Jones, T. M., N. W. Cooper, H. A. Haradon, A. R. Brunner, B. C. Dossman, M. P. Ward, T. Scott Sillett, and S. A. Kaiser. 2024. Considerations for radio-transmitter specifications on songbirds: color and antenna length matter too. Journal of Field Ornithology 95(1):7. https://doi.org/10.5751/JFO-00426-950107

Ornithological Methods

Considerations for radio-transmitter specifications on songbirds: color and antenna length matter too

Consideraciones sobre especificaciones de radiotransmisores para pájaros cantores: el color y la longitud de la antena también importan

Todd M. Jones[1,2], *Nathan W. Cooper*[1], *Haley A. Haradon*[1,3], *Alicia R. Brunner*[4], *Bryant C. Dossman*[5], *Michael P. Ward*[2,3], *T. Scott Sillett*[1] and *Sara A. Kaiser*[6]

ABSTRACT. Researchers studying avian space use, dispersal, survival, and migration select tracking tags that optimize tag size (dimensions) and mass relative to the focal species to minimize risk to birds as they move and fly. Here we argue that antenna length and transmitter color are also critical tag design parameters that must be considered. Based on a review of the songbird tracking literature and unpublished cases, we found most cases of entanglement, which can result in bird injuries and death, occurred with longer antennas (>13 cm). However, such cases cannot infer rates of mortality or survival, nor may they be representative of entanglements across antenna lengths and studies using radio tags. Additionally, white or brightly colored transmitters that contrast with plumage, particularly of cryptically colored females and juveniles, may increase visibility to predators and result in higher mortality, or alternatively, cause a female to eject a nestling by mistaking the tag for a fecal sac or foreign object. Consequently, we call on researchers to report and publish cases of antenna entanglement, and for journal editors to encourage and applaud such reports, such that data can be compiled to inform guidelines on tag antenna lengths for different species. Future research is also needed to examine the impacts of tag color on parental behavior and survival of tagged birds. Meanwhile, researchers should strive to ensure that their tag color does not contrast markedly with avian plumages, while also taking care not to alter (i.e., do not color over) areas required for harness attachment, activating and deactivating tags. We hope such efforts will enable researchers and manufacturers to make more informed decisions about tracking tag design, particularly with respect to balancing the benefits of longer antennas, which provide greater power and detection distance, with risks of bird entanglement and mortality.

RESUMEN. Los investigadores que estudian el uso del espacio por las aves, dispersión, supervivencia y migración, seleccionan dispositivos de seguimiento que optimizan el tamaño del dispositivo (dimensiones) y la masa respecto a la especie en cuestión para minimizar el riesgo para las aves mientras se mueven y vuelan. Aquí argumentamos que la longitud de la antena y el color del transmisor son también parámetros críticos del diseño de los dispositivos que deben tenerse en cuenta. En base a una revisión de la bibliografía sobre el seguimiento de pájaros cantores y casos no publicados, encontramos que la mayoría de los casos de entrelazamientos, los cuales pueden provocar lesiones y muerte de aves, ocurrieron con antenas largas (>13 cm). Sin embargo, estos casos no pueden inferir tasas de mortalidad o supervivencia, ni pueden ser representativos de entrelazamientos a través de distintas longitudes de antenas y estudios que utilizan radiotransmisores. Además, los radiotransmisores de colores blanco o brillantes que contrastan con el plumaje, particularmente de hembras y juveniles con colores crípticos, pueden aumentar la visibilidad para los depredadores resultando en una mayor mortalidad, o alternativamente, provocar que la hembra expulse un polluelo al confundir la etiqueta con un saco fecal u objeto extraño. En consecuencia, pedimos a los investigadores que reporten y publiquen casos de entrelazamiento de antenas y a los editores de revistas que alienten y elogien estos informes, de manera que se puedan recopilar datos para proporcionar pautas sobre longitudes de antenas de radiotransmisores para diferentes especies. También son necesarios estudios futuros para examinar los impactos del color de los radiotransmisores en el comportamiento parental y la supervivencia de las aves que portan radiotransmisores. Mientras tanto, los investigadores deberían esforzarse para asegurar que el color de sus radiotransmisores no contraste marcadamente con los plumajes de las aves y al mismo tiempo tener cuidado de no alterar (i.e., no colorear) las áreas utilizadas para sujetar el arnés, lo que afecta la activación o desactivación de los radiotransmisores. Esperamos que estos esfuerzos permitan a los investigadores y fabricantes tomar decisiones más concretas acerca del diseño de los dispositivos de seguimiento, particularmente con respecto a balancear los beneficios de antenas más largas, las cuales proveen mayor potencia y distancia de detección, con los riesgos de enredo de aves y mortalidad.

