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RESEARCH ARTICLE

Postbreeding ecology of wood ducks in the Illinois River Valley

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Abstract

The wood duck (*Aix sponsa*) consistently ranks within the top 5 harvested duck species for both Illinois and the Mississippi Flyway. While substantial research has been done on wood ducks, especially their breeding ecology, few studies have investigated the postbreeding ecology of the species. We captured and marked wood ducks with either a very high frequency (VHF) radio transmitter or a solar-charged global system of mobile communication (GSM) transmitter during the postbreeding period from August through September 2018–2020. Capture locations were within the La Grange Pool of the Illinois River extending from near Pekin, Illinois to the La Grange Lock and Dam near Meredosia, Illinois, USA. We used conventional radio-telemetry techniques to track wood ducks to determine cover type use, home range size, daily movement patterns, survival, and migration chronology. Home range size (95% minimum convex polygon) for wood ducks averaged 6,820 ± 572 ha (SE) and we did not find evidence for a difference by age, sex, or transmitter type. Daily movement distance in August (2,031 ± 51 m) was similar to daily movement distance in September (1,922 ± 44 m), but daily movement distances for August and September were less than daily movement distance for October (3,509 ± 53 m) and November (3,347 ± 106 m). Wood ducks primarily used wetlands with woody (45.0%) and emergent vegetation (40.4%), and the most commonly used wetland types by wood ducks were impounded wetlands (53.8%), lakes (17.6%), and ponds (10.7%). Model-derived survival during the postbreeding period was 0.79 (95% CI = 0.74–0.84). Daily survival was positively related to increased river level and had a mean increase of 4.06 ± 0.67% for every 0.3-m increase in the Illinois River level at low river levels (1.5–3.0 m) and a mean increase of 1.38 ± 0.32% for every 0.3-m increase in the Illinois River level at high river levels (4.0–5.5 m). Average departure date of wood ducks leaving the Illinois River Valley was 27 October (range =13 August–15 December), and adult male wood ducks left the study area 11–16 days earlier than the other age and sex cohorts ($H_2 = 11.6$, $P = 0.01$). Providing additional waterfowl sanctuaries that contain wooded wetlands, especially in years of low river levels, may increase survival for wood ducks during the postbreeding period.

KEYWORDS

Aix sponsa, autumn, departure date, home range, movement, resource use, survival

The wood duck (*Aix sponsa*) is the most abundant breeding duck species in Illinois, USA, and consistently ranks within the top 5 harvested duck species in both the state of Illinois and the Mississippi Flyway (Havera 1999, Raftovich et al. 2020). Because of their importance in the waterfowl harvest and their near extinction in the early twentieth century, wood ducks have been extensively studied and much of the research has involved aspects of wood duck breeding ecology. Such studies have included the use of cavities for nesting (Bellrose et al. 1964, Ryan et al. 1998, Yetter et al. 1999, Roy Nielsen et al. 2007), nest success (Semel et al. 1988, Roy Nielsen and Gates 2007), and brood ecology (Davis et al. 2007, Dyson et al. 2018, Rush 2019). However, despite their consistent and maintained harvest, relatively few studies have investigated the postbreeding ecology of wood ducks, especially in Illinois (Parr et al. 1979, Bellrose and Holm 1994).

The postbreeding period for wood ducks begins at the end of breeding activities and ends when they begin autumn migration (Bellrose and Holm 1994, Baldassarre 2014). The timing of the postbreeding period can vary based on individual breeding status but typically starts at the end of the remigial molt when wood ducks regain flight (Bellrose and Holm 1994). The postbreeding period for waterfowl is important for rebuilding energy reserves that were depleted during breeding and molt for use during autumn migration and overwintering (Hohman et al. 1992). The late summer timeframe of the postbreeding period offers abundant food resources for wood ducks, allowing them to use a wider array of cover types than during other times of the year (Bellrose and Holm 1994).

Wildlife managers need to understand the movement ecology and distribution of the species of interest to make informed decisions about resource management and conservation planning (Legagneux et al. 2009, Yetter et al. 2018). An animal's home range is the area it uses during its normal activities of acquiring needed resources, and the size of an animal's home range can be influenced by a variety of factors including the distribution of food, habitat composition, mate selection, and disturbance (Burt 1943, Bengtsson et al. 2014, Yetter et al. 2018). Previous work during the postbreeding period in Minnesota, USA, found wood ducks generally had smaller home ranges than mallards (*Anas platyrhynchos*) and made infrequent changes to their daily movement routines (Gilmer et al. 1977). Gilmer et al. (1977) also reported that most of the wood ducks in their study had left their study area before the onset of waterfowl hunting season. Parr et al. (1979) reported that postbreeding home ranges for wood ducks during autumn in southern Illinois averaged 91 ha and the maximum distance traveled daily from roosts was 10 km. Similarly, Hein and Haugen (1966) reported a maximum roost flight of 13 km in northeastern Iowa, USA. More detailed information on movement and behavior of wood ducks can improve our understanding of the mechanisms that influence population dynamics (Morales et al. 2010).

Generally, postbreeding wood ducks prefer forested wetlands (Baldassarre 2014). Parr et al. (1979) evaluated wood duck movements and habitat use during autumn in southern Illinois and they noted that the majority of wood duck locations were found in buttonbush (*Cephalanthus occidentalis*) swamp diurnally (75%) and nocturnally (99%). Likewise, woody wetlands and swamps were preferred by postbreeding wood ducks diurnally in northern Alabama, USA (Thompson and Baldassarre 1989) and in southeastern Missouri, USA (Heitmeyer and Fredrickson 1990). Wetlands with emergent vegetation have also been found to be important for wood ducks (Hein and Haugen 1966, Thompson and Baldassarre 1989, Bellrose and Holm 1994). During the postbreeding period, wood ducks can gather in large groups of hundreds or thousands of individuals at roost sites (Baldassarre 2014). Roost sites for wood ducks are characterized by a low canopy of dense cover located in water depths of less than 1.2 m deep, which emergent vegetation can provide (Bellrose and Holm 1994).

