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SURVIVAL OF RADIO-MARKED MALLARD DUCKLINGS IN SOUTH DAKOTA

JOSHUA D. STAFFORD[1,3,4] AND AARON T. PEARSE[2]

ABSTRACT.—Numerous researchers have investigated survival of Mallard (*Anas platyrhynchos*) ducklings, but few have modeled survival of ducklings radio-marked at hatch relative to time-dependent factors. We estimated survival of 48 radio-marked ducklings for two study sites (Oakwood and Mickelson) in eastern South Dakota during summers 1998–1999. Our best-approximating model of survival indicated duckling age, study site, precipitation, and the interaction of study site and precipitation influenced survival. Survival of ducklings to 30 days was 0.42 at Oakwood (95% CI, 0.13–0.67) and 0.77 at Mickelson (95% CI, 0.42–0.92). Duckling mortality was 31.9 and 1.6 times more likely for each 1 cm of precipitation at Oakwood and Mickelson, respectively. We suggest this difference was partially attributable to greater cover of emergent vegetation at Mickelson, which potentially reduced body heat loss via evaporative cooling. Our best model also indicated daily survival increased with duckling age. Models containing daily minimum temperature received little support ($w_i \leq 0.01$) indicating the covariate had negligible influence on daily survival of ducklings. *Received 7 September 2006. Accepted 12 February 2007.*

Duckling survival may critically influence Mallard (*Anas platyrhynchos*) recruitment in the Prairie Pothole Region (PPR) of North America (Cowardin and Johnson 1979, Johnson et al. 1987, Sayler and Willms 1997), potentially accounting for 14% of variation in the finite population growth rate (Hoekman et al. 2002). Cowardin et al. (1985), in an intensive study of Mallard breeding ecology in the late 1970s, identified duckling survival as one of the least understood components of recruitment. Several researchers have estimated Mallard duckling survival in the PPR since this pioneering work (e.g., Talent et al. 1983, Rotella and Ratti 1992, Sayler and Willms 1997, Gendron and Clark 2002).

Duckling survival is commonly estimated by radio-marking females prior to hatch and periodically relocating the female and brood to count number of ducklings surviving. However, assumptions must be made to use this method. Duckling counts may be inaccurate (Orthmeyer and Ball 1990, Mauser et al. 1994, Davis et al. 1999) due to secretive behavior of females and ducklings during brood rearing (Sedinger 1992:121). Ducklings are known to leave their natal brood and join other broods (i.e., brood mixing; Mauser et al. 1994), and ducklings absent from a count must be assumed dead. Similarly, if the brood female dies, the entire brood is assumed dead, but ducklings can survive independently or mix with another brood even at a relatively young age (Davis et al. 1999, Stafford et al. 2002); however, when considered, such instances do not bias survival estimates (Flint et al. 1995). Advances in telemetry equipment have allowed radio-marking of individual neonate ducklings (Mauser and Jarvis 1991). Despite these advantages, few published studies have reported survival of radio-marked day-old Mallard ducklings (Krementz and Pendleton 1991; Mauser et al. 1994; Howerter et al. 1996; Stafford et al. 2002; Krapu et al. 2004, 2006). Only Krapu et al. (2004, 2006) examined survival relative to time-dependent covariates (e.g., daily temperature).

Modeling survival based on factors thought to influence duckling mortality has been a natural extension of earlier estimation efforts. Researchers have examined many covariates, but factors influencing duckling survival and associated effect sizes have varied among studies. Stafford et al. (2002) modeled the proportion of ducklings within broods surviving to ≥20 days post-hatch using brood counts in relation to coarse-scale covariates where the best model explained only 26% of the variation in survival. Predation was identified or

[1] South Dakota State University, Wildlife and Fisheries, NPB 142B, Brookings, SD 57007, USA.

[2] Department of Wildlife and Fisheries, Box 9690, Mississippi State University, Mississippi State, MS 39762, USA.

[3] Current address: Illinois Natural History Survey, Bellrose Waterfowl Research Center, Forbes Biological Station, P. O. Box 590, Havana, IL 62644, USA.