Key Words: *antenna length; color; entanglement; mortality; radio-telemetry; survival; tracking tags*

INTRODUCTION

Tracking tags have become an essential tool for ornithologists, allowing them to monitor and follow individuals of various species to gain important insights into behavior and survival that would otherwise be difficult or impossible to describe (Barron et al. 2010). For example, radio-telemetry studies have dramatically changed our understanding of movement and survival during the post-fledging period (Naef-Daenzer et al. 2001, Cox et al. 2014, Jones and Ward 2022), timing and routes of migration (Robinson et al. 2010, Brunner et al. 2022, Cooper et al. 2023a, b), predator-prey interactions (DeGregorio et al. 2015), and have allowed researchers to find and study nests of secretive species (Legare and Eddleman 2001). Moreover, the recent expansion of the Motus Wildlife Tracking System (Taylor et al. 2017) and

[1]Migratory Bird Center, Smithsonian's National Zoo and Conservation Biology Institute, Washington, D.C., USA, [2]Illinois Natural History Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, Champaign, IL, USA, [3]Department of Natural Resources and Environmental Sciences, University of Illinois at Urbana-Champaign, Champaign, IL, USA, [4]Department of Neurobiology and Behavior, Cornell University, Ithaca, NY, USA, [5]Department of Biology, Georgetown University, Washington, D.C., USA, [6]Center for Biodiversity Sciences, Cornell Lab of Ornithology, Cornell University, Ithaca, NY, USA

development of other automated radio-telemetry systems (e.g., Jones and Ward 2022) holds great potential for future research on avian behavior and survival. Furthermore, advances in miniaturization allows researchers to place tags on virtually any avian species (e.g., hummingbirds; Zenzal et al. 2014). However, for tracking tags to be effective tools, they must have minimal impact on behavior and survival of the organism.

Meta-analyses have shown that tracking tags can have negative impacts (Barron et al. 2010) and that negative effects are underreported in the avian literature (Hill and Elphick 2011). Researchers must therefore select tag specifications (e.g., size, mass, material, harness type) that minimize the potential for negative effects (Anich et al. 2009). Tag weight and shape generally receive the most consideration because they affect the amount of drag produced during flight, with larger, heavier tags being more energetically costly, producing more drag, and likely having a greater impact on behavior and survival (Aldridge and Brigham 1988, Obrecht et al. 1988). Consequently, institutional animal care and use committees, government regulatory agencies, and researchers often limit or select transmitters based on the relative mass of focal species, usually following a 3% or 5% of body mass rule, below which the impact of a transmitter's weight is thought to be minimal. However, we have little empirical basis for such thresholds (summarized in Barron et al. 2010).

Tag antenna length and cases of entanglement in songbirds

Antenna length also affects birds but is generally overlooked as a tag design parameter. Antenna length contributes to the overall drag of a transmitter during flight (Obrecht et al. 1988), how a tag influences a bird's center of gravity during flight (and thus energetics), and may influence behavior (e.g., Zenzal et al. 2014). Perhaps more importantly, antenna length influences the risk of tag entanglement with vegetation (Hill and Elphick 2011). To reduce tag mass for smaller birds, antennas are often made of thinner, more flexible materials that are prone to curl or become hook-like over time (Fig. 1; e.g., Dougill et al. 2000). Longer antennas are also more likely to touch or rub against the ground, vegetation, and pick up spider webs and other sticky substances, increasing the chances that antennas may become entangled, particularly in ground foraging or grassland species (Hill and Elphick 2011, Van Vliet and Stutchbury 2018); picking up such substances may also increase the weight and weight distribution of transmitters.

