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Radio Transmitters did not Affect Apparent Survival Rates of Adult Piping Plovers (*Charadrius melodus*)

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Abstract.—Assessments of possible adverse effects of transmitters on marked individuals is an important component of individual-based tracking studies, particularly for species that are listed under the U.S. Endangered Species Act. The breeding and post-breeding movements of adult Piping Plovers (*Charadrius melodus*) from the federally-threatened Atlantic Coast Population were studied by gluing miniature, 1.0-g, digital VHF radio-transmitters on their interscapular region. Mark-resighting data from 2015-2018 was used to estimate apparent survival rates for 289 adult Piping Plovers in Massachusetts, Rhode Island, and New Jersey in order to compare survival estimates between individuals with a transmitter attached and control individuals without a transmitter. Cormack–Jolly–Seber models were used for live-encounter data in a Bayesian framework to estimate apparent survival rates based on resightings of uniquely marked individuals. There was no evidence that mean apparent survival rates differed between adults with transmitters (0.756; 95% CI = 0.611 – 0.877) and without transmitters (0.673; 95% CI = 0.607 – 0.740). In addition, there was no evidence of differences in apparent survival rates between breeding location (state) or years. This study provides further evidence that radio transmitters glued temporarily to the inter-scapular region can be an effective tool to monitor local and regional movements of sensitive shorebirds, such as Piping Plovers. *Received 19 December 2018, accepted 10 April 2019.*

Key words.—apparent survival, *Charadrius melodus*, Piping Plover, researcher effect, transmitter.

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Radio telemetry has been used successfully to study the movement ecology of shorebirds for decades (Warnock and Warnock 1993; Warnock and Takekawa 2003). Despite their widespread application, transmitters can have potential negative impacts on survival rates, reproductive success, and behavior of birds (Calvo and Furness 1992; Murray and Fuller 2000; Barron *et al.* 2010). Therefore, researchers need to be cautious when conducting any telemetry study, particularly for sensitive species, such as those listed as Threatened or Endangered under the U.S. Endangered Species Act.

We studied the breeding and post-breeding movements of the federally-threatened Atlantic Coast Piping Plover (*Charadrius melodus*) in Massachusetts, Rhode Island, and New Jersey by attaching light-weight (≤ 1.0 g) digital VHF tags and tracking locations using automated radio telemetry receivers within the Motus network (Taylor *et al.* 2017), in addition to manual telemetry surveys on the breeding grounds. While previous studies have documented that this species can be sensitive to external devices (Lingle and Sidle 1989; Amirault *et al.* 2006), more recently, researchers have used radio transmitters on Piping Plovers on their wintering range and did not document any adverse impacts (Drake *et al.* 2001; Cohen *et al.* 2006). Additionally, we previously found no evidence that transmitters decreased daily nest survival or chick survival of Piping Plover pairs nesting on the Atlantic Coast (Stantial *et al.* 2018). To our knowledge, the effects of radio-transmitters (hereafter, tags) on apparent survival of Piping Plovers along the Atlantic Coast have not yet been investigated. The objective of this study was to compare yearly apparent survival rates of adult Piping Plovers with tags to control birds without tags, with both study groups having unique field-readable band combinations to monitor interannual resighting rates of individuals.

METHODS

We studied Piping Plovers nesting in Massachusetts, Rhode Island, and New Jersey, USA at 21 nesting sites from 2015-2018. We captured adult Piping Plovers at nests using walk-in funnel and drop traps. We then uniquely marked individuals with either two-colored Darvic leg bands (model XCLD, internal diameter 3.1 mm, AVINET, Dryden, New York) on each tibiotarsus, or a combination of a Darvic leg band on one tibiotarsus and a multi-layered impact acrylic coded flag (internal diameter 3.1 mm, Interrex, Lodz, Poland) on the opposite tibiotarsus, depending on the study site. We attached digital 0.67-g or 1.0-g VHF tags (model NTQB-3-2 or NTQB-4-2, Lotek Wireless, Ontario, Canada) to a random sample of breeding adults, one per nesting pair, from each study site. We attached tags to clipped feathers in the interscapular region using cyanoacrylate glue or epoxy (Warnock and Warnock 1993; Drake *et al.* 2001; Mong and Sandercock 2010), depending on the year and site. Tags had a battery life ranging from 80 to 160 days (depending on year) and were expected to fall off birds within 6 months of initial attachment due to molt and breakdown of the attachment material. We attempted to resight all color-banded birds at each study site at least once per week throughout the nesting season. Observers surveyed transects through all known nesting, roosting, and foraging areas between 06:00 hr and 20:00 hr. For each banded bird encountered, we recorded the band combination of the individual and whether the individual was wearing a tag. Because the sampling occasion of interest was yearly survival, these weekly encounters were then combined to identify 1) whether each banded individual was present during each breeding season and 2) whether a tag was attached during that breeding season.

