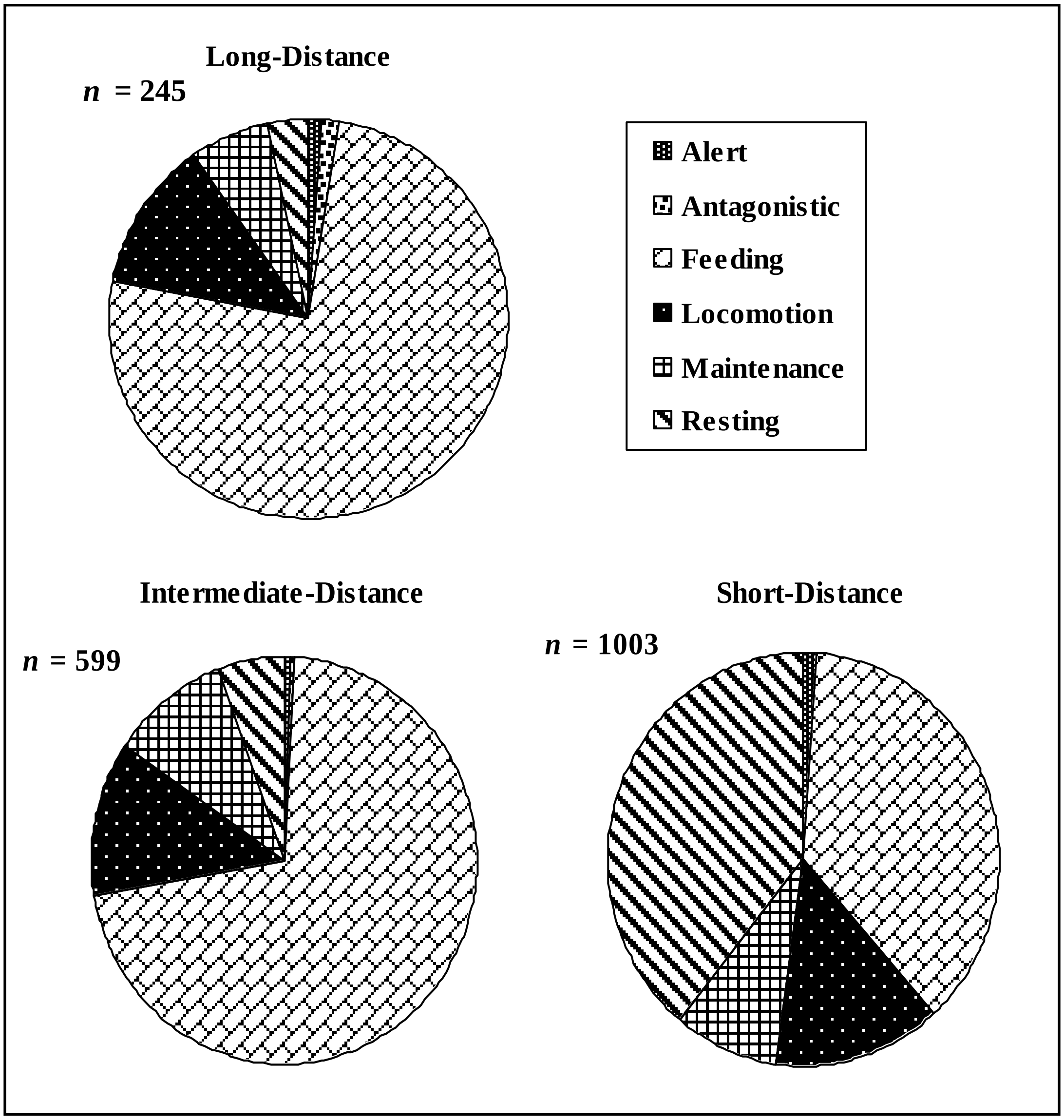

Figure 28. Percent occurrence of activities exhibited by long-, intermediate-, and short- distance migrant shorebirds in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley. Classification is based on average migration distance according to Skagen and Knopf (1993, Appendix).