We searched the songbird tracking literature for cases when entanglements were documented alongside antenna lengths, and we also reached out to colleagues and peers for unpublished cases. Based on these published and unpublished accounts (11 studies), all but one case of songbird entanglement occurred with antennas 13 cm in length ("longer antennas"; Table 1). Notably, some antennas were two to three times longer than the focal species' tail length, and the antenna length rivaled tags placed on birds 10 to 20 times their size (e.g., warblers [13–18 cm] vs. terns [14 cm] and geese [15 cm]; Demers et al. 2003, Rock et al. 2007). These entanglements occurred across life stages, with natural and artificial aspects of the environment (e.g., trees, barbed wire fence), and included cases where tagged nestling and incubating females became entangled in their own nests. We also note that similar antenna lengths may cause entanglements in larger bird species (e.g., Northern Bobwhite [*Colinus virginianus*], Mallard [*Anas platyrhynchos*]; Burger et al. 1995, Kirby and Sargeant 1999). Additionally, cases of antenna entanglement in songbirds appear underreported in the literature; Hill and Elphick (2011) surveyed researchers and found that amongst their studies, 27% of species incurred some issue with entanglement, with more than half of those species becoming entangled because of the antenna (lengths were not reported). Only two of these transmitter-related problems were actually published, and in several studies, researchers noted that they trimmed and used shorter antennas after the first entanglement (Hill and Elphick 2011). Lastly, many studies may tag but do not actively track birds (e.g., migratory departure, connectivity; González et al. 2020, Herbert et al. 2022), such that cases of entanglement would be under discovered. Moreover, birds that become entangled in such studies may not be able to escape their transmitter nor be rescued, further highlighting the importance of selecting an appropriate antenna length.

Fig. 1. Example of how longer antennas (in this case, 18 cm) may curl or become hooked over time (right) relative to their appearance at deployment (left). This curled or hook-like shape may increase the likelihood of tagged birds becoming entangled in vegetation and other parts of their environment.

Despite the potential for entanglement and associated mortality (Dougill et al. 2000, Van Vliet and Stutchbury 2018), few guidelines for selecting tag antenna length are available. Similar to mass, this is largely because we have little empirical basis for

Table 1. Species and associated studies in which a transmitter antenna resulted in a songbird becoming entangled in the surrounding vegetation, and for which the antenna length was also listed. Additional cases of entanglement (without antenna length listed) can be found in the supplementary material of Hill and Elphick (2011).

Species	Scientific name	Study	Length (cm)	Entangled in?	Removal?[†]
Canada Warbler	*Cardellina canadensis*	G. Mitchell, *personal obs.* (Long Point, Ontario)	18.0	Vegetation	Yes
Henslow's Sparrow	*Centronyx henslowii*	Young et al. 2019	15.0	Vegetation	Yes
Swainson's Warbler	*Limnothlypis swainsonii*	Anich et al. 2009	14.0	Vegetation	No
Palila	*Loxioides bailleui*	Dougill et al. 2000	16.0	Vegetation	Yes
Savannah Sparrow	*Passerculus sandwichensis*	Van Vliet and Stutchbury 2018	14.5	Vegetation	Yes
Savannah Sparrow	*P. sandwichensis*	Rae et al. 2009, Mitchell et al. 2012, 2015	18.0	Vegetation	Yes
Cassin's Sparrow	*Peucaea cassinii*	Forrest 2022	13.0	Vegetation	Yes
Black-throated Blue Warbler	*Setophaga caerulescens*	L. Hao and A. Bechler, *personal obs.* (New Hampshire)	18.0; 8.0	Nest materials; Vegetation	No; Yes
Kirtland's Warbler	*S. kirtlandii*	H. Haradon, *personal obs.* (Michigan)	18.0; 14.0	Vegetation, other antennas	No; Yes
American Redstart	*S. ruticilla*	B. Dossman, *personal obs.* (Jamaica)	18.0	Vegetation	No
Eastern Bluebird	*Sialia sialis*	Pitts 1995	13.3	Fence	Yes

[†] Indicates whether a researcher was needed to remove a bird from being entangled by its transmitter antenna.

determining thresholds for antenna length across species. Indeed, we are limited in what we can infer from reported cases of entanglement. For example, though cases reported in this paper hint that longer antennas may be more problematic for birds, they do not indicate rates of mortality or survival, and they might not be representative of entanglements across antenna lengths and studies using radio tags. Further complicating matters, entanglement rates by antenna length may vary depending on habitat type. Entanglements appear to be higher in birds preferring denser vegetation (Hill and Elphick 2011, Van Vliet and Stutchbury 2018), such as grassland birds and fledglings of many species (Jones et al. 2017). Shorter antennas (e.g., 6–8 cm) have therefore been recommended in those cases (e.g., Streby et al. 2015, Van Vliet and Stutchbury 2018). Perhaps most importantly, few resources exist for researchers to report cases of entanglements without fear of judgment or repercussions, even though there appears to be widespread agreement among ornithologists that such information should be made available to inform guidelines and future research (sensu Hill and Elphick 2011).