Information on when a migratory species departs from its breeding location can be an important tool for waterfowl and wetland managers to inform population management and monitoring efforts (Soulliere and Al-Saffar 2017). The decision for waterfowl to depart from a location on their autumn migration can be initiated by myriad factors (Bellrose and Holm 1994, Schummer et al. 2010, O'Neal et al. 2018). Likewise, there are often differences in migration chronologies among age and sex cohorts within waterfowl species (Bellrose 1980). In wood ducks, adult males tend to migrate earlier during autumn migration than other age and sex cohorts (Gilmer et al. 1977, Bellrose and Holm 1994). Differential migratory timing of age and sex cohorts could influence the amount of time each cohort is exposed to local harvest and could have implications on local population dynamics.

The postbreeding period can be a time when wood ducks are more vulnerable to mortality because of the onset of waterfowl hunting seasons. Shirkey and Gates (2020) analyzed band recoveries from birds banded in Ohio, USA, and found that sex, age, and daily bag limit best-explained survival rates of wood ducks, and harvest rate ranged from 6.9% in adult females to 12.1% in hatch-year males. For many species of ducks, including wood ducks, juvenile birds are more susceptible to harvest than adult birds (Krementz et al. 1987, Metz and Ankney 1991, Bellrose and Holm 1994) and males are more susceptible to harvest than female birds (Bellrose and Holm 1994, Bartzen and Dufour 2017, Shirkey and Gates 2020).

We investigated the postbreeding ecology of wood ducks in the Illinois River Valley (IRV). Our primary objectives were to better understand wetland use, home range size, daily movement patterns, and survival of wood ducks during the postbreeding period. We predicted that 1) daily movement distance and home range size would be similar to that of mallards in the IRV (2,822 m, 21,306 ha; Yetter et al. 2018); 2) wood ducks would use wetlands with either woody or emergent vegetation; 3) survival of wood ducks would be influenced by sex, age, and whether the hunting period was open or closed; and 4) adult male wood ducks would depart for their autumn migration earlier than the other age and sex cohorts of wood ducks.

STUDY AREA

We investigated wood ducks along the La Grange Pool of the IRV extending from near Pekin, Illinois (River Mile 157.7), to the La Grange Lock and Dam (River Mile 80.2) near Meredosia, Illinois (Figure 1). In addition to floodplain wetlands, we also monitored wood ducks on adjacent agricultural lands, tributary streams, and ponds. This segment of the IRV included portions of Cass, Fulton, Mason, Peoria, Schuyler, and Tazewell counties in Illinois. Many