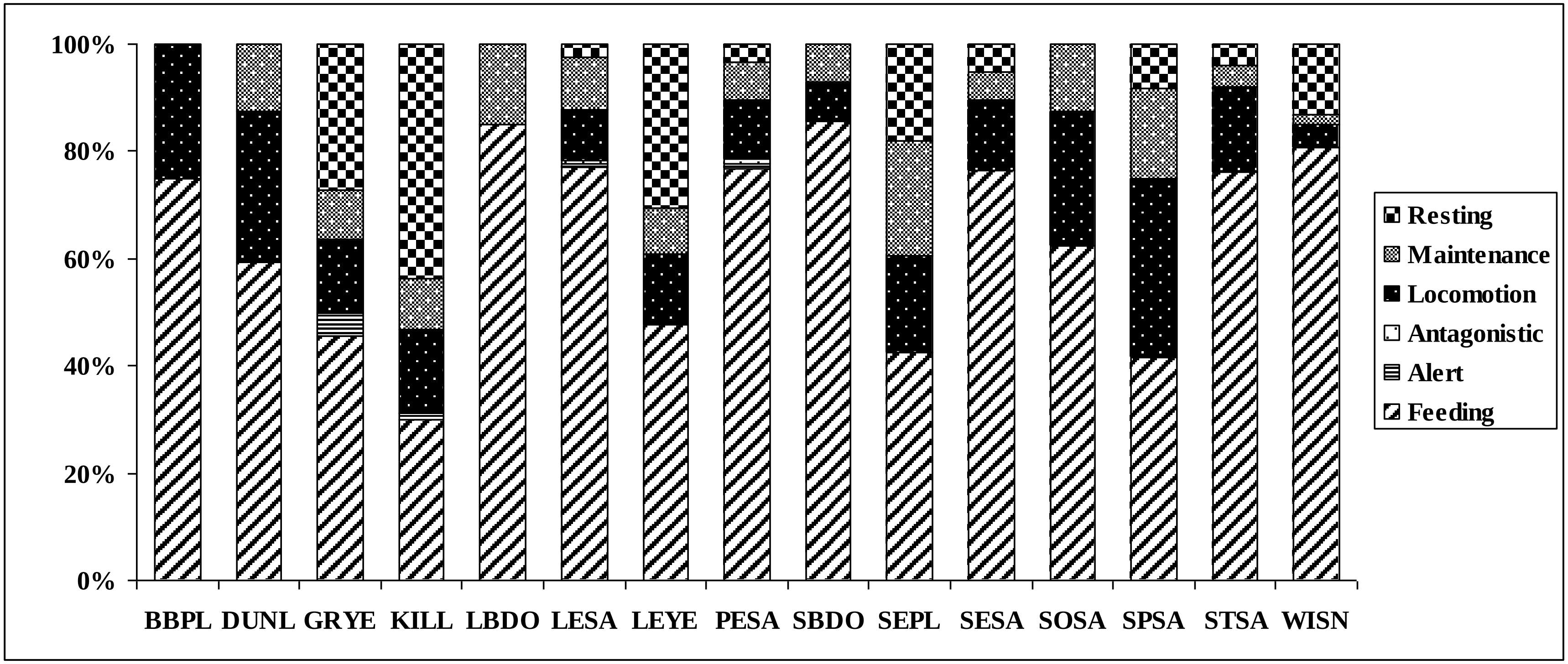

Figure 29. Percent occurrence of activities exhibited by shorebirds using mudflats in Kentucky Reservoir, Tennessee River Valley from August – December 2006 and 2007. BBPL = black-bellied plover (*Pluvialis squatarola*), DUNL = dunlin (*Calidris alpina*), GRYE = greater yellowlegs (*Tringa melanoleuca*), 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*), SBDO = short-billed dowitcher (*Limnodromus griseus*), SEPL = semipalmated plover,

Figure 29. (continued).

