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Radio-transmitters have no impact on survival of pre-fledged American Woodcocks

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ABSTRACT. American Woodcocks (*Scolopax minor*) are a high priority species of conservation need across most of their breeding range due to long-term population declines. Survival of juveniles may be key to understanding these population declines, but there have been few direct estimates of juvenile woodcock survival rates, and no recent assessment of the possible effect of radio-tagging on juvenile survival. In 2011 and 2012, we radio-tagged 73 juvenile American Woodcocks in west-central Minnesota and compared survival rates of radio-tagged ($N = 58$) and non-radio-tagged ($N = 82$) juveniles during the period from hatching to fledging. We compared survival rates of juveniles with known fates and used logistic-exposure models to assess the potential impact of radio-transmitters on survival. We evaluated variables related to juvenile survival including age, hatch date, maximum and minimum temperature, precipitation, and year to assess the possible effects of radio-transmitters. The best-supported model of survival rate of juvenile American Woodcocks included the interaction of age and year and a negative effect of precipitation ($\beta = -0.76$, 85% CI: -1.08 to -0.43), but did not include a negative effect of transmitters. Our results suggest that radio-transmitters did not impact survival of juvenile American Woodcocks and that transmitters are a reliable tool for studying survival of juvenile American Woodcocks, and perhaps other precocial shorebirds.

RESUMEN. **Los radio transmisores no tienen ningún impacto en la supervivencia de *Scolopax minor* previo a su salida del nido**

Scolopax minor es una especie con alta prioridad de conservación a través de la mayoría de su rango de reproducción, debido al declive de sus poblaciones a largo plazo. La supervivencia de juveniles puede ser la clave para comprender estos declives poblacionales, sin embargo, hay pocas estimaciones directas de las tasas de supervivencia de juveniles de *Scolopax minor* y, no hay existen determinaciones recientes sobre si el uso de radio trasmisores en juveniles influencian la supervivencia. En 2011 y 2012, instalamos radio transmisores en 73 individuos juveniles de *Scolopax minor* en el oeste-central de Minnesota y comparamos la supervivencia de juveniles con ($N = 58$) y sin ($N = 82$) radio transmisores, a lo largo del periodo desde la eclosión hasta su salida del nido. Comparamos la supervivencia de los juveniles con destinos conocidos y utilizamos modelos de exposición logística con el fin de determinar el impacto potencial de los radio transmisores en la supervivencia. Evaluamos variables relacionadas a la supervivencia juvenil, incluyendo edad, fecha de eclosión, temperatura máxima y mínima, precipitación y año para determinar los posibles efectos de los radio transmisores. El modelo con mayor soporte sugiere que la supervivencia de los juveniles de *Scolopax minor* esta influenciado por, la interacción entre la edad y el año y negativamente por la precipitación ($\beta = -0.76$, 85% IC: -1.08 hasta -0.43); sin embargo, no incluyo un efecto negativo de los transmisores. Nuestros resultados sugieren que los radio transmisores no tienen un impacto sobre la supervivencia de los juveniles de *Scolopax minor* y que los transmisores son una herramienta confiable para estudiar la supervivencia de juveniles de *Scolopax minor* y quizás de otras aves playeras precociales.

Key words: juvenile survival, logistic-exposure, radio telemetry, *Scolopax minor*, transmitter effect

Radio-telemetry is commonly used to estimate survival rates of birds (e.g., Ackerman et al. 2014, Blomberg et al. 2014) and it is often assumed that radio-marking does not impact survival of marked individuals (Amundson and Arnold 2010). However, if attachment of

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radio-transmitters impacts survival, estimates of vital rates resulting from radio-telemetry studies will be biased. As a result, effects of radio-transmitters must be critically analyzed (e.g., Amundson and Arnold 2010, Streby et al. 2013) in evaluations of survival based on individuals marked with radio-transmitters.