We used Cormack–Jolly–Seber models for live-encounter data to estimate adult annual apparent survival rate (ϕ) as a function of tag presence, year and state. Tag presence was a time-varying binary covariate, because birds had a tag in some years but not others. We modeled resighting probability (p) as a function of state, to account for different observers and habitat types. We fit the models in a Bayesian framework by specifying models in the BUGS language, with posterior distributions for parameters of interest estimated using Markov Chain Monte Carlo (MCMC) simulation with Gibbs sampling as implemented in JAGS v. 4.3.0 (Plummer 2013) called from program R v. 3.5.1 (R Core Team 2018) via the package jagsUI (Kellner 2015). We used wide non-informative priors for all parameters: a normal distribution with mean 0 and variance 1000 for all coefficients in the linear predictors, and a uniform distribution between 0 - 50 for all variance parameters. We checked for convergence of 3 parallel MCMC chains per model by visually inspecting the trace plots and by using the Gelman-Rubin diagnostic ($\hat{R}$; Gelman *et al.* 2004) and considered convergence to be achieved at < 1.05 for all parameters. We considered covariates to be important predictors if the 95% credible intervals on the regression parameter did not overlap zero (Kuo and Mallick 1998; Link and Barker 2006).

RESULTS

We individually marked and monitored a total of 289 Piping Plovers in Massachusetts, Rhode Island and New Jersey from 2015-2018. We attached a nanotag during one or more field seasons to 181 individuals throughout the duration of this study (Table 1). Of the 85 plovers tagged in Rhode Island, 76 were tagged in one field season, 8 were tagged in two field seasons, and 1 bird received a tag in 3 different field seasons. In Massachusetts, of 59 tagged plovers, 44 were tagged in one field season, 14 in two field seasons, and 1 in three field seasons. In New Jersey, of 39 tagged plovers, 4 plovers received a tag in two different field seasons.

There was no evidence that annual apparent survival rates differed among states, and annual apparent survival was highest in year 2 (Table 2). Mean apparent survival rates were similar for individuals with a tag

Table 1. Total number of adult Piping Plovers (*Charadrius melodus*) that had a digital VHF transmitter and unique color bands (tagged) or had only unique color bands (control) that were marked or detected nesting in three states in USA in 2015-2018.

	Tagged			Control		
Year	MA[a]	RI	NJ	MA	RI	NJ
2015[b]	25	25	22	0	0	18
2016	25	25	21	9	14	53
2017	25	25	0	19	28	68
2018	0	20	0	20	32	73

[a]MA = Massachusetts, RI = Rhode Island, and NJ = New Jersey, USA
[b]Individuals may have been tagged during one or more years of the study and therefore counted as both tagged and control.

Table 2. Summary statistics for posterior distributions of parameter estimates for Cormack-Jolly-Seber survival model for Piping Plovers (*Charadrius melodus*) in 2015-2018 in Massachusetts (MA), Rhode Island (RI), and New Jersey (NJ), USA. Model coefficients are on the logistic scale.

			Quantile		
Parameter	Mean	SD	2.5%	50%	97.5%
Intercepts					
Apparent annual survival (year 1)	0.542	0.327	-0.091	0.0536	1.196
Apparent annual survival (year 2)	0.823	0.282	0.283	0.819	1.391
Apparent annual survival (year 3)	0.235	0.264	-0.272	0.228	0.775
Detection	0.960	0.037	0.863	0.971	0.999
Nanotag coefficient (0 = control, 1 = tagged)					
Apparent annual survival	0.439	0.393	-0.296	0.428	1.249
State coefficients					
Apparent annual survival (NJ)	-0.249	0.281	-0.803	-0.249	0.301
Detection (NJ)	-0.020	0.055	-0.133	-0.019	0.095
Apparent annual survival (RI)	0.638	0.333	0.000	0.633	1.308
Detection (RI)	-0.037	0.055	-0.149	-0.037	0.074

(0.756; 95% CI = 0.611 – 0.877) and control individuals without a tag (0.673; 95% CI = 0.607 – 0.740; Fig. 1).

DISCUSSION

Apparent survival rates of adult Piping Plovers nesting at our sites did not appear to be affected by a ≤ 1.0-g radio transmitter glued to the interscapular region. Although it is not possible to estimate survival of most birds without auxiliary-markers of some kind, apparent survival of banded birds without nanotags in our study was similar or higher than estimates from other Piping Plover populations or sites for after hatching year (AHY) birds. The revised recovery plan for the Atlantic Coast Piping Plover estimated apparent annual survival rates for adults