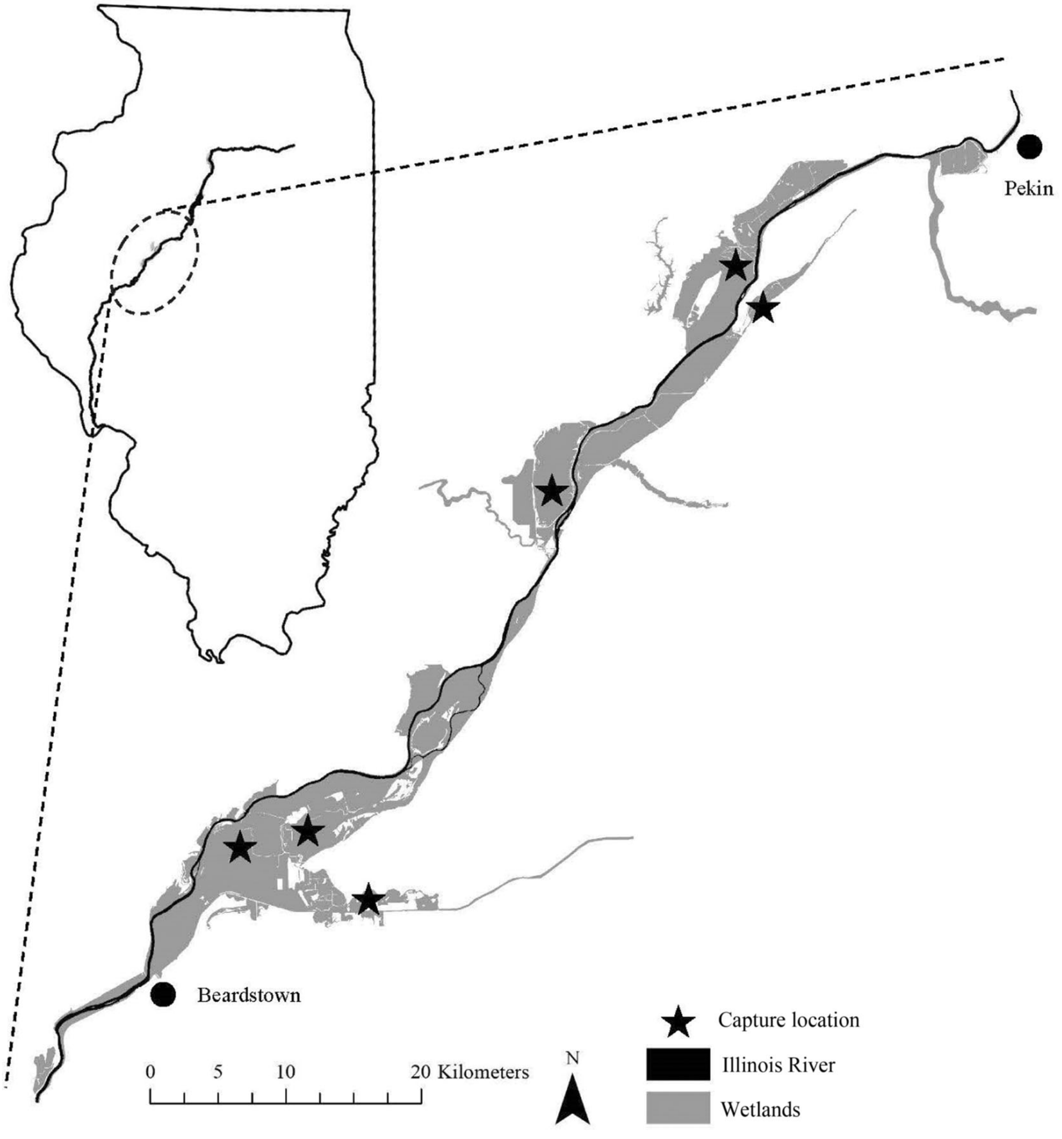

FIGURE 1 Capture locations of wood ducks along the Illinois River in central Illinois, USA, during the postbreeding period (August–December) in 2018–2020.

wetlands within the study area were managed to provide stopover habitat for migratory waterfowl and other waterbirds (Stafford et al. 2010, Yetter et al. 2018). Management of wetlands ranged from areas that allowed private or public access for recreational activities (e.g., waterfowl hunting, boating, fishing, wildlife viewing) to areas designated as sanctuaries where anthropogenic disturbance to waterfowl and other waterbirds were limited (Havera 1999). Our capture locations included The Emiquon Preserve and Rice Lake State Fish and Wildlife Area (SFWA) in Fulton County, Sanganois SFWA and Quiver Creek in Mason County, and Spring Lake SFWA in Tazewell County.

Historically the La Grange Pool was bordered by numerous shallow floodplain lakes and wetlands that contained submersed and emergent aquatic vegetation (Havera 1999). Additionally, other bottomland areas throughout the floodplain contained large tracts of mast-producing hardwoods such as oaks (*Quercus* spp.) and pecans (*Carya illinoensis*; Havera 1999). Because of anthropocentric events since the early twentieth century, many wetlands in the IRV have been modified, degraded, or drained and many are subjected to an extremely variable hydrology (Sparks et al. 1998). Over the duration of the study, river gauge readings ranged from 1.6–5.5 m. Contemporary wetland cover types in the IRV are primarily composed of open water, non-persistent emergent, scrub-shrub, and forested wetlands that are devoid of persistent and submersed aquatic vegetation (Havera 1999, Stafford et al. 2010, Lemke et al. 2017). Wetlands with persistent and submersed aquatic vegetation were only abundant on a small number of wetlands that were disconnected from the Illinois River (Stafford et al. 2010, Hine et al. 2017, Lemke et al. 2017). Additionally, much of the contemporary bottomland forest within the IRV has been replaced by species such as silver maple (*Acer saccharinum*), eastern cottonwood (*Populus deltoides*), green ash (*Fraxinus pennsylvanica*), American sycamore (*Platanus occidentalis*), and willow (*Salix* spp.; Havera 1999).

METHODS

Trapping and telemetry

From August through September of 2018–2020, we captured wood ducks using confusion Y-traps and rocket nets baited with corn (Dill and Thornsberry 1950, Hankla and Smith 1963). We leg banded, aged (adult or juvenile; Carney 1992), sexed (Carney 1992), weighed (±1 g), and took morphological (head, culmen, keel, and tarsus length [±0.1 mm] and wing chord [±1 mm]) measurements of each wood duck. We attached either a 12-g very high frequency (VHF) radio transmitter equipped with an 8-hour mortality switch (Lotek, Newmarket, Ontario, Canada) and mounted on a bib-style necklace constructed of Herculite fabric (Herculite Products, York, Pennsylvania, USA; Montgomery 1985, Ryan et al. 1998, Rush 2019) or a 10.5-g solar-charged global system of mobile communication (GSM) transmitter (Ornitela, Vilnius, Lithuania) with a backpack-style attachment. The backpack attachment was a modified Dwyer design using 6-mm Teflon ribbon with an additional section of ribbon that ran through plastic tubing (outside diameter: 0.6 mm, inside diameter: 0.4 mm, length: ~70 mm) that was positioned along the keel to connect the neck loop to the body loop (Dwyer 1972, Namgail et al. 2011).

We deployed transmitters on birds that were capable of flight and had completed remigial molt. By capturing wood ducks early in the postbreeding period, we focused our capture on birds that had spent the breeding period within our study area, but some wood ducks could have immigrated into the study area prior to capture. However, we do not believe that the inclusion of birds that did not spend the breeding season within the study area would have influenced our conclusions. We released all wood ducks at the capture location on the same day as capture. We attempted to distribute radio-marked wood ducks equally across age (i.e., after hatch year, hatch year) and sex cohorts. We distributed GSM transmitters only in 2019 and 2020 and only on adult birds.

We used truck-mounted, null-peak antenna systems to triangulate radio-marked wood ducks (White and Garrott 1990; Samuel and Fuller 1996; Fuller et al. 2005; Yetter et al. 2009, 2018). We attempted to collect 2 locations per day, 1 diurnal (30 min after sunrise to 30 min before sunset) and 1 nocturnal (30 min after sunset to 30 min before sunrise), 7 days/week, excluding the first day after capture, until all radio-marked birds had left the study area (Yetter et al. 2018). We used a rotating tracking schedule during portions of the postbreeding period when we were unable to locate each bird twice daily because of time constraints. During the rotating tracking schedule, we divided wood ducks into 3 groups and tracked each group 2 out of every 3 days. We conducted aerial searches using fixed-wing aircraft affixed with tracking antennas when we failed to locate an individual from the ground for ≥7 days. We removed individuals from the tracking schedule if they were not located on consecutive aerial searches. We followed up aerial search locations with a confirmation and triangulation from the ground crew during the same day as the aerial search.