Based on singing-ground surveys, American Woodcocks (*Scolopax minor*; hereafter, woodcocks) have experienced significant long-term (1968–2014) declines in population across their breeding distribution (Cooper and Rau 2014). These apparent declines in population are coupled with declines in recruitment (indexed via juvenile/adult female ratios derived from wing-collection surveys; Cooper and Rau 2014), suggesting that juvenile survival could be key to understanding the decline. However, there have been few direct estimates of the survival rates of juvenile woodcocks and previous survival-rate estimates based on telemetry studies (e.g., Horton and Causey 1981, Wiley and Causey 1987) involved the use of transmitters weighing ~10 times more than those currently available. Moreover, the possible impact of transmitters on the survival of juvenile woodcocks in previous studies was not critically evaluated.

We deployed radio-transmitters on juvenile woodcocks as young as 2 d post-hatching and assessed factors related to survival rate during the period from hatching to fledging (15 d for woodcocks). Because juvenile survival rates are usually lowest after hatching and increase with age, marking younger juveniles provides a more complete assessment of daily and period survival than marking older juveniles and offers the opportunity to account for accumulating effects of transmitters over time (Streby et al. 2013). We also radio-tagged and tracked adult female woodcocks, which allowed us to locate and determine the fates of unmarked juveniles. By determining fates of radio-tagged and non-radio-tagged juvenile woodcocks, we tested for effects of radio-transmitters on survival rates of juvenile woodcocks and evaluated other covariates that could potentially influence survival that were related to attributes of broods and environmental conditions (e.g., weather). Based on published estimates of the survival rates of juvenile woodcocks (Gregg 1984, Wiley and Causey 1987, Derleth and Sepik 1990, McAuley et al. 2010), we expected survival rates to increase with age and be negatively impacted by cold, wet, spring weather.

METHODS

We conducted our study from April to July 2011 and 2012 on the Tamarac National Wildlife Refuge (NWR; coordinates: 47°2′N, 95°7′W) in Becker County, Minnesota. Timber harvest, brushland shearing, and prescribed fire programs on Tamarac NWR have sustained early successional forest cover, which is primary breeding, nesting, and brood-rearing habitat for woodcocks (McAuley et al. 2013). Woodcocks are early-spring migrants to northern breeding latitudes, with adult females often re-nesting after losing a nest or brood, but only raising one brood to independence per year. Female woodcocks regularly produce clutches of four eggs in initial nesting attempts, with subsequent nesting attempts having clutches of three eggs or less (McAuley et al. 1990).

We used mist-nets (Avinet, Inc., Dryden, NY) to capture woodcocks during the period from ~18:30 to 22:00 CDT, when woodcocks leave diurnal areas to roost or feed, and male woodcocks perform aerial display flights (Sheldon 1955, 1960, 1971). We aged and sexed woodcocks based on plumage characteristics (Martin 1964) and radio-marked adult females with 5.0-g transmitters (Advanced Telemetry Systems, Isanti, MN) attached with backpack-style harnesses (McAuley et al. 1993a, b; transmitter and harness = ≤3% of female mass). We tracked females using standard ground-based telemetry for 5–7 d per week throughout the breeding, nesting, and brood-rearing periods. When relocating radio-marked woodcocks, we assessed their status (alive or dead) and, during the brood-rearing period, counted the number of juveniles present to estimate survival of unmarked juveniles.

We also radio-marked a sample of juveniles in broods of radio-marked adult females. During the brood-rearing period, we used trained pointing dogs (Ammann 1977, McAuley et al. 1993a) to find additional broods that we subsequently captured and radio-marked. We fitted randomly selected juveniles with collar-type micro-transmitters (BD-2NC or BD-2C, Holohil Systems Ltd., Carp, ON, Canada, and custom transmitters made by Blackburn Transmitters, Nacogdoches, TX) with whip antennas.

Transmitters were ≤3% of juvenile mass and the Holohil transmitters included an elastic collar designed to stretch as juveniles grew. We attached elastic loops made from 1-mm-diameter black craft elastic cord (Kid's Jewelry 1-mm D elastic cord, Shanghai, China) to the Blackburn transmitters to mimic the attachment of the Holohil transmitters. Based on the neck circumference of each juvenile, we custom-fit an elastic collar that we then slipped over the juvenile's head and positioned at the base of the neck with the transmitter antenna protruding down the juvenile's back.