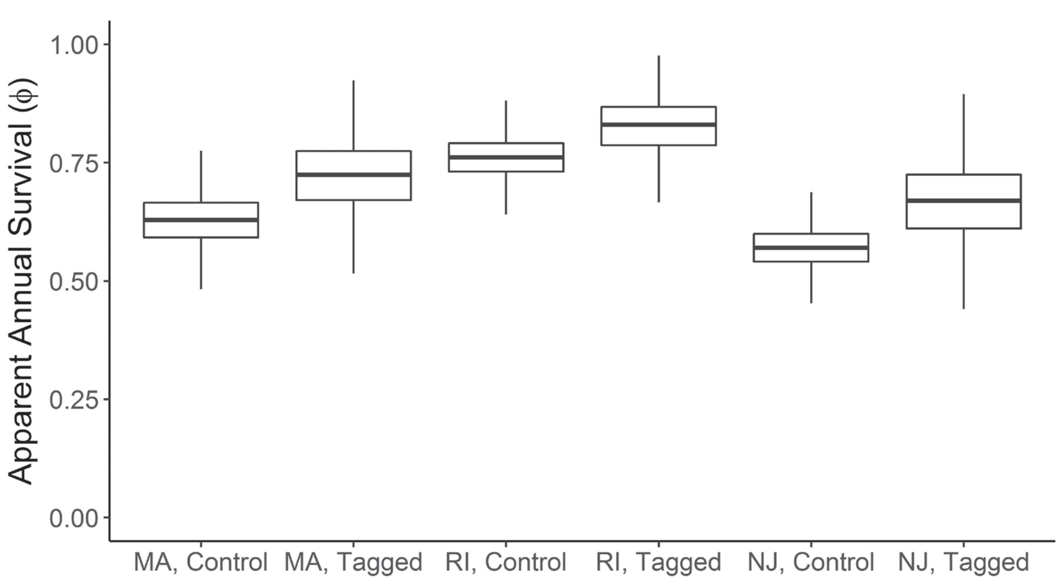

Figure 1. Estimated annual apparent survival probabilities for Atlantic Coast Piping Plovers without radio transmitters (Control) and with transmitters (Tagged) that were monitored from 2015-2018 in Massachusetts (MA), Rhode Island (RI), and New Jersey (NJ), USA. Boxes represent 25-75% interquartile ranges (IQR), lines represent medians, and whiskers represent data range excluding outliers (> 1.5 times IQR).

was 0.74 (Melvin and Gibbs 1996), which was less than our apparent survival estimate of 0.756 for tagged plovers. Survival estimates of adult Piping Plovers tend to be highest for the Great Plains population (range = 0.69-0.81) (apparent survival: Larson *et al.* 2000; Roche *et al.* 2010; Saunders *et al.* 2014; true survival: Cohen and Gratto-Trevor 2011), slightly lower for the Great Lakes population (true survival mean = 0.76, LeDee *et al.* 2010; apparent survival mean = 0.71, Roche *et al.* 2010), and lowest for the Atlantic Coast population (apparent survival: Atlantic Canada mean = 0.66, Long Island mean = 0.56, Roche *et al.* 2010; eastern Canada mean = 0.73, Calvert *et al.* 2006). However, Cohen *et al.* (2006) documented higher true survival rates (mean = 0.703) for adult Piping Plovers nesting at one site on Long Island, NY after partially accounting for the dispersal bias.

Transmitters that are temporarily attached with glue are less likely to adversely affect behavior relative to more permanent attachments such as harness-mounted transmitters (Warnock and Warnock 1993; Warnock and Takekawa 2003; Barron *et al.* 2010). Because we were interested in short-term movement ecology in the present study, birds generally needed to retain tags for < 90 days. Loring *et al.* (2019) assessed retention rates of transmitters for plovers tagged in Rhode Island and Massachusetts, and documented that 42%, 44%, and 54% from 2015 to 2017, respectively, retained transmitters through migratory departure from the breeding grounds in early July through September. In a previous study, we found that tags glued on the back of one adult Piping Plover from a nesting pair did not affect nest and chick survival rates (Stantial *et al.* 2018). Additionally, Drake *et al.* (2001) monitored 49 tagged Piping Plovers during the 1997-1998 wintering period and documented no mortality of radio-marked birds. Other attachment methods that can increase retention time (e.g., leg loop harnesses) can have adverse impacts on annual return rates (Mong and Sandercock 2010), so should not be used for short-term studies where temporary attachments are suitable to address objectives.

Due to risks inherent in all tag attachment techniques, telemetry studies should include assessments of potential negative impacts of transmitters on the individuals being investigated. This is crucial as deleterious impacts can bias the research, as well as affect populations (Barron *et al.* 2012). In our study of a rare species, we assessed potential impacts on reproductive success (Stantial *et al.* 2018) and apparent survival rates (this study). We found no evidence that external transmitters temporarily glued to the intrascapular region of plovers had negative effects on productivity or survival of adults, indicating that this technique might be suitable for use on similar sized birds with minimal impact. However, we recommend that tracking studies include species-specific assessments of tag effects to ensure that transmitters are not adversely affecting tagged individuals and biasing results.

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