(*Charadrius semipalmatus*), SESA = semipalmated sandpiper (*Calidris pusilla*), SOSA = solitary sandpiper (Tringa solitaria), SPSA = spotted sandpiper (*Actitus macularius*), STSA = stilt sandpiper (*Calidris himantopus*), and WISN = Wilson's snipe (*Gallinago delicata*).

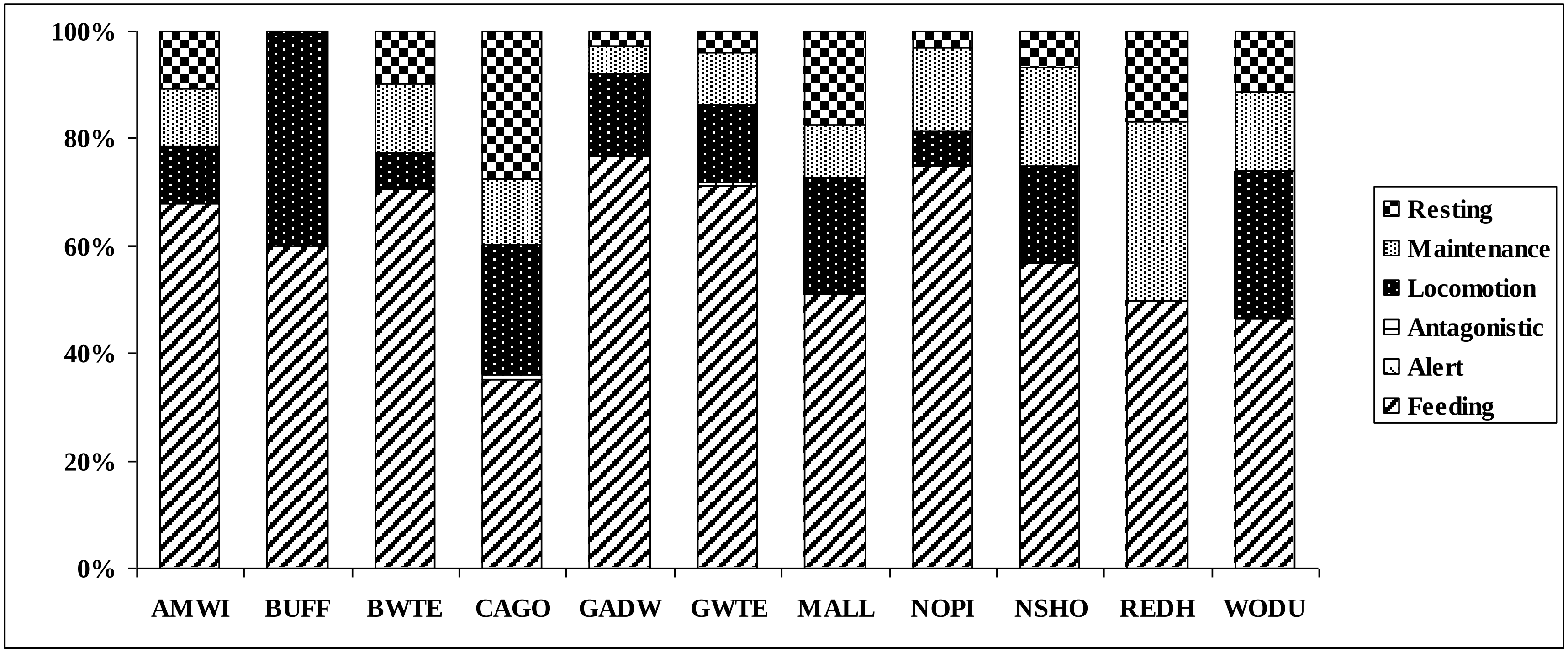

Figure 30. Percent occurrence of activities exhibited by waterfowl using mudflats in Kentucky Reservoir, Tennessee River Valley from August – December 2006 and 2007. AMWI = American wigeon (*Anas americana*), BUFF = bufflehead (*Bucephala albeola*), BWTE = blue-winged teal (*Anas discors*), CAGO = Canada goose (*Branta canadensis*), GADW = gadwall (*Anas strepera*), GWTE = green-winged teal (*Anas crecca*), MALL = mallard (*Anas platyrhynchos*), NOPI = northern pintail (*Anas acuta*), NSHO = northern shoveler (*Anas clypeata*), REDH = redhead (*Aythya americana*), and WODU = wood duck (*Aix sponsa*).