We radio-marked one to four juveniles (usually two) per brood and monitored the entire brood by locating radio-marked juveniles. We attempted to locate broods using standard ground-based telemetry 5–7 d per week by tracking either adult females with transmitters or juveniles with transmitters. After locating a brood, we observed each individual from a distance using binoculars to assess any possible negative impacts of radio-transmitters (e.g., entanglement in the elastic collar or feather or skin wear). We assessed status (alive or dead) of juveniles and broods and counted both marked and unmarked juveniles to document brood size. Beginning around 15 d post-hatching, entire broods often flushed as we approached radio-marked woodcocks, providing the opportunity to determine brood size.

Statistical analysis—survival covariates. For each juvenile woodcock monitored, we measured or derived covariates to use in developing survival models, including a transmitter covariate, continuous covariates for age (days), hatch date (julian date), total period precipitation (cm), minimum temperature (°C), maximum temperature (°C), and a categorical covariate for year (2011 or 2012). We estimated age by either knowing hatch date or using the equation presented by Sepik (1994) based on bill length. Because intervals between relocations of individual broods were short (usually 2–3 d), we assigned the age of a juvenile as the midpoint of the interval between consecutive relocations. We estimated hatch date by either monitoring nests of radio-marked females or by aging juveniles when captured and back-dating to date of hatching (hatch date = Julian date − age).

We obtained daily weather data from precipitation gauges and digital temperature loggers at Tamarac NWR during 2011 and 2012. If weather data were not available for Tamarac NWR, we used weather data from the nearest National Weather Service station in Detroit Lakes, Minnesota (~22 km southeast of Tamarac NWR). We used the sum of daily precipitation (cm) for each day in the interval between observations to calculate total interval precipitation. We used the recorded maximum and minimum temperatures during each interval between observations. We included year in our models of survival to account for temporal variation and included it as a class variable in models of juvenile survival.

Survival models. We used the logistic-exposure method (Shaffer 2004) to evaluate effects of radio-transmitters on survival rates of juvenile woodcocks and assess relationships between survival rate and factors we hypothesized to be related to survival. We developed a set of models of juvenile survival rate during the first 15 d following hatch *a priori* and evaluated models using a stepwise approach (sensu Amundson and Arnold 2010) in an information-theoretic framework (Burnham and Anderson 2002).

A major assumption of known-fate models is that survival of individuals in a brood is independent of other members of the brood. However, mortality of entire broods may result in non-independence of survival between and among brood mates (Chouinard and Arnold 2007, Amundson and Arnold 2010). We used Winterstein's (1992) second Chi-squared goodness-of-fit test to evaluate intra-brood independence of juveniles with the null hypothesis that survival of individuals in broods was independent.

We considered two base models that incorporated the linear-logistic function of age and year because survival varied between years: (1) age + year and (2) age × year, where + and × denote additive versus factorial relationships between covariates. We identified models best-supported by our data based on Akaike's Information Criteria with a correction factor for small samples sizes (AICc; Burnham and Anderson 2002). We defined competing models as the model with the lowest AICc value (top model, ΔAICc = 0) and any models with ΔAICc compared to the top model ≤ 2. We considered covariates uninformative if they did not lead to a net reduction in ΔAICc when added to the best-supported model (i.e., did not reduce overall ΔAICc by ≥0; Arnold 2010).

After identifying the best-supported model of juvenile survival rate incorporating age and year, we added brood-specific covariates to account for additional variation in the data. These brood-specific covariates included hatch date and year × hatch date. We used the logit function to transform hatch date into a continuous variable. We included the interaction of hatch date and year (2011 or 2012) as a covariate in models because annual changes in temperature and precipitation affect the timing of woodcock breeding (Gregg 1984, McAuley et al. 2010). We retained these covariates in models of juvenile survival if their inclusion led to a net reduction in AICc (ΔAICc reduction of >0).

We added weather covariates to the best-fitting model of juvenile survival rate that incorporated age, year, and brood-specific covariates to account for effects of weather conditions on survival of juvenile woodcocks. These covariates included total period precipitation, maximum temperature, and minimum temperature, and we treated these as continuous variables in models of survival rate. We retained covariates in models of survival rate if their inclusion led to a net reduction in AICc (ΔAICc reduction of > 0).