We determined locations of wood ducks from azimuths using a global positioning system, digital compass (Cox et al. 2002), and laptop computer using Location of a Signal software (LOAS 4.0.3.8, Ecological Software Solutions, Hegymagas, Hungary). We used the maximum likelihood estimator within LOAS to estimate locations of wood ducks. We calibrated the electronic compasses of the truck-mounted antenna system with beacon transmitters to within 0.5°.

We collected 3 azimuths to reduce error around our location estimates and tracking crews were trained on a beacon transmitter until they achieved azimuth standard deviations of ≤3° (Davis et al. 2009). When needed we collected additional azimuths to reduce error ellipses to within a single vegetation cover and wetland type (Table 1; Williams et al. 2020). For wood ducks affixed with GSM transmitters, we programmed the transmitters to collect locations once an hour, but we reduced the duty cycle of GSM transmitters if battery levels were below 50%. We programmed GSM transmitters on a reduced duty cycle to try to maximize battery life and the number of locations per day, and the lowest duty cycle that we programmed was 2 locations per day. We censored all location data within 200 m of a bait site, as a visual inspection of the location and movement data outside of this buffer did not appear to be influenced by the presence of bait.

Movements and home range

We used point locations to calculate home range size (95% minimum convex polygon) for each wood duck that was present in the study area for at least 37 days and had at least 25 point locations using the mcp function from the

TABLE 1 Vegetation cover type and wetland type descriptions used to classify wood duck locations along the Illinois River in central Illinois, USA, during the postbreeding period (August–December) in 2018–2020.

	Classification	Description
Vegetation cover types	Aquatic bed	Dominated by plants on or below the surface of the water (Cowardin et al. 1979)
	Dry agricultural	Row-crop agricultural fields with <0.2 ha of contiguous water (Williams et al. 2020)
	Wet agricultural	Row-crop agricultural fields with ≥0.2 ha of contiguous water (Williams et al. 2020)
	Emergent vegetation	Dominated by rooted, herbaceous vegetation (Suloway and Hubbell 1994)
	Woody vegetation	Woody vegetation covering ≥30% of the area (Suloway and Hubbell 1994)
	Mudflat	Wet earth composed predominantly of clay- and silt-sized mineral particles (Cowardin et al. 1979)
	Open water	Non-vegetated areas covered by water (Suloway and Hubbell 1994)
Wetland type	Impounded wetland	Wetland surrounded by a levee, dike, or other earthen dam capable of water-level management
	Lake	A topographic depression with ≥8.1 ha of contiguous water (Suloway and Hubbell 1994)
	Pond	A topographic depression with <8.1 ha of contiguous water (Suloway and Hubbell 1994)
	Riverine wetland	Rivers and streams within non-impounded channels (Suloway and Hubbell 1994)
	Ditch	An excavated channel used to transport water
	Bottomland forest	Temporally or seasonally flooded forested wetlands that lack consistent standing water (Suloway and Hubbell 1994)
	Agricultural area	Locations primarily devoted to the production of crops

adehabitatHR package (version 0.4.18; Calenge 2006) in R (version 3.6.0; R Core Team 2020). We selected 37 days as the threshold for including individuals in the home range analysis because it represented 50% of the average time wood ducks spent in the study area before autumn migration. Additionally, we included 25 point locations in the threshold (i.e., 66.6% of 37 days) because the rotating tracking schedule tracked individuals 2 out of every 3 days.

We calculated the Euclidean distance between diurnal and nocturnal point locations to determine movement distances by using the Pythagorean Theorem from estimated point locations (Davis and Afton 2010). When we were able to collect multiple diurnal and nocturnal point locations each day from GSM-tagged ducks, we randomly selected 1 diurnal and 1 nocturnal location each day for movement distance calculation. When possible, we selected night-to-day movements as the daily movement distance, but if a night-to-day movement was not available for a particular 24-hour period, we selected the day-to-night movement.

We first tested for an effect of transmitter type on home range size and daily movement distance using linear mixed models containing transmitter type and year as a random effect and evaluated model support using second-order Akaike's Information Criterion (AIC_c; Akaike 1974) with the AICcmodavg package (version 2.3-1; Mazerolle 2020) in R. We constrained the data in the transmitter type models to only include data from 2019 and 2020 and only from adult birds because we did not use GSM transmitters in 2018 or on juvenile birds. We found no effect of transmitter type, so we combined data from all birds for further models of home range size and daily movement distance. We also used AIC_c to evaluate linear mixed models to determine factors that influenced home range size and daily movement distance. To determine factors that influenced home range size, we evaluated linear mixed models containing additive and interactive combinations of sex and age as fixed effects and year as a random effect. To determine factors affecting daily movement distance of wood ducks, we evaluated linear mixed models including sex, age, and month as fixed effects and year as a random effect. We conducted a square-root transformation to normalize the daily movement distance data. We calculated model weights (w_i) for all models and we considered models within 2 ΔAIC_c units of the highest-ranked model to be competitive (Burnham and Anderson 2002, Arnold 2010). We compared beta estimates of parameters within the top model for overlap in confidence intervals to determine differences in parameters.

Resource use

We determined vegetation cover type use and wetland type use for individual wood ducks by overlaying point locations with National Agricultural Imagery Program imagery (1-m resolution), National Wetlands Inventory, and the Illinois Landcover Database in ArcMap 10.8 (Esri, Redlands, CA, USA). We condensed vegetation cover types into 7 cover types including aquatic bed, dry agricultural, wet agricultural, emergent vegetation, woody vegetation, mudflat, and open water (Table 1). Additionally, we recorded all locations within the emergent vegetation cover type where the dominant vegetation species was American lotus (*Nelumbo lutea*). We also condensed wetland type into 7 wetland types including impounded wetland, lake, pond, riverine wetland, ditch, bottomland forest, and agricultural area (Table 1). We calculated the proportional cover and wetland type use for each of the individuals that were included in the home range analysis and averaged proportions across these individuals to determine the proportional cover and wetland type use by wood ducks (Yetter et al. 2018).