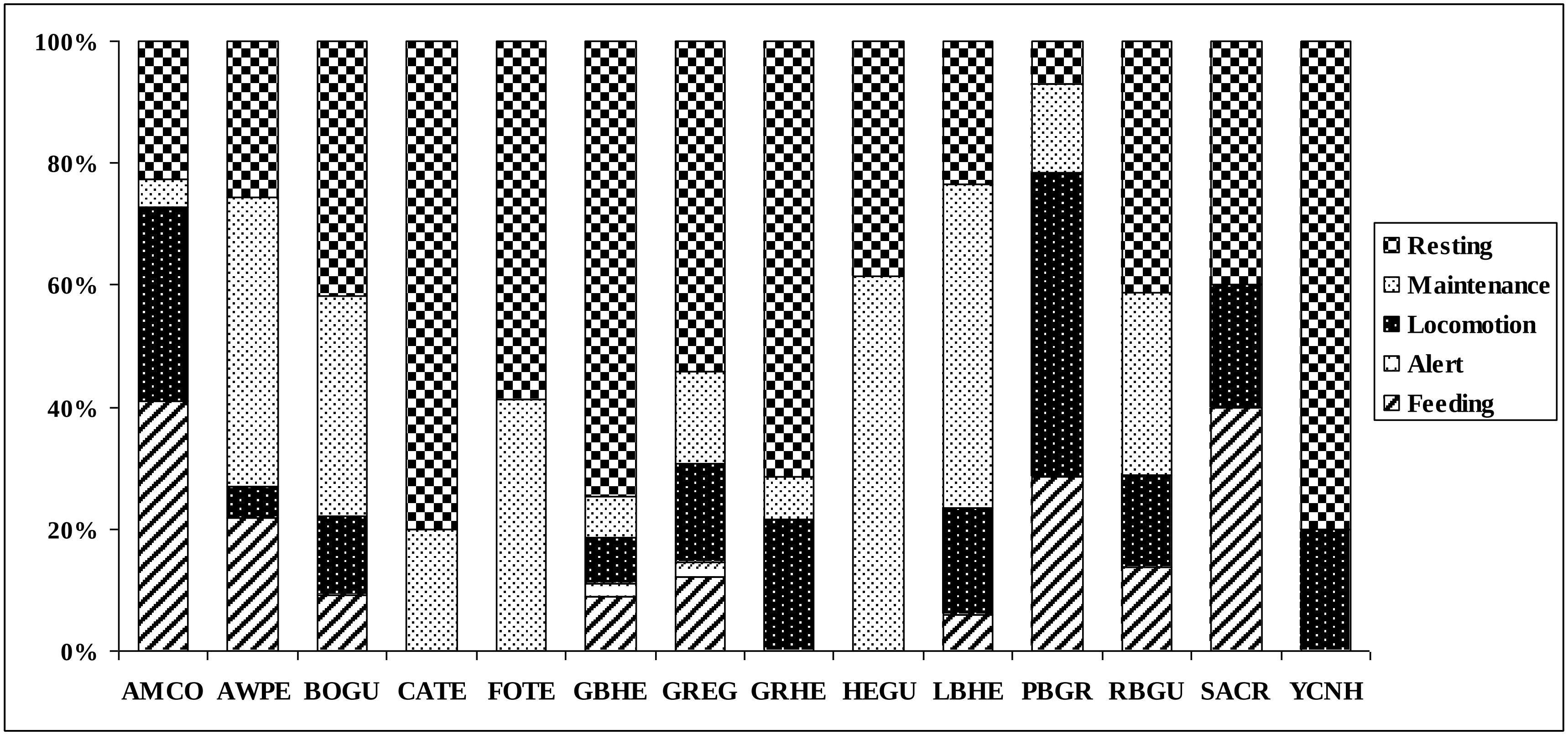

Figure 31. Percent occurrence of activities exhibited by waterbirds using mudflats in Kentucky Reservoir, Tennessee River Valley from August – December 2006 and 2007. AMCO = American coot (*Fulica americana*), AWPE = American white pelican (*Pelicanus erythrorhynchos*), BOGU = Bonaparte's gull (*Larus philadelphia*), CATE = Caspian tern (*Sterna caspia*), FOTE = Forster's tern (*Sterna forsteri*), GBHE = great blue heron (*Ardea herodias*), GREG = great egret (*Ardea alba*), GRHE = green heron

Figure 31. (continued).

(*Butorides virescens*), HEGU = herring gull (*Larus argentatus*), LBHE = little blue heron (*Egretta caerulea*), PBGR = pied-billed grebe (*Podilymbus podiceps*), RBGU = ring-billed gull (*Larus delawarensis*), SACR = sandhill crane (*Grus canadensis*), and YCNH = yellow-crowned night-heron (*Nyctanassa violacea*).

Appendix II. Mudflats and sampling locations in Kentucky Reservoir used in this study, Tennessee River Valley, USA.

Mudflat	Sampling Location	Longitude	Latitude
Eagle Creek N.	Survey	88°7'23.90"	36°25'3.60"
	Veg 1	88°7'23.21"	36°25'10.48"
	Veg 2	88°7'18.16"	36°25'10.65"
	Veg 3	88°7'13.10"	36°25'11.02"