Finally, we added a covariate to indicate whether juvenile woodcocks were radio-marked (TRANS) to the best-supported model that incorporated age, year, brood-specific, and weather covariates. Using TRANS as an additive covariate allowed us to evaluate radio-transmitter effects across all ages and years equally (Amundson and Arnold 2010). We retained TRANS in survival models if its inclusion led to a net reduction in AICc (ΔAICc reduction of > 0).

Survival rate estimates. We used the Kaplan-Meier method with staggered entry (Pollock et al. 1989) using the KMsurv package in Program R (version 2.15.2, R Core Team, 2012) to estimate survival rates of juvenile woodcocks for days 1–15 post-hatching. We recorded the number of days from when transmitters were deployed on juveniles to better censor individuals if radio-transmitters failed prematurely. We assumed transmitters failed if they performed irregularly and there was no indication the individual had died. We also assumed transmitters failed if they were nearing the end of their projected battery life and we subsequently were unable to detect the signal from the transmitter. We right-censored individuals in both of these circumstances, assuming the individual survived until transmitter failure (Korschgen et al. 1996). We assumed a juvenile died if brood counts indicated a juvenile(s) was absent from the brood on two consecutive counts.

RESULTS

During 2011 and 2012, we radio-marked 73 (2011: $N = 22$, 2012: $N = 51$) juvenile woodcocks from 51 broods (2011: $N = 16$, 2012: $N = 35$). We knew fates of 49 transmitter-marked and 79 unmarked juveniles from 45 broods from our sample of marked juveniles and by tracking transmitter-marked adult females with broods. We were unable to ascertain fates of 24 marked juveniles due to uncertain times of transmitter failure and we censored these individuals from analyses.

We observed no apparent negative impacts (e.g., entrapment in radio harness, or skin or feather wear) of radio-transmitters on juvenile woodcocks during our study. We found no evidence of dependence among juveniles in the same broods ($\chi^2_{44} = 17.2$, $P = 0.99$) so we treated the fate of all individuals in our sample as independent. Our best-supported model of juvenile woodcock survival rate included the interaction of age × year and the additive effect of total precipitation (Table 1). Precipitation had a negative relationship with juvenile survival rate ($\beta_{precipitation} = -0.76$, 85% CI: -1.08 to -0.43). Although TRANS, minimum temperature, and maximum temperature all appeared in survival models competitive with our best-supported model ($\Delta AIC_c \leq 2$), these variables were uninformative because they did not decrease the overall AIC_c by ≥ 2 when they were added as an additional covariate (Arnold 2010). Therefore, we did not consider models including these covariates to be competitive with our best-supported model. We found no evidence to suggest that either TRANS or hatch date influenced survival of juvenile woodcocks (Table 1).

The effect of the age × year interaction was approximately zero in 2011 ($\beta_{YR\times AGE}$ for 2011 $= -0.01$), but was positive in 2012 ($\beta_{year\times age}$ for 2012 $= 0.12$). Cumulative survival of juvenile woodcocks to 15 d of age based on Kaplan-Meier survival estimates was 0.746 (95% CI: 0.646 – 0.862) in 2011 and 0.843 (95% CI: 0.762 – 0.933) in 2012.

Table 1. Models of the survival rate of juvenile American Woodcocks at Tamarac National Wildlife Refuge, Rochert, Minnesota, in 2011 and 2012. We evaluated survival related to age (AGE; 1–15 d), year (YR; 2011 or 2012), hatch date (HD; Julian date), precipitation (PCPT), maximum and minimum temperature (MAXT and MINT), and the presence or absence of transmitters (TRANS). Models were ranked according to the difference in Akaike's information criterion (ΔAIC_c) corrected for small effective sample size ($N = 1041$ intervals), Akaike model weights (ω_i), and number of estimable parameters (K).