Survival

We combined survival data from all years to use in known-fate models in the RMark package (version 3.0.0; Laake 2013) in R with staggered entry to model daily survival as a function of age (juvenile or adult), sex, hunting period (open [~26 Oct]or closed [~24 Dec]), river level (U.S. Army Corps of Engineers river gauge at Havana, IL), and daily movement distance (Pollock et al. 1989). We excluded individuals from the survival analysis if they died within 24 hours of release or had <5 point locations. We defined the postbreeding period for the survival analysis as

1 August–31 December. We used AIC_c to identify the relative importance of predictor variables on survival (Akaike 1974). We considered single-variable and multivariable models for all predictors. Each multivariable model included age and sex, as we expected these to be sources of variation in survival, and additive combinations of 1 or 2 of the following (hunting period, river level, or daily movement distance). We also considered a global model that included all covariates. We calculated w_i for all models and we considered models within 2 ΔAIC_c units of the top model to be competitive (Burnham and Anderson 2002, Arnold 2010). We calculated the proportion of wood ducks killed by hunters for age and sex cohorts of wood ducks by dividing the number of hunter harvested wood ducks of each cohort by the total number of wood ducks in that cohort at the beginning of the waterfowl hunting season. We classified a wood duck as hunter harvested if the leg band was reported as hunter harvested, the hunter used the contact info on the transmitter to report the bird as harvested, or if we recorded the location of a wood duck at a residence during hunting season. We attempted to contact all hunters that harvested marked wood ducks to confirm cause of death.

Departure dates

We defined an individual's departure date as the last location obtained within the counties comprising our study area. We assumed that VHF birds emigrated from the study area if we were not able to locate them via ground and aerial methods. For GSM birds, we included only individuals for which we confirmed emigration by receiving a location from outside of our study area. We conducted a Kruskal Wallis test with the Dunn's multiple comparisons method using the res.kruskal function from the rstatix package (version 0.7.1; Kassambara 2023) in R to determine if differences occurred in departure dates of wood duck age and sex cohorts.

RESULTS

During August and September 2018–2020, we captured 306 wood ducks (2018: $n = 103$; 2019: $n = 103$; 2020: $n = 100$; Table 2) using confusion Y-traps ($n = 267$) and rocket nets ($n = 39$). We marked 249 wood ducks with VHF transmitters (2018: $n = 103$; 2019: $n = 73$; 2020: $n = 73$) and placed GSM transmitters on 57 wood ducks (2019: $n = 30$; 2020: $n = 27$). We recorded 13,029 point locations (diurnal: 8,367; nocturnal: 4,662) from wood ducks with VHF transmitters and 30,939 point locations (diurnal: 15,791; nocturnal: 15,148) from wood ducks with GSM transmitters.

TABLE 2 The number of very high frequency (VHF) radio transmitters and global system of mobile communication (GSM) transmitters deployed on adult and juvenile wood ducks along the Illinois River in central Illinois, USA, during the postbreeding period (August–December) in 2018–2020.

	VHF				GSM	
	Adult		Juvenile		Adult	
	Male	Female	Male	Female	Male	Female
2018	26	20	30	27	0	0
2019	16	6	27	24	20	10
2020	8	3	31	31	13	14
Total	50	29	88	82	33	24

Movements and home range

We estimated home range size for 228 wood ducks (male: 126; female: 102). The model including transmitter type ($\beta = -14.24 \pm 12.12$, 95% CI = −38.00–9.52) was the best-supported model for determining if there were differences in home range size based on transmitter type (Table 3). However, 95% confidence intervals overlapped zero, so we determined that transmitter type did not influence home range size in wood ducks and combined data from all birds for further analysis. Home range size (95% minimum convex polygon) averaged 6,820 ± 572 ha. An additive combination of sex ($\beta = -4.98 \pm 5.50$, 95% CI = −15.75–5.79) and age ($\beta = 1.44 \pm 6.33$, 95% CI = −11.00–13.86) were included in the best-supported model for wood duck home range size (Table 3). However, 95% confidence intervals for age and sex overlapped zero, so we determined that age and sex did not influence home range size in wood ducks.

We calculated 9,206 daily movement distances of wood ducks. The model including transmitter type ($\beta = -0.53 \pm 0.19$, 95% CI = −0.90 to −0.17) was the best-supported model for determining if there were differences in daily movement distance based on transmitter type (Table 3). Daily movement distance of wood ducks marked with VHF transmitters (2,990 ± 34 m [SE]) was greater than daily movement distance of wood ducks marked with GSM transmitters (2,893 ± 50 m). However, because 97 m was approximately 3% of the daily movement distances of each of the transmitter types, we believed that was not biologically significant and combined all movement data for further analyses. Daily movement distance of wood ducks within the IRV was 2,906 ± 28 m. Month ($\beta = 0.86 \pm 0.05$, 95% CI = 0.76–0.96) was included in the best-supported model for wood duck daily movement distance (Table 3). Daily movement distances in August (2,031 ± 51 m, $\beta = 5.12 \pm 0.36$, 95% CI = 4.40–5.83) and September (1,922 ± 44 m, $\beta = 3.94 \pm 0.24$, 95% CI = 3.47–4.41) were similar. However, daily movement distances in August and September were less than in October (3,509 ± 53 m, $\beta = 2.76 \pm 0.20$, 95% CI = 2.37–3.16) and November (3,347 ± 106 m, $\beta = 1.56 \pm 0.28$, 95% CI = 1.03–2.15).