Britton Ford	Survey	88°8'21.11"	36°20'44.84"
	Veg 1	88°8'26.42"	36°20'43.81"
	Veg 2	88°8'21.85"	36°20'42.86"
	Veg 3	88°8'17.52"	36°20'42.31"
Lick Creek	Survey	88°0'35.70"	36°19'25.87"
	Veg 1	88°0'43.43"	36°19'23.94"
	Veg 2	88°0'40.66"	36°19'26.53"
	Veg 3	88°0'38.04"	36°19'29.54"
Big Sandy River	Survey	88°6'18.26"	36°14'35.78"
	Veg 1	88°6'10.59"	36°14'38.88"
	Veg 2	88°6'14.07"	36°14'48.70"
	Veg 3	88°6'16.24"	36°14'56.40"
Beaverdam Creek	Survey	88°1'38.56"	36°3'44.28"
	Veg 1	88°1'51.03"	36°3'44.56"
	Veg 2	88°1'46.13"	36°3'41.68"
	Veg 3	88°1'39.85"	36°3'37.62"
TVA Island	Survey	87°59'54.75"	36°2'32.81"
	Veg 1	87°59'48.85"	36°2'37.25"
	Veg 2	87°59'51.17"	36°2'37.75"
	Veg 3	87°59'53.25"	36°2'38.33"
Cypress Creek	Survey	88°2'37.24"	36°2'7.40"
	Veg 1	88°2'49.10"	36°2'10.29"
	Veg 2	88°2'38.65"	36°2'9.64"
	Veg 3	88°2'29.99"	36°2'9.64"
Duck River	Survey	87°54'53.65"	35°58'3.84"
	Veg 1	87°54'57.52"	35°58'1.28"
	Veg 2	87°55'0.16"	35°57'58.82"
	Veg 3	87°55'2.88"	35°57'56.80"
Eagle Creek S.	Survey	87°57'17.94"	35°55'2.72"
	Veg 1	87°57'33.24"	35°54'58.03"
	Veg 2	87°57'29.43"	35°54'56.05"
	Veg 3	87°57'23.51"	35°54'54.43"

[a]Survey = permanent waterbird survey location; Veg 1, 2, 3 = 1-m^2 plot locations.