Model[a]	ΔAIC_c	ω_i	K
(YR × AGE) + PCPT	0.00	0.38	4
(YR × AGE) + PCPT + MINT	1.36	0.19	5
(YR × AGE) + PCPT + TRANS	1.78	0.16	5
(YR × AGE) + PCPT + MAXT	1.91	0.15	5
(YR × AGE) + PCPT + MAXT + MINT	3.06	0.08	6
(YR × AGE)	6.97	0.01	3
(YR × AGE) + HD	7.30	0.01	4
(YR × AGE) + MINT	7.83	0.01	4
YR + AGE	8.12	0.01	3
(YR × AGE) + MAXT	8.54	0.01	4
(YR × AGE) + MAXT + MINT	8.88	0.00	5
(YR × AGE) + (YR × HD)	8.98	0.00	5

[a]AIC_c of top-ranked model = 182.01.

DISCUSSION

We found that attaching small (considerably smaller than those used in previous studies) radio-transmitters using elastic harnesses to juvenile woodcocks did not negatively affect survival rate, indicating that currently available radio-transmitters can be used to estimate survival rate of juvenile woodcocks without bias. Furthermore, our transmitter-attachment methods and materials appeared to have no negative impacts on the survival rates of juvenile woodcocks because we observed no obvious signs of distress, and our best-supported models of survival rate did not include the covariate TRANS.

Of the weather and brood-specific covariates we considered, only total precipitation was related to the survival rate of juvenile woodcocks when we accounted for age and temporal variation (age and year) in models of survival rate. Precipitation, especially periods of extreme precipitation, was negatively related to survival rate of juvenile woodcocks. Precipitation likely limits the ability of juvenile woodcocks to thermoregulate and may especially impact precocial birds (Sheldon 1971, Owen 1977, Pietz et al. 2003). Sheldon (1971) and Owen (1977) suggested that periods of adverse weather (e.g., precipitation) can cause significant mortality of juvenile woodcocks. Rabe et al. (1983) suggested that, due to growth requirements of juvenile woodcocks, weather-related stress has the greatest potential to limit survival rates during the brood-rearing period. We did not assess a precipitation × age interaction in our models of survival rate, but the negative relationship between juvenile woodcock survival rate and precipitation likely decreases with juvenile age because older juveniles are better able to thermoregulate and have developed plumage that provides more protection from wet and cold conditions.

In our study, survival rates of juvenile woodcocks during the 15-d period from hatch to fledging was higher in 2012 than in 2011. Compared to 2011, 2012 was warmer, with less precipitation during the brood-rearing period. Although we attributed most juvenile mortality to predation, we could not distinguish between mortality of marked juvenile woodcocks resulting directly from predation and those resulting from exposure where the juvenile was subsequently consumed by a predator. As a consequence, we were unable to determine if the apparent negative effect of precipitation on survival rates of juvenile woodcocks resulted from exposure, increased efficiency of predators in wet conditions, or perhaps different predator densities and predation pressure between years.

There are potential limitations to extrapolating our conclusions beyond our study. Although we selected juvenile woodcocks to fit with radio-transmitters randomly within broods, our sample of broods may have been biased because some broods in the larger population in our study area may have been more likely than others to be included in our sample due to possible biases in our efforts to find broods with pointing dogs. Pointing dogs generally searched near edges, a habitat thought to be frequently used by woodcock broods, which may have biased our sample against broods using other habitats. If juveniles in the broods we marked had higher or lower survival rates than juveniles in broods in the entire population of broods in our study area, our estimates of survival rate could be biased. In addition, bias in survival rate estimates could result from radio-marking older juveniles (closer to 15 d old) because older individuals may have a higher survival probability than juveniles marked at an earlier age. However, we minimized this potential source of bias by including the best-supported combination of age and year in all of our models of survival rate.

Overall, our results suggest that the transmitters and the attachment methods we used had little or no negative effect on survival rates of juvenile woodcocks during the period from hatching to fledging, which we assumed was when juveniles are most vulnerable to mortality due to capture stress and deploying transmitters. Consistent with other studies of survival rates of juvenile woodcocks (and other precocial birds), survival rates varied by year and age and were negatively related to precipitation during the brood-rearing period. By employing methods similar to ours, we believe investigators can obtain unbiased estimates of survival rates and a better understanding of factors related to survival rates of juvenile woodcocks (and likely other shorebirds and precocial birds).

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