Although the solution to these cases of entanglement may at first seem simple (e.g., just use shorter antenna lengths), in reality choosing an appropriate antenna length poses a significant dilemma for researchers given the relationship between antenna length, detection distance, and detection rates. Longer antennas provide greater signal power, allowing a tag to be detected further away and with greater reliability (detection rate). Longer antennas therefore enhance the ability of researchers to find and monitor tagged birds, and for automated receiver stations to detect them. Critically, the relationship between antenna length and aspects of detection are non-linear, with each cm of an antenna length shortened likely resulting in a greater decline in detection distance and rate. Quantifying how detection distances and rates vary with antenna length under different field conditions (e.g., habitat types, topography) would therefore enable researchers and manufacturers to make more informed decisions about tracking tag design. Tests could show that detection distances and rates are similar across a range of antenna lengths (e.g., 8–20 cm) and that smaller antennas (< 10 cm) are sufficiently detected for collecting data on a variety of topics (e.g., migration, post-fledging ecology, home range use). Alternatively, tests could show a significant drop in detection range and rate with shorter antennas, highlighting a clear dilemma for researchers. Regardless of the findings, such tests could ultimately aid researchers in selecting an antenna length that balances tag detections with risks of avian entanglement and mortality.

Are tracking tag colors problematic for songbirds?

In addition to antenna length, tracking tag color is another overlooked consideration. Depending on the company and model, transmitters come in a variety of colors and may have effects on individual recognition, status signaling, mate choice, and reproductive success, as has been found in other color markers such as color bands and leg flags (Hagan and Reed 1988, Metz and Weatherhead 1991, Calvo and Furness 1992). Additionally, researchers need to consider whether tag color might compromise the camouflage of their study species. Whereas more darkly colored tags (e.g., green, brown, black) tend to blend with most plumages (e.g., juveniles), white and brighter colored tags (e.g., yellow, orange, red, blue) may be in stark contrast to the bird's color(s), and essentially paint a target on a bird's back (Fig. 2) for visually oriented predators (Stevens et al. 2013). We note this is likely more of an issue for nestlings, as tags can be concealed under the back feathers of adults, though this issue may still occur during periods when adults are molting. Moreover, such tag colors (white tags, in particular) may increase the likelihood of parents attacking or removing tagged nestlings from their nests, mistaking them for fecal sacs, parasites, or foreign objects (e.g., Mattsson et al. 2006, Fisher et al. 2010). Tag color could therefore lead to reduced feeding, lower body condition, early fledging, and ultimately lower survival rates, especially for incubating females and immobile nestlings or fledglings that rely on camouflage, a concern that is particularly relevant given the recent uptick in studies using white Motus nanotag transmitters (Taylor et al. 2017). To our knowledge no studies have examined associations between contrasts in transmitter color and plumage with regards to survival and behavior of parental birds. Until such studies are

Fig. 2. Example of how radio-transmitters can contrast markedly with avian plumage. White or brightly colored transmitters may make birds more visible to predators, particularly for fledglings (such as the Painted Bunting, *Passerina ciris*, depicted here). Additionally, females may mistake white tags for fecal sacs or be more likely to notice tags as foreign objects in their nest. We note that this nanotag transmitter was placed on the bird for demonstration purposes only, and subsequently removed.

conducted, researchers may help to mitigate these potential issues by changing the color of their transmitters via waterproof markers, paint, or nail polish - past studies have camouflaged transmitters in birds (e.g., Severson et al. 2019) and other taxa, including those in aquatic environments (e.g., Aitken et al. 2005). Notably, researchers may need to take steps to ensure that their coloring materials do not block infrared-activation (i.e., do not color over the activation area), do not impair adhesion of harness materials to the tag (we recommend researchers glue harnesses to their tags before making color adjustments), and do not make tags conspicuous with regards to ultraviolet vision.