Appendix III. Plant species observed on mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

Group	Scientific Name	Common Name
Forb	*Alternanthera philoxeroides* (Mart.) Griseb.	alligator weed
Forb	*Amaranthus tuberculatus* (Moq.) J.D. Sauer	roughfruit amaranth
Forb	*Ammannia coccinea* Rottb.	valley redstem/purple ammania
Forb	*Bacopa rotundifolia* (Michx.) Wettst.	disc waterhyssop
Forb	*Bidens frondosa* L.	devil's beggartick
Forb	*Cardamine pensylvanica* Muhl. Ex Willd.	Pensylanvia bittercress
Forb	*Lindernia dubia* (L.) Pennell	yellowseed false pimpernel
Forb	*Nuphar advena* (Ait.) W.T. Ait.	yellow pond-lilly
Forb	*Polygonum lapathifolium L.*	curlytop knotweed
Forb	*Polygonum pensylvanicum (L.) Small*	Pennsylanvia smartweed
Forb	*Rotala ramosior* (L.) Koehne	lowland rotala
Forb	*Sagittaria calycina* Engelm.	hooded arrowhead
Forb	*Senecio glabellus* Poir.	butterweed
Forb	*Xanthium strumarium* L.	rough cocklebur
Grass	*Eragrostis hypnoides* (Lam.) B.S.P.	teal grass
Sedge	*Cyperus esculentus* L.	chufa flatsedge
Sedge	*Cyperus flavicomus* Michx.	whiteedge flatsedge
Sedge	*Cyperus squarroses* L.	bearded flatsedge
Sedge	*Eleocharis acicularis* (L.) Roem. & Schult.	needle spike rush
Sedge	*Eleocharis obtusa* (Willd) Schult.	blunt spike rush
Sedge	*Fimbristylis vahlii* (Lam.) Link	Vahl's fimbry
Sedge	*Hemicarpha micrantha* (Vahl) G. Tucker	smallflower halfchaff sedge

Appendix IV. Mean end-of-year[a] vegetation biomass (g m^{-2}) produced within 0.305-m mudflat contours in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

	2006				2007			
	Contour 1[b]		Contour 2		Contour 1		Contour 2	
Species	$\bar{x}$ [c]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Alternanthera philoxeroides (Mart.) Griseb.	0.605 A	0.606	0	0	24.557 A	23.589	4.8428 A	4.843
Sagittaria calycina Engelm.	0.973 A	0.938	0.025 A	0.026	0.810 A	0.810	0.002 A	0.003
Cyperus squarroses L.	0.341 A	0.186	0 B	0	0.005 A	0.004	0	0
Eleocharis obtusa (Willd) Schult.	8.316 A	8.087	0.001 A	0.001	0	0	0	0
Cyperus esculentus L.	0.545 A	0.292	0.032 B	0.032	0.006 A	0.004	0.006 A	0.006
Bidens frondosa L.	0.592 A	0.512	0	0	0.735 A	0.585	0	0
Bacopa rotundifolia (Michx.) Wettst.	0.328 A	0.329	0	0	0	0	0	0
Senecio glabellus Poir.	0.003 A	0.003	0	0	0.099 A	0.099	0	0
Rotala ramosoir (L.) Koehne	6.103 A	2.730	0.001 B	0.001	19.596 A	9.517	0.1087 B	0.107
Eleocharis acicularis (L.) Roem. & Schult.	103.452 A	54.825	3.537 B	2.642	49.501 A	28.156	2.199 A	2.199
Cardamine pensylvanica Muhl. Ex Willd.	0.490 A	0.398	0	0	0.288 A	0.247	0	0
Ammannia coccinea Rottb.	3.727 A	3.100	0.046 A	0.047	19.523 A	18.444	0	0
Amaranthus tuberculatus (Moq.) J.D. Sauer	0.454 A	0.454	0.006 A	0.007	0.150 A	0.150	0.355 A	0.355
Xanthium strumarium L.	0	0	0	0	0.376 A	0.288	0	0
Hemicarpha micrantha (Vahl) G. Tucker	0.936 A	0.937	0	0	0	0	0	0
Eragrostis hynoides (Lam.) B.S.P.	1.965 A	1.246	0.003 A	0.002	1.026 A	0.710	0.016 A	0.016
Fimbristylis vahlii (Lam.) Link	2.810 A	2.810	0	0	0.105 A	0.071	0.006 A	0.006
Cyperus flavicomus Michx.	0.057 A	0.057	0	0	0	0	0	0
Lindernia dubia (L.) Pennell	0	0	0	0	1.188 A	0.970	0	0

Appendix IV (continued).