Resource use

Wood ducks primarily used wetlands with woody (45.0%) and emergent vegetation (40.4%; Table 4). Wood ducks most frequently used wetlands with woody vegetation (56.0%) diurnally and wetlands with emergent vegetation

TABLE 3 Rankings of competitive models ($\Delta AIC_c \leq 2$) and the null according to Akaike's Information Criterion for small sample size (AIC_c), including the number of parameters (K), ΔAIC_c, and model weights (w_i) for predicting wood duck home range size, daily movement distance, and survival along the Illinois River in central Illinois, USA, during the postbreeding period (August–December) in 2018–2020.

Model	Variables	ΔAIC_c	w_i	K
Home range - transmitter type	Transmitter	0.00	1.00	4
	Null	5.91	0.00	3
Home range	Age + sex	0.00	1.00	5
	Null	7.48	0.00	3
Daily movement distance - transmitter type	Transmitter	0.00	1.00	4
	Null	4.49	0.00	3
Daily movement distance	Month	0.00	1.00	4
	Null	258.23	0.00	3
Survival	River level	0.00	1.00	2
	Null	12.55	0.00	1

TABLE 4 Estimates of proportional cover and wetland type use by wood ducks along the Illinois River in central Illinois, USA, during the postbreeding period (August–December) in 2018–2020.

	All locations (%)	Diurnal (%)	Nocturnal (%)
Land cover type			
Woody vegetation	45.0	56.0	27.4
Emergent vegetation	40.4	29.8	57.3
Aquatic bed	10.6	9.8	11.5
Open water	2.9	3.2	2.8
Wet agricultural	0.7	0.7	0.7
Dry agricultural	0.4	0.5	0.2
Mudflat	0.0	0.0	0.0
Wetland type			
Impounded wetland	53.8	50.6	59.1
Lake	17.6	13.1	25.0
Pond	10.7	11.6	9.2
Riverine wetland	8.8	12.8	2.0
Bottomland forest	5.2	6.7	2.5
Ditch	3.4	4.5	1.7
Agricultural areas	0.6	0.8	0.4

(57.3%) nocturnally. Use of American lotus by wood ducks accounted for 57.3% (diurnal: 52.5%, nocturnal: 62.6%) of emergent vegetation cover type use. The most frequently used wetland type by wood ducks was impounded wetland (53.8%), followed by lake (17.6%), pond (10.7%), riverine wetland (8.8%), and bottomland forest (5.2%; Table 4).

Survival

We documented 66 mortalities (2018: 18; 2019: 14; 2020: 34) of 293 wood ducks during the postbreeding period within our study area. The model that included the single variable of river level ($\beta = -0.18 \pm 0.08$, 95% CI = −0.02 to −0.35) was the only competitive model ($\Delta AIC_c \leq 2$; Table 3). Overall survival of wood ducks was 0.79 (0.74-0.84) for the postbreeding period (August–December). Daily survival was positively related to increased river level and had a mean increase of 4.06 ± 0.67% for every 0.3-m increase in the Illinois River level at low river levels (1.5–3.0 m) and a mean increase of 1.38 ± 0.32% for every 0.3-m increase in the Illinois River level at high river levels (4.0–5.5 m, Figure 2). Known hunter harvest accounted for 33 mortalities. The proportion of wood ducks killed by hunters for adults (n = 14) was 11.7% and for juveniles (n = 19) was 12.5%. The proportion of wood ducks killed by hunters for males (n = 18) was 12.0% and for females (n = 15) was 12.3%.

Departure dates

We determined wood duck emigration dates for 190 wood ducks. Mean departure date was 27 October (range = 13 August–15 December), but peak wood ducks emigration from the study area was in early to mid-November

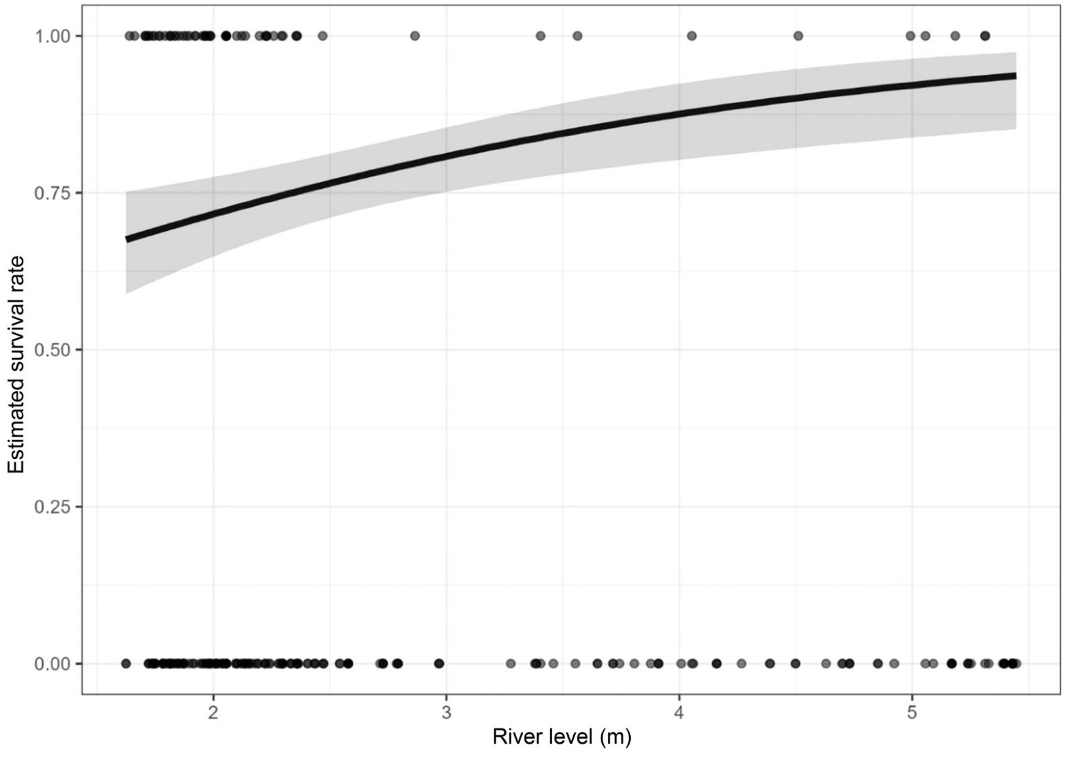

FIGURE 2 Predicted daily survival rates with 95% confidence intervals of wood ducks (n = 293) in relation to river level (U.S. Army Corps of Engineers river gauge at Havana, IL) along the Illinois River in central Illinois, USA, during the postbreeding period (August–December) in 2018–2020.