CONCLUSIONS

In conclusion, we emphasize that caution must be used when considering tag specifications and their potential for deleterious effects on songbirds. In addition to assessing the appropriate transmitter size and mass, we argue that selection of antenna length and the color of transmitters are also critical. Here we call on researchers to report and publish cases of entanglement and the associated antenna length used, such that more information on antenna length and survival can be compiled and eventually used to produce informed guidelines on antenna length. When data are compiled, researchers and manufacturers can make more informed decisions on tag design (e.g., manufacturers could design detachable antennas for when birds become entangled). Moreover, editors of journals and other organizations should encourage and applaud researchers for reporting and publishing such cases, such that researchers are not judged or suffer repercussions. A central database with a worldwide organization or databank (e.g., Movebank; https://www.movebank.org), as well as regional organizations (e.g., USGS Bird Banding Laboratory in North America) would allow researchers to report such cases. Further research is needed to determine (1) the effect of antenna length on rates of entanglement and survival of tagged birds; (2) what practical effect antenna length may have on detection range and rates in both automated and handheld telemetry studies; and (3) how variation in tag color affects adult and juvenile survival, including parental behavior toward tagged nestlings and their subsequent survival. Ultimately, such efforts will enable researchers and manufacturers to make more informed decisions about tracking tag design, particularly with respect to balancing the benefits of longer antennas, which provide greater power and detection distance, with risks of bird entanglement and mortality.

Acknowledgments:

Thanks to G. Mitchell, A. Bechler, and L. Hao for unpublished records of songbird entanglements, and to the anonymous reviewers for their contributions to this manuscript.

Data Availability:

Data/code sharing is not applicable to this article because no data/code were analyzed in this study.

LITERATURE CITED

Aitken, J. P., R. K. O'Dor, and G. D. Jackson. 2005. The secret life of the giant Australian cuttlefish *Sepia apama* (Cephalopoda): behaviour and energetics in nature revealed through radio acoustic positioning and telemetry (RAPT). Journal of Experimental Marine Biology and Ecology 320:77-91. https://doi.org/10.1016/j.jembe.2004.12.040

Aldridge, H. D. J. N., and R. M. Brigham. 1988. Load carrying and maneuverability in an insectivorous bat: a test of the 5% "rule" of radio-telemetry. Journal of Mammalogy 69:379-382. https://doi.org/10.2307/1381393

Anich, N. M., T. J. Benson, and J. C. Bednarz. 2009. Effect of radio transmitters on return rates of Swainson's Warblers. Journal of Field Ornithology 80:206-211. https://doi.org/10.1111/j.1557-9263.2009.00210.x

Barron, D. G., J. D. Brawn, and P. J. Weatherhead. 2010. Meta-analysis of transmitter effects on avian behaviour and ecology. Methods in Ecology and Evolution 1:180-187. https://doi.org/10.1111/j.2041-210X.2010.00013.x

Brunner, A. R., B. C. Dossman, V. Jirinec, K. L. Percy, C. M. Tonra, E. I. Johnson, and P. P. Marra. 2022. Migratory behavior and connectivity revealed in a secretive Neotropical migratory songbird, the Swainson's Warbler. Journal of Field Ornithology 93(3):5. https://doi.org/10.5751/JFO-00134-930305

Burger, L. W., T. V. Dailey, E. W. Kurzejeski, and M. R. Ryan. 1995. Survival and cause-specific mortality of Northern Bobwhite in Missouri. Journal of Wildlife Management 59:401-410. https://doi.org/10.2307/3808954

Calvo, B., and R. W. Furness. 1992. A review of the use and the effects of marks and devices on birds. Ringing & Migration 13:129-151. https://doi.org/10.1080/03078698.1992.9674036

Cooper, N. W., B. C. Dossman, L. E. Berrigan, J. M. Brown, A. R. Brunner, H. E. Chmura, D. A. Cormier, C. Bégin-Marchand, A. D. Rodewald, P. D. Taylor, C. M. Tonra, J. A. Tremblay, and P. P. Marra. 2023a. Songbirds initiate migratory flights synchronously relative to civil dusk. Movement Ecology 11:24. https://doi.org/10.1186/s40462-023-00382-5

Cooper, N. W., B. C. Dossman, L. E. Berrigan, J. M. Brown, D. A. Cormier, C. Bégin-Marchand, A. D. Rodewald, P. D. Taylor, J. A. Tremblay, and P. P. Marra. 2023b. Atmospheric pressure predicts probability of departure for migratory songbirds. Movement Ecology 11:23. https://doi.org/10.1186/s40462-022-00356-z