[4] Corresponding author;
e-mail: stafford@inhs.uiuc.edu

suspected in only 42% of radio-marked duckling mortalities (Stafford et al. 2002:331) and several mortalities appeared to coincide with exposure to weather events (i.e., cold nights or heavy rains; Stafford 2000). Stafford et al. (2002) did not model survival of radio-marked ducklings using fine-scale weather variables with the potential to explain unidentified mortality agents. The objectives of our study were to: (1) use recently developed survival estimation techniques (i.e., Rotella et al. 2004) to model variation in survival of Mallard ducklings radio-marked at two study sites in eastern South Dakota during 1998–1999, and (2) relate our results to previous findings for other areas of North America.

METHODS

Study Areas.—We studied duckling survival within the Coteau des Prairie physiographic region of eastern South Dakota (Johnson et al. 1995, Johnson and Higgins 1997). The Prairie Coteau is a highland region between the Minnesota–Red River Lowland and James River Lowland. It is characterized by large numbers of wetlands and is used extensively by breeding and staging waterfowl.

Our study areas consisted of the Mickelson Memorial Wetland (hereafter Mickelson), a 400-ha marsh in southern Hamlin County (44° 36′ 00″, 96° 58′ 00″), and the Oakwood lakes complex (hereafter Oakwood) comprised of 2,330 ha of wetlands and adjacent uplands in northern Brookings County (44° 26′ 30″, 96° 59′ 00″).

Mickelson was a class IV (semipermanent) hemi-marsh (Stewart and Kantrud 1971) with extensive interspersed emergent cover consisting mostly of cattail (*Typha* spp.). Water control structures at Mickelson allowed water level manipulation, although stable levels were maintained during the study period. Few other wetlands were present near Mickelson. Oakwood was a mixture of class III (seasonal) and IV wetlands surrounding two large class V (permanent) lakes (Stewart and Kantrud 1971). Class IV wetlands were predominant due to abundant precipitation prior to and during the study period. Some bays of the two permanent lakes exhibited class IV characteristics. Most wetlands at Oakwood contained peripheral emergent vegetation of cattail, bulrush (*Schoenoplectus* spp.), and common reed (*Phragmites australis*).

Data Collection.—All broods in our study were hatched from overwater nesting structures (Stafford et al. 2002). We checked structures starting 10 May 1998–1999 for active Mallard nests and ascertained incubation stage by egg candling (Weller 1956). We returned to nests on the predicted hatch date to radio-mark ducklings. We selected two ducklings per brood at random and fitted them with modified Mauser subcutaneous prong and suture transmitters (Mauser and Jarvis 1991). Transmitters weighed 1.5 g with a range of 0.8 km and a battery life of ≥30 days (Advanced Telemetry Systems, Isanti, MN, USA). We fitted ducklings without transmitters with plasticine-filled aluminum leg bands (Blums et al. 1994, 1999), and captured and fit all attending hens (i.e., with or without radio-marked ducklings) with a 4.5-g radio transmitter attached via a subcutaneous prong and sutures (Pietz et al. 1995, Stafford et al. 2002).

We followed radio-marked ducklings to their brood-rearing wetland after they departed the nesting structure and sought locations daily using handheld Yagi and truck mounted null-peak antennas. We confirmed survival of ducklings (i.e., they were moving) via multiple triangulations or walking in with handheld equipment when visual observations could not be obtained. Survival of Mallard ducklings generally stabilizes by 30 days (Rotella and Ratti 1992, Mauser et al. 1994); thus, we monitored ducklings until 30 days post-hatch, loss of contact, or mortality.

We monitored ducklings most intensively from sunrise to 1000 hrs CDT and from 1800 hrs until dark, because waterfowl broods are most active during those times (Beard 1964, Ringelman and Flake 1980). We investigated status of radio-marked ducklings immediately if they were not close to the female to maximize the possibility of identifying timing and cause of mortalities. We examined duckling carcasses and the immediate vicinity of carcasses for signs of depredation. If we were uncertain of the specific day of mortality we used the last date the duckling was known to be alive to compute the survival interval in subsequent analyses.