[a]Growing season duration for Kentucky Reservoir (i.e., 26 March – 12 November in Henry County, TN; Natural Resources Conservation Service 2001).

[b]Contour 1 = 108.56 m (356.17 ft) MSL, and contour 2 = 108.36 m (355.5 ft) MSL.

[c]Means within rows followed by unlike letters within years are different ($P \leq 0.05$).

Appendix V. Mean end-of-year[a] seed production (g m^{-2}) within 0.305-m mudflats contours in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

Species	2006				2007			
	Contour 1[b]		Contour 2		Contour 1		Contour 2	
	$\bar{x}$ [c]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Cyperus squarroses L.	0.037 A	0.020	0 B	0	0.023	0.024	0	0
Eleocharis obtusa (Willd) Schult.	0.486	0.417	0	0	0.084	0.068	0	0
Bidens frondosa L.	0.415	0.357	0	0	0.076	0.061	0	0
Eleocharis acicularis (L.) Roem. & Schult.	0.126 A	0.062	<0.001 B	<0.001	0.062	0.046	0	0
Ammannia coccinea Rottb./*Rotala ramosior* (*L*.)	0.733 A	0.317	0 B	0	11.406	9.548	0	0
Xanthium strumarium L.	0	0	0	0	0.705	0.461	0	0
Eragrostis hynoides (Lam.) B.S.P.	0.355	0.244	0	0	0.517 A	0.275	0.003 B	0.003
Fimbristylis vahlii (Lam.) Link	0.784	0.784	0	0	0.047 A	0.04	0.001 A	0.001
Cyperus esculentus L.	0.043	0.043	0	0	0	0	0	0
Hemicarpha micrantha (Vahl) G. Tucker	0.075	0.075	0	0	0	0	0	0
Cyperus flavicomus Michx.	0.003	0.003	0	0	0	0	0	0

[a]Growing season duration for Kentucky Reservoir (i.e., 26 March – 12 November, Henry County; Natural Resources Conservation Service 2002).

[b]Contour 1 = 108.56 m (356.17 ft) MSL, and contour 2 = 108.36 m (355.5 ft) MSL.

[c]Means within rows followed by unlike letters within years are different ($P \leq 0.05$).

Appendix VI. Waterbird species observed using mudflats in Kentucky Reservoir from August – December 2006 and 2007, Tennessee River Valley.

Group	Common Name	Scientific Name
Shorebirds	American avocet	*Recurvirostra americana*
	American golden-plover	*Pluvialis dominica*
	Baird's sandpiper	*Calidris bairdii*
	black-bellied plover	*Pluvialis squatarola*
	buff-breasted sandpiper	*Tryngites subruficollis*
	Wilson's snipe	*Gallinago delicata*
	dunlin	*Calidris alpina*
	greater yellowlegs	*Tringa melanoleuca*
	killdeer	*Charadrius vociferus*
	long-billed dowitcher	*Limnodromus scolopaceus*
	least sandpiper	*Calidris minutilla*
	lesser yellowlegs	*Tringa flavipes*
	pectoral sandpiper	*Calidris melanotos*
	piping plover	*Charadrius melodus*
	sanderling	*Calidris alba*
	short-billed dowitcher	*Limnodromus griseus*
	semipalmated plover	*Calidris pusilla*
	semipalmated sandpiper	*Charadrius semipalmatus*
	solitary sandpiper	*Tringa solitaria*
	spotted sandpiper	*Actitis macularia*
	stilt sandpiper	*Calidris himantopus*
	western sandpiper	*Calidris mauri*
	willet	*Catoptrophorus semipalmatus*
	Wilson's phalarope	*Phalaropus tricolor*
	white-rumped sandpiper	*Calidris fuscicollis*
	ruddy turnstone	*Arenaria interpres*
Waterfowl	American black duck	*Anas rubripes*
	American wigeon	*Anas americana*
	bufflehead	*Bucephala albeola*
	blue-winged teal	*Anas discors*
	cackling goose	*Brana hutchinsii*
	Canada goose	*Branta canadensis*
	gadwall	*Anas strepera*
	greater white-fronted goose	*Anser albifrons*
	green-winged teal	*Anas crecca*
	hooded merganser	*Lophodytes cucullatus*
	lesser scaup	*Aythya affinis*
	mallard	*Anas platyrhynchos*
	northern pintail	*Anas acuta*
	northern shoveler	*Anas clypeata*
	redhead	*Aythya americana*
	ring-necked duck	*Aythya collaris*
	ruddy duck	*Oxyura jamaicensis*

