A review of Impacts of Tracking Devices on Birds

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ABSTRACT

Over the past few decades, extrinsic tracking devices (e.g., radio transmitters, GPS loggers, satellite transmitters, geolocators) have been widely used to study wildlife movement and other demographic parameters. Remote tracking and monitoring technology is continually advancing, and its use by researchers is becoming more widespread. Minimizing any potential impacts of tracking devices on focal species is of upmost importance in order to ensure and promote animal welfare and reliable scientific information. Many researchers aim to understand any potential short- or long-term impacts of remote tracking, and to develop methods that support the responsible and safe tagging of birds (e.g., Geen et al. 2019). As tracking projects become more mainstream, it is critical that banders and researchers stay up to date and contribute to current base of knowledge on the topic. This review summarizes available research demonstrating the impacts of attaching a variety of tracking devices to birds in order to guide and promote minimally invasive methods of deploying tracking devices, and to highlight the need for continued study of the effects of devices and attachment methods on bird welfare.

INTRODUCTION

There is a strong body of literature that provides conflicting evidence regarding the impacts of tracking devices on birds (e.g., Calvo and Furness 1992, see **Table 1**). Some recent meta-analyses have shown that tracking devices have no effects on body condition, phenology, and breeding performance, while others have shown that they can have an overall negative effect on such traits, as well as on survival (Barron et al. 2010, Bridge et al. 2013, Costantini and Møller 2013, Bodey et al. 2018, Brlík et al. 2018).

Review of the literature shows high variability in the effects of tags on research subjects, with reported tag effects depending on intrinsic attributes of the focal individual, ecological attributes during the period of tag attachment, as well as physical characteristics of the tags and attachment method. For instance, bird group, foraging and flying style, migration distance, life history stage, method of device attachment, device mass as a proportion of bird mass, and device design are important in determining the likelihood of effects (Haramis and Kearns (2000), However, Barron et al. (2010), found that effects were independent of attributes of the individual birds. Additionally, impacts may depend on attachment duration, in that long-term impacts such as on return rates may be a result of longer-term attachment of devices with backpack and leg-loop harnesses (Mong and Sandercock 2007), but see Bodey et al. (2018).

DISCUSSION

The majority of individual studies that have assessed the effects of tagging on birds have occurred during the breeding season, and many have reported no or negligible impacts of tagging adults on within-breeding-season survival (e.g., Mong and Sandercock 2007, Raybuck et al. 2017, Stantial and Cohen 2020, Nicoll et al. 2022); annual return rates (e.g., Clewley et al. 2021, Mong and Sandercock 2007, Peterson et al. 2015, van Wijk et al. 2016, Stantial et al. 2019, Nicoll et al. 2022); long-term stress levels (e.g., Suedkamp Wells et al. 2003, Fairhurst et al. 2015, van Wijk et al. 2016); short- and long-term health conditions (e.g., Peterson et al. 2015, van Wijk et al. 2016, Musseau et al. 2021, Williamson and Witt 2021); and breeding performance measures, including breeding phenology (van Wijk et al. 2016), copulation success, clutch size, egg volume, daily nest survival, nestling growth rates, quality of young fledged, daily chick survival, nest success (e.g., Hill et al. 1999, Gow et al. 2011, Gómez et al. 2014, Bell et al. 2017, Raybuck et al. 2017, Kavelaars et al. 2018, Stantial et al. 2018, Gillies et al. 2020, Stantial and Cohen 2020), seasonal productivity (e.g., Streby et al. 2013, Rodríguez-Ruiz et al. 2016, and van Wijk et al. 2016), as well as parental care behaviours, namely, nest attendance, nestling provisioning rates, and delivered prey biomass were not impeded for birds outfitted with tracking devices (e.g., Neudorf and Pitcher 1997, Gow et al. 2011, Gómez et al. 2014, Raybuck et al. 2017, Gillies et al. 2020, Seward et al. 2021). Moreover, deployment of geolocators on male Barn Swallows (*Hirundo rustica*) during the breeding season did not compromise their short-term flight performance, which is important for predator avoidance and aerial foraging efficiency, and thus chick-feeding ability (Matyjasiak et al. 2016).