Survival Estimation and Modeling.—Stafford et al. (2002) placed radio transmitters on

58 ducklings at 1-day post hatch during their study period. We censored 10 of those ducklings for our analysis; eight of these were marked at a third study site, of which all died, providing no variation in survival for modeling. We excluded the two other ducklings because of unverifiable inconsistencies in data recording. We estimated duckling survival to 30 days post-hatch using the nest survival model in program MARK (White and Burnham 1999, Dinsmore et al. 2002). This approach allowed us to model duckling survival as a function of group- (e.g., study site) and time-specific (e.g., daily precipitation) covariates. We used the nest survival model in MARK because the exact date of mortality was not known for all ducklings. This procedure only required an interval within which a duckling died instead of an exact date of mortality (White and Burnham 1999). The nest survival model estimated relationships of daily survival rates to covariates using a logit link function (Dinsmore et al. 2002). Daily survival rate (DSR) of a duckling on day *i* was modeled as:

$$\mathrm{DSR} = \frac{\exp\left(\beta_0 + \sum_j \beta_j x_{ij}\right)}{1 + \exp\left(\beta_0 + \sum_j \beta_j x_{ij}\right)},$$

where x_{ij} were values for j covariates on day i, and β_j are coefficients estimated from the data (Rotella et al. 2004).

We identified best approximating and competing models using Akaike's Information Criterion corrected for small sample size and overdispersion ($Q\mathrm{AIC}_c$) (Burnham and Anderson 1998; Anderson et al. 2000, 2001). We attempted to correct for overdispersion to account for dependence in survival among brood mates (*sensu* Flint et al. 1995, Dinsmore et al. 2002). However, the nest survival model in program MARK did not have developed goodness-of-fit tests (Dinsmore et al. 2002). Thus, we computed the overdispersion coefficient ($\hat{c}$ = 1.38) by dividing the deviance by degrees of freedom from the model with most parameters (S. J. Dinsmore, pers. comm.). We recognize that estimating $\hat{c}$ from deviances may not be valid if deviances were not Chi-square distributed (White and Burnham 1999). Program MARK ranked models from least to greatest $Q\mathrm{AIC}_c$, and calculated the simple difference between the best approximating model and competing models (Δ_i), and respective model weights (w_i) (Burnham and Anderson 1998, Anderson et al. 2001).

Covariates.—We developed a set of *a priori* candidate models intended to explain variation in Mallard duckling survival and included four covariates in our candidate set. We interpreted importance of covariates by calculating 95% confidence intervals about parameter estimates or odds ratios (i.e., back-transformed parameter estimates).

1. Study site (SITE). The Mickelson and Oakwood study areas differed with respect to wetland size, vegetative cover, water permanency, and wetland density (Stafford 2000). Stafford et al. (2002) estimated duckling survival, based on periodic brood counts, was greater at Mickelson than at Oakwood. We hypothesized survival would differ between study sites and included SITE as a group effect in 7 of 12 duckling survival models.

2. Precipitation (PRECIP). Precipitation has been associated with mortality of radio-marked Canvasback (*Aythya valisineria*), Gadwall (*Anas strepera*), and Mallard ducklings (Korschgen et al. 1996, Pietz et al. 2003, Krapu et al. 2006). Pietz et al. (2003) and Krapu et al. (2006) coded precipitation as a binary variable (0 = no rain, 1 = rain), but we hypothesized that amount of rainfall would negatively influence survival in a continuous fashion. We used precipitation data (cm/day) from the weather station nearest each study site (Castlewood, South Dakota for Mickelson [16.7 km from site]; Brookings, South Dakota for Oakwood [19.6 km from site]) as a time-dependent continuous covariate in analyses.

3. Temperature (TEMP). Minimum temperature was negatively associated with survival of radio-marked Gadwall, Canvasback, and Mallard ducklings (Korschgen et al. 1996, Pietz et al. 2003, Krapu et al. 2006). We hypothesized that cold temperatures could predispose ducklings to attrition from cold stress, reduced food availability and growth or increased vulnerability to predation due to restricted mobility (Korschgen et al. 1996). We included daily low temperature (°C) obtained from the weather station nearest the study area

TABLE 1. Model selection results for survival of radio-marked Mallard ducklings in eastern South Dakota including the number of estimable parameters (K), -2 log likelihood score ($-2\log(L(\hat{\theta}))$), quasi-likelihood second order Akaike's information criterion ($QAIC_c$), model weight (w_i), and quasi-likelihood deviance score (QDeviance).