Cox, W. A., F. R. Thompson III, A. S. Cox, and J. Faaborg. 2014. Post-fledging survival in passerine birds and the value of post-fledging studies to conservation. Journal of Wildlife Management 78:183-193. https://doi.org/10.1002/jwmg.670

DeGregorio, B. A., J. H. Sperry, M. P. Ward, and P. J. Weatherhead. 2015. Wait until dark? Daily activity patterns and nest predation by snakes. Ethology 121:1225-1234. https://doi.org/10.1111/eth.12435

Demers, F., J.-F. Giroux, G. Gauthier, and J. Bety. 2003. Effects of collar-attached transmitters on behaviour, pair bond and breeding success of Snow Geese *Anser caerulescens atlanticus*. Wildlife Biology 9:161-170. https://doi.org/10.2981/wlb.2003.047

Dougill, S. J., L. Johnson, P. C. Banko, D. M. Goltz, M. R. Wiley, and J. D. Semones. 2000. Consequences of antenna design in telemetry studies of small passerines. Journal of Field Ornithology 71:385-388. https://doi.org/10.1648/0273-8570-71.3.385

Fisher, R. J., K. M. Dohms, and S. K. Davis. 2010. Removal of nestling radio-transmitters by adult Sprague's Pipit (*Anthus spragueii*). Journal of Ornithology 151:749-753. https://doi.org/10.1007/s10336-010-0503-2

Forrest, A. W. 2022. Habitat selection of the declining Cassin's Sparrow in an imperiled grassland biome. Dissertation. Colorado State University, Pueblo, Colorado, USA.

González, A. M., N. J. Bayly, and K. A. Hobson. 2020. Earlier and slower or later and faster: spring migration pace linked to departure time in a Neotropical migrant songbird. Journal of Animal Ecology 89:2840-2851. https://doi.org/10.1111/1365-2656.13359

Hagan, J. M., and J. M. Reed. 1988. Red color bands reduce fledging success in Red-Cockaded Woodpeckers. Auk 105:498-503. https://doi.org/10.1093/auk/105.3.498

Herbert, J. A., D. Mizrahi, and C. M. Taylor. 2022. Migration tactics and connectivity of a Nearctic-Neotropical migratory shorebird. Journal of Animal Ecology 91:819-830. https://doi.org/10.1111/1365-2656.13670

Hill, J. M., and C. S. Elphick. 2011. Are grassland passerines especially susceptible to negative transmitter impacts? Wildlife Society Bulletin 35:362-367. https://doi.org/10.1002/wsb.84

Jones, T. M., J. D. Brawn, and M. P. Ward. 2017. Post-fledging habitat use in the Dickcissel. Condor 119:497-504. https://doi.org/10.1650/CONDOR-17-21.1

Jones, T. M., and M. P. Ward. 2022. Post-fledging behavioral ecology of migratory songbirds: how do fledgling activity rates vary across species? Behavioral Ecology 33:336-342. https://doi.org/10.1093/beheco/arab122

Kirby, R. E., and G. A. Sargeant. 1999. Survival of postfledging Mallards in northcentral Minnesota. Journal of Wildlife Management 63:403-408. https://doi.org/10.2307/3802526

Legare, M. L., and W. R. Eddleman. 2001. Home range size, nest-site selection and nesting success of Black Rails in Florida. Journal of Field Ornithology 72:170-177. https://doi.org/10.1648/0273-8570-72.1.170

Mattsson, B. J., J. M. Meyers, and R. J. Cooper. 2006. Detrimental impacts of radiotransmitters on juvenile Louisiana Waterthrushes. Journal of Field Ornithology 77:173-177. https://doi.org/10.1111/j.1557-9263.2006.00038.x

Metz, K. J., and P. J. Weatherhead. 1991. Color bands function as secondary sexual traits in male Red-winged Blackbirds. Behavioral Ecology and Sociobiology 28:23-27. https://doi.org/10.1007/BF00172135

Mitchell, G. W., A. E. M. Newman, M. Wikelski, and D. R. Norris. 2012. Timing of breeding carries over to influence migratory departure in a songbird: an automated radiotracking study. Journal of Animal Ecology 81:1024-1033. https://doi.org/10.1111/j.1365-2656.2012.01978.x