(Figure 3). Only 7 individuals remained within the study area by December, and the latest wood duck to emigrate from the study area was on 15 December. Departure dates were similar for adult females ($\bar{x}$ = 3 November, median = 6 November), juvenile females ($\bar{x}$ = 31 October, median = 5 November), and juvenile males ($\bar{x}$ = 29 October, median = 5 November), but adult males departed earlier ($\bar{x}$ = 18 October, median = 24 October; H_2 = 11.6, P = 0.01) than the other age and sex cohorts.

DISCUSSION

Daily movement distances of wood ducks (2,906 ± 28 m) during the postbreeding period were similar to that reported by Yetter et al. (2018) for mallards within the IRV (2,822 ± 120 m). However, home range size of postbreeding wood ducks (6,820 ± 572 ha) was much smaller than that of mallards within the IRV (21,306 ± 1,925 ha; Yetter et al. 2018). We observed that wood ducks within the IRV made fewer changes to roost and daytime locations than did previously studied mallards, which likely led to their home ranges being smaller. Similarly, postbreeding wood ducks in north-central Minnesota made fewer changes to roosting sites and daytime locations, which likely led to wood ducks being much less disturbed by hunters than mallards (Gilmer et al. 1977). Large home range sizes and the highly mobile nature of mallards within the IRV were attributed to high hunting pressure that caused mallards to travel more to locate loafing and feeding areas (Yetter et al. 2018). Similar to mallards in the IRV, we observed that daily movements of wood ducks increased later in autumn (Yetter et al. 2018), which may be attributed to a variety of factors including increased disturbance from waterfowl hunting (Yetter et al. 2018),

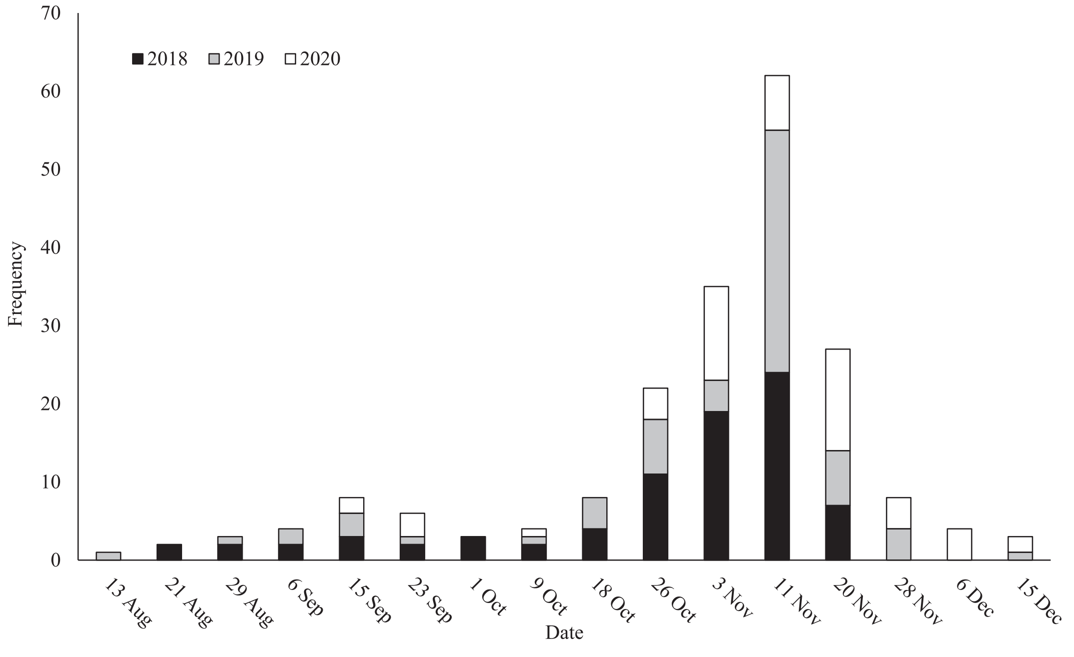

FIGURE 3 Frequency of departure dates of wood ducks emigrating from the Illinois River Valley in central Illinois, USA, during the postbreeding period (August–December) in 2018–2020.

increased food-searching activities from decreasing food availability (Greer et al. 2009), and an increase in migratory disposition from changing photoperiods and weather conditions (Caton 2015).