Model	K	$-2\log(L(\hat{\theta}))$,	$QAIC_c$	$\Delta QAIC_c$	w_i	QDeviance
$S_{SITE+AGE+PRECIP+SITE*PRECIP}$	5	143.81	114.07	0.00	0.70	104.00
$S_{SITE+AGE+PRECIP}$	4	150.75	117.06	2.99	0.16	109.02
$S_{SITE+AGE}$	3	155.12	118.20	4.13	0.09	112.18
S_{AGE}	2	162.22	121.33	7.26	0.02	117.31
$S_{AGE+PRECIP}$	3	159.63	121.47	7.40	0.02	115.44
$S_{AGE+TEMP}$	3	161.88	123.10	9.03	0.01	117.07
$S_{SITE+PRECIP+SITE*PRECIP}$	4	159.97	123.73	9.66	0.00	115.68
$S_{SITE+PRECIP}$	3	166.24	126.25	12.18	0.00	120.22
S_{SITE}	2	169.32	126.46	12.39	0.00	122.45
$S_{SITE+PRECIP+TEMP}$	4	165.87	128.00	13.93	0.00	119.95
$S_{(.)}$	1	178.75	131.27	17.21	0.00	129.27
S_{PRECIP}	2	177.58	132.43	18.36	0.00	128.42
S_{TEMP}	2	178.48	133.09	19.02	0.00	129.07

as a continuous time-dependent covariate in some duckling-survival models.

4. Duckling age (AGE). An assumption of the nest survival model is that daily survival rates are constant over time, but this may not be realistic. For example, duckling survival may be least during the first week post-hatch (Talent et al. 1983, Cox et al. 1998, Gendron and Clark 2002, Hoekman et al. 2004). Therefore, we hypothesized that survival likely increased as age of ducklings increased and included daily duckling age as a covariate in some models of duckling survival to control for the effect of this possible relationship.

RESULTS

We included 48 radio-marked ducklings from 24 broods in survival analyses (n = 22 [Mickelson] and 26 [Oakwood]). The best approximating model was 3.0 $QAIC_c$ units from the second-best model, accounted for 70% of the w_i, and included the main effects of AGE, SITE, and PRECIP, as well as an interaction between SITE and PRECIP (Table 1). This model indicated that ducklings were 31.9 (95% CI, 4.0–251.6) times more likely at Oakwood and 1.6 (95% CI: 0.3–9.6) times more likely at Mickelson to die for each 1 cm increase in daily precipitation ($\bar{x}$ = 0.1, range: 0.0–6.8 cm/day), although the latter confidence interval about the odds ratio included 1. Additionally, this model indicated that duckling survival increased with AGE ($\hat{\beta}_{AGE}$ = 0.13, SE = 0.05; 95% CI = 0.04–0.22). Based on the best approximating model, survival to 30 days was 0.77 (95% CI, 0.42–0.92) and 0.42 (95% CI, 0.13–0.67) at Mickelson and Oakwood, respectively (0.62 overall). Daily low temperature occurred in the sixth best model (TEMP; $\Delta QAIC_c$ = 9.03 [Table 1]; range: 1–21° C), and the 95% confidence interval about the parameter estimate included zero ($\hat{\beta}_{TEMP}$ = −0.03, SE = 0.07; 95% CI = −0.17–0.10).

DISCUSSION

Precipitation negatively influenced duckling survival based on our best approximating model, but the effect was weaker at Mickelson than Oakwood (Table 1). Precipitation may influence duckling survival by increasing the energy demand of thermoregulation via evaporative cooling (Bakken et al. 1999). This increased energy expenditure may have sublethal effects leaving ducklings more susceptible to predation (Korschgen et al. 1996, Pietz et al. 2003). Thus, the possible effect of precipitation on survival in our study may be conservative. Pietz et al. (2003) documented a relationship between survival of Gadwall ducklings and an interaction between rain events occurring within 2 days of mortality and temperature, where the greatest survival was observed when conditions were warm (>10° C) and without rain. We cannot directly compare the effect of precipitation on duckling mortality with these findings because our covariates were scaled differently, and our best approximating model did not include an interaction with temperature.