Mitchell, G. W., B. K. Woodworth, P. D. Taylor, and D. R. Norris. 2015. Automated telemetry reveals age specific differences in flight duration and speed are driven by wind conditions in a migratory songbird. Movement Ecology 3:19. https://doi.org/10.1186/s40462-015-0046-5

Naef-Daenzer, B., F. Widmer, and M. Nuber. 2001. Differential post-fledging survival of great and coal tits in relation to their condition and fledging date. Journal of Animal Ecology 70:730-738. https://doi.org/10.1046/j.0021-8790.2001.00533.x

Obrecht, H. H., C. J. Pennycuick, and M. R. Fuller. 1988. Wind tunnel experiments to assess the effect of back-mounted radio transmitters on bird body drag. Journal of Experimental Biology 135:265-273. https://doi.org/10.1242/jeb.135.1.265

Pitts, T. D. 1995. A tail-mounted radio transmitter for Eastern Bluebirds. North American Bird Bander 20:106-110.

Rae, L. F., G. W. Mitchell, R. A. Mauck, C. G. Guglielmo, and D. R. Norris. 2009. Radio transmitters do not affect the body condition of Savannah Sparrows during the fall premigratory period. Journal of Field Ornithology 80:419-426. https://doi.org/10.1111/j.1557-9263.2009.00249.x

Robinson, W. D., M. S. Bowlin, I. Bisson, J. Shamoun-Baranes, K. Thorup, R. H. Diehl, T. H. Kunz, S. Mabey, and D. W. Winkler. 2010. Integrating concepts and technologies to advance the study of bird migration. Frontiers in Ecology and the Environment 8:354-361. https://doi.org/10.1890/080179

Rock, J. C., M. L. Leonard, and A. W. Boyne. 2007. Do co-nesting Arctic and Common Terns partition foraging habitat and chick diets? Waterbirds 30:579-587. https://doi.org/10.1675/1524-4695(2007)030[0579:DCAACT]2.0.CO;2

Severson, J. P., P. S. Coates, B. G. Prochazka, M. A. Ricca, M. L. Casazza, and D. J. Delehanty. 2019. Global positioning system tracking devices can decrease Greater Sage-Grouse survival. Condor 121:duz032. https://doi.org/10.1093/condor/duz032

Stevens, M., K. L. A. Marshall, J. Troscianko, S. Finlay, D. Burnand, and S. L. Chadwick. 2013. Revealed by conspicuousness: distractive markings reduce camouflage. Behavioral Ecology 24:213-222. https://doi.org/10.1093/beheco/ars156

Streby, H. M., T. L. McAllister, S. M. Peterson, G. R. Kramer, J. A. Lehman, and D. E. Andersen. 2015. Minimizing marker mass and handling time when attaching radio-transmitters and geolocators to small songbirds. Condor 117:249-255. https://doi.org/10.1650/CONDOR-14-182.1

Taylor, P. D., T. L. Crewe, S. A. Mackenzie, D. Lepage, Y. Aubry, Z. Crysler, G. Finney, C. M. Francis, C. G. Guglielmo, D. J. Hamilton, R. L. Holberton, P. H. Loring, G. W. Mitchell, D. Norris, J. Paquet, R. A. Ronconi, J. Smetzer, P. A. Smith, L. J. Welch, and B. K. Woodworth. 2017. The Motus Wildlife Tracking System: a collaborative research network to enhance the understanding of wildlife movement. Avian Conservation and Ecology 12(1):8. https://doi.org/10.5751/ACE-00953-120108

Van Vliet, H. E. J., and B. J. M. Stutchbury. 2018. Radiotagged fledgling Savannah Sparrows *Passerculus sandwichensis* at risk of entanglement in vegetation. Ibis 160:919-922. https://doi.org/10.1111/ibi.12615

Young, A. C., W. A. Cox, J. P. McCarty, and L. L. Wolfenbarger. 2019. Postfledging habitat selection and survival of Henslow's Sparrow: management implications for a critical life stage. Avian Conservation and Ecology 14(2):10. https://doi.org/10.5751/ACE-01418-140210

Zenzal, T. J., R. H. Diehl, and F. R. Moore. 2014. The impact of radio-tags on Ruby-throated Hummingbirds (*Archilochus colubris*). Condor 116:518-526. https://doi.org/10.1650/CONDOR-13-142.1