Postbreeding wood ducks within the IRV primarily used woody or emergent cover types. Other research on autumn wood ducks found similar wetland habitat use (Hein and Haugen 1966, Parr et al. 1979, Thompson and Baldassarre 1989, Heitmeyer and Fredrickson 1990). We found wood ducks primarily used emergent vegetation during the nocturnal period, which is consistent with the wider literature that shows emergent vegetation is important for wood ducks because it can provide a low canopy of dense cover for roosting (Bellrose and Holm 1994). Hein and Haugen (1966) evaluated use of wood duck roosts on the Mississippi River in northeastern Iowa and found that wood ducks principally used emergent vegetation, and Thompson and Baldassarre (1989) found that wood ducks primarily roosted in American lotus beds in northern Alabama. We also found that American lotus beds were commonly used by wood ducks for roosting in the IRV. Within our study area American lotus was generally only found on wetlands that were disconnected from the Illinois River (Hine et al. 2017, Lemke et al. 2017). We found that some wood ducks used wooded wetlands as roost locations, but use of the woody cover type decreased by approximately 50% between diurnal and nocturnal periods. Many of the wooded wetlands that were used by wood ducks as roost locations were in wetlands hydrologically connected to the Illinois River. Fluctuations in water depths of these wetlands due to changes in river levels may have made these woody wetlands unsuitable for roosting during autumn because water levels became too deep for preferred roost sites (Bellrose and Holm 1994).

Ponds also appeared to be important to wood ducks within our study area. We found that many locations that were classified as ponds were also classified as having aquatic bed vegetation. Within the IRV, submersed aquatic vegetation was typically only found within wetlands that were disconnected from the Illinois River (Hine et al. 2017, Lemke et al. 2017). Wood ducks may have used ponds because of the submersed aquatic vegetation present in many of them, which can produce high-quality and diverse food resources for waterfowl (Bowyer et al. 2005, Baldassarre and Bolen 2006, Gross et al. 2020). Anecdotally, many of these ponds also appeared to be in locations that received less human disturbance (e.g., hunting, fishing) than many of the other wetland types within our study area. Additional research may be necessary to assess wood duck response to human disturbance across different wetland types in the IRV.

There are few published survival estimates of wood ducks during the postbreeding period for comparison to our estimates (0.79 [0.74-0.84]). Annual survival rates of wood ducks derived from band recoveries have been reported at 0.41–0.55 in the Mississippi Flyway and 0.39–0.62 in the Atlantic Flyway (Johnson et al. 1986, Shirkey and Gates 2020). Gilmer et al. (1977) reported that 5 of 45 (11%) radio-marked female wood ducks were killed during the postbreeding period in north-central Minnesota. However, unlike wood ducks in the IRV, many of these wood ducks began their autumn migrations before the start of the waterfowl hunting season (Gilmer et al. 1977). Survival of mallards during the autumn in the IRV ranged from 0.39 to 0.62 and most deaths (70–85%) were attributed to hunting (Yetter et al. 2018), whereas we attributed only half of IRV wood duck mortalities to hunting.

We found wood duck survival increased as river levels increased. For many of the wetlands that are hydrologically connected to the Illinois River and tributary streams, wetland inundation is typically influenced by the level of the Illinois River (Havera 1999). Low river levels generally correspond to drought conditions and low inundation of floodplain wetlands and high river levels generally correspond to flood conditions and greater inundation. We believe that wood duck survival was lower during times of low river levels because many of the floodplain wetlands were dry during these times and there was an overall lower amount of habitat for wood ducks. With wood ducks confined to lower overall amounts of habitat, they were likely more concentrated in wetlands and may have been more susceptible to predation and harvest mortality.

We predicted that age and sex would be important in influencing the survival of wood ducks during the postbreeding period, but these variables were not included in competitive models. For many duck species, including wood ducks, research has shown that generally juvenile birds are harvested at a greater rate than adults (Krementz et al. 1987, Metz and Ankney 1991, Bellrose and Holm 1994, Thompson et al. 2022) and males are harvested at a greater rate than females (Bellrose and Holm 1994, Bartzen and Dufour 2017, Shirkey and Gates 2020). However, the proportion of wood ducks killed by hunters within the IRV was similar for both age (adult: 11.7%; juvenile: 12.5%) and sex (male:12.0%; female:12.3%) cohorts. We recognize that this harvest estimate was likely negatively biased because of undocumented crippling loss. However, crippling loss was likely equal for all age and sex cohorts. Therefore, because age and sex cohorts were harvested at a similar rate, it appeared harvest was not disproportionately affecting any age or sex cohort of wood ducks within the IRV.

Bellrose and Holm (1994) used band returns to determine that adult male wood ducks left the IRV approximately 10 days earlier than the other age and sex cohorts for their autumn migrations. Our results corroborated these findings, and we found that adult male wood ducks left the IRV approximately 11–16 days earlier than females and juvenile males. Although adult male wood ducks departed the IRV earlier than the other age and sex cohorts, the proportion of harvested wood ducks was similar between the age and sex cohorts. Within the IRV, waterfowl hunting season began 24–27 October. The pattern of males being harvested at a greater rate than females may not have occurred during our study because a greater proportion of males had left the IRV ($\bar{x}$ = 18 October, median = 24 October) before the onset of waterfowl hunting season. We acknowledge that our methods for determining departure dates of VHF individuals could not differentiate between emigration events and transmitter failure. However, because of the number of VHF transmitters that we confirmed to be functioning from hunter-harvested birds, we do not believe that transmitter failure occurred at a high enough level to influence our conclusions.

MANAGEMENT IMPLICATIONS

Cover types such as emergent vegetation and aquatic bed appear to be important for providing foraging and roosting locations for postbreeding wood ducks in the IRV. We recommend the restoration of wetlands within the IRV that promotes the growth of emergent and aquatic bed vegetation communities, which provide foraging and roosting areas for wood ducks (Hine et al. 2017, Lemke et al. 2017). We also found that survival of wood ducks decreased with decreasing river levels. We suggest that, if possible, managers should provide waterfowl sanctuaries that contain wooded wetlands, especially in years of low river levels when that cover type is less available within the IRV.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

Our methods complied with all United States Fish and Wildlife Service, Illinois Department of Natural Resources (W18.6079, W19.6079, and W20.6079A), and University of Illinois guidelines on the ethical treatment of animals (protocols 15032 and 17278) and were authorized for use by our United States Federal Bird Banding Permit (23923).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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