Appendix VI (continued).

Group	Common Name	Scientific Name
	Ross's goose	*Chen rossii*
	snow goose	*Chen caerulescens*
	wood duck	*Aix sponsa*
Other Waterbirds	American coot	*Fulica americana*
	American white pelican	*Pelicanus erythrorhynchos*
	belted kingfisher	*Ceryle alcyon*
	black tern	*Chlidonias niger*
	Bonaparte's gull	*Larus philadelphia*
	Caspian tern	*Sterna caspia*
	common tern	*Sterna hirundo*
	double-crested cormorant	*Phalacrocorax*
	Forster's tern	*Sterna forsteri*
	Franklin's gull	*Larus pipixcan*
	great blue heron	*Ardea herodias*
	great egret	*Ardea alba*
	green heron	*Butorides virescens*
	herring gull	*Larus argentatus*
	horned grebe	*Podiceps auritus*
	laughing gull	*Larus atricilla*
	little blue heron	*Egretta caerulea*
	least tern	*Sterna antillarum*
	pied-billed grebe	*Podilymbus podiceps*
	ring-billed gull	*Larus delawarensis*
	roseate spoonbill	*Platalea ajaja*
	sandhill crane	*Grus canadensis*
	snowy egret	*Egretta thula*
	white-faced ibis	*Plegadis chihi*
	yellow-crowned night-heron	*Nyctanassa violacea*
Other Birds	American crow	*Corvus brachyrhynchos*
	American goldfinch	*Carduelis tristis*
	American kestrel	*Falco sparverius*
	American pipit	*Anthus rubescens*
	bald eagle	*Haliaeetus leucocephalus*
	blue jay	*Cyanocitta cristata*
	black vulture	*Coragyps atratus*
	common grackle	*Quiscalus quiscula*
	Cooper's hawk	*Accipiter cooperii*
	eastern bluebird	*Sialia sialis*
	eastern meadowlark	*Sturnella magna*
	European starling	*Sturnus vulgaris*
	horned lark	*Eremophila alpestris*
	mourning dove	*Zenaida macroura*
	northern flicker	*Colaptes auratus*
	northern harrier	*Circus cyaneus*
	northern rough-winged swallow	*Stelgidopteryx serripennis*

Appendix VI (continued).

Group	Common Name	Scientific Name
	osprey	*Pandion haliaetus*
	peregrine falcon	*Falco peregrinus*
	prothonotary warbler	*Protonotaria citrea*
	red-winged blackbird	*Agelaius phoeniceus*
	tree swallow	*Tachycineta bicolor*
	turkey vulture	*Cathartes aura*
	wild turkey	*Meleagris gallopavo*

[a]Other waterbirds included additional water-dependent species (Weller 1999); other birds were species using mudflats but were not water dependent.

VITA

Drew W. Wirwa, son of Carl and Carol Wirwa, was born in Jackson, Tennessee on 5 January, 1984. He attended elementary school in Alamo and graduated from Crockett County High School in 2002. He received his Bachelor of Science in Natural Resources Management (Wildlife Concentration) from the University of Tennessee, Martin in 2006. He attended the University of Tennessee, Knoxville, where he received his Master of Science in Wildlife and Fisheries Science in May 2009.