The negative effect of precipitation was markedly stronger at Oakwood. Broods at Mickelson used a large (400 ha) semipermanent marsh with interspersed emergent vegetation (~60% cover; Stafford et al. 2002), whereas ducklings at Oakwood spent most days on wetlands with <25% emergent cover (Stafford et al. 2004). It is possible precipitation had little influence on survival at Mickelson due to extensive emergent cover, which provided better thermoregulatory conditions during rain events. Wetland vegetation may reduce heat loss in Mallard ducklings due to wind (Bakken et al. 1999). We speculate increased cover might reduce heat loss from evaporative cooling by lessening exposure to precipitation. Alternatively, previous research indicated that rain events may inhibit emergence of chironomid larvae, an important food source for Mallard ducklings (Nelson 1989). This situation may be especially important if ducklings require increased energy to maintain homeothermy during cool, wet periods.

As hypothesized, results of our best model indicated duckling survival was positively associated with AGE. Indeed, the relationship between duckling survival and increasing age is well documented (Talent et al. 1983, Orthmeyer and Ball 1990, Mauser et al. 1994, Cox et al. 1998). Our inclusion of AGE in models addressed an assumption of the survival model (i.e., constant daily survival) and effectively controlled a source of variation in duckling survival, similar to the use of a covariate in analysis of covariance.

Korschgen et al. (1996), Davis (2001), Pietz et al. (2003), and Krapu et al. (2006) reported negative influences of precipitation, colder temperatures, or both on survival of radio-marked ducklings. Previous modeling efforts either categorized temperature above and below some threshold (e.g., 10° C; Pietz et al. 2003) or averaged minimum temperatures for the exposure day and two previous days (Davis 2001, Krapu et al. 2006). Our models including temperature may not be directly comparable with previous findings. However, we found that temperature within the range observed in this study did not considerably influence daily survival.

Stafford et al. (2002) attributed 58% of deaths of radio-marked ducklings to unknown causes and speculated these deaths were caused by exposure. We found precipitation events negatively influenced daily survival of ducklings; therefore, exposure due to precipitation events may have accounted for a large proportion of unknown and total mortalities. If tenable, this result is in contrast to findings from other duckling survival studies, where predation was the leading cause of death for Mallard ducklings in northeastern California (90%; Mauser et al. 1994) and North Dakota (89%; Krapu et al. 2004), Wood Duck (*Aix sponsa*) ducklings in Mississippi (81%; Davis 2001), and Gadwall ducklings in North Dakota (86%; Pietz et al. 2003). Furthermore, Pearse and Ratti (2004) found that 30-day Mallard duckling survival was 1.6 times greater on sites where mammalian predator density was experimentally reduced. Our situation was not entirely unique; Krementz and Pendleton (1991) also attributed few (16%) mortalities of radio-marked Mallard ducklings to predation on Chesapeake Bay.

Our results are not subject to the assumptions necessary for studies where only brood females were marked, but certain assumptions and caveats must be made. All ducklings in our study hatched in overwater nesting structures. Our estimates may be biased high in comparison to ducklings hatched from upland nests if the length of the initial overland movement adversely affects survival of Mallard ducklings (Ball et al. 1975, Rotella and Ratti 1992; but see Talent et al. 1983, Dzus and Clark 1997, Gendron and Clark 2002). Duckling survival also may be influenced by radio-marking (Pietz et al. 2003, Krapu et al. 2004). Krapu et al. (2004) increased 30-day duckling survival rates by 0.16 to account for transmitter effects. Stafford et al. (2002) detected no difference in survival between radio-marked and unmarked ducklings within years and sites, and we detected no difference in survival between radio-marked and unmarked ducklings when years and sites were pooled (χ^2_1 = 0.86, P = 0.353). Thus, we did not account for transmitter effects in the current analysis and our survival rates may be considered conservative if transmitters negatively influenced survival.

Duckling survival was greater at a site with extensive interspersed emergent vegetation, possibly the result of reduced thermoregulatory stress. Management for interspersed emergents was possible at Mickelson because water control structures allowed for periodic drawdown. Placement of water control structures in larger restored wetlands could allow for improved management of emergent cover, but these efforts are costly and perhaps not efficient or predictable in promoting quality brood habitat over a large spatial extent. Thus, we suggest future research to investigate the potential effect of varying amounts and juxtaposition of emergent cover on duckling survival in managed wetlands.

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