Other studies, however, have reported detrimental impacts of tagging on a number of key reproductive measures. The tagging of breeding adults has resulted in lowered nesting propensity (Snijders et al. 2017), delayed breeding (Arlt et al. 2013), diminished clutch size (Scandolara et al. 2014), reduced foraging efficiency (Gillies et al. 2020), decreased nestling growth rates (Rodríguez-Ruiz et al. 2016), lowered nest success (Arlt et al. 2013), and reduced annual return rates (e.g., Mong and Sandercock 2007, Arlt et al. 2013, Gómez et al. 2014, Rodríguez-Ruiz et al. 2016, Raybuck et al. 2017a, 2017b, but see Streby and Kramer 2017; Morganti et al. 2018, Taff et al. 2018, Stantial and Cohen 2020).

The deployment of tracking devices can be used to monitor survival of free-living precocial avian young, though tagging impacts were variable in reviewed studies. Survival of shorebird chicks was unaffected by attachment of radio transmitters (Lees et al. 2019), whereas the attachment of radio transmitters had negative effects on growth and survival of Forster's Tern (*Sterna forsteri*) chicks (Herzog et al. 2020).

Outside of the breeding period, when transmitter effects were assessed during the energetically costly moult period, Gow et al. (2011) actually found improved physical condition in tagged Wood Thrushes (*Hylocichla mustelina*) compared to untagged birds. Transmitters did not affect body condition of adults or juvenile Savannah Sparrows (*Passerculus sandwichensis*) during the post-breeding pre-migratory period (Rae et al. 2009), nor did it induce stress in overwintering Hermit Thrushes (*Catharus guttatus*, Davis et al. 2008) or reintroduced Grey Partridges (*Perdix perdix*, Homberger et al. 2021). Tagging had no deleterious effects on post-fledging survival of Great Tits (*Parus major*) and Coal Tits (*P. ater*) (Naef-Daenzer 2001), nor annual survival of Whinchats (*Saxicola rubetra*) tagged on their wintering grounds (Blackburn et al. 2016) or Soras (*Porzana carolina*) tagged during their stopover (Haramis and Kearns 2000). However, survival of reintroduced Grey Partridges in their winter covey phase was negatively affected by radio tags (Homberger et al. 2021).

Tracking devices have been known to hamper survival by causing entanglement and injury (Hill and Elphick 2011, Vliet et al. 2018); reducing flight capacity (e.g., Tomotani et al. 2018, 2021, Homberger et al. 2021, Longarini et al. 2021);

or increasing thermoregulatory costs (Godfrey et al. 2003b). Further, the aerodynamic drag produced from attaching external devices can increase energy costs and decrease migratory range (Obrecht et al. 1988, Powell et al. 1998, Bowlin et al. 2010, Portugal and White 2021). However, the attachment of tracking devices did not impose a significant handicap on Ruby-throated Hummingbird (*Catharus guttatus*) activity (Zenzal et al. 2014) nor Great and Coal tit fledgling movements (Naef-Daenzer 2001). Further, Soras radiotagged during their stopover experienced successful migration (Haramis and Kearns 2000).

Knowledge gaps

Outside of these dedicated studies and reviews, detailed information, or even general observations about potential tag effects, or lack thereof, are missing from the vast majority of tracking studies (Barron et al. 2010, Bodey et al. 2018, Geen et al. 2019). A possible source of bias in reporting results of no effects is that investigators perceive that no effect may not be as publishable. Publishing of general observations and anecdotes within the results of tracking studies may provide valuable insights for future studies. In addition, studies should try and differentiate between statistical or biological effect, since the former may be based on the statistical power for an experiment or study, and the latter based on a consideration of many factors that may exacerbate biological effects.

A robust examination of the potential effects of tracking devices during the migration period is also lacking, primarily due to the difficulty of assessing and comparing individual condition of tagged and non-tagged birds during this highly mobile period, and many birds tagged with remotely monitored devices like satellite tags or automated radio telemetry, are rarely, if ever, recaptured. One potential solution is through wind-tunnel and other experimental studies that could reveal any physiological constraints on flight or energy consumption (see Birnie-Gauvin et al. 2020).

Assessing the potential impacts of tracking devices on birds is not a simple problem to address, as the impacts can be context- and species-specific (discussed above) and likely also vary by the environmental conditions they encounter. There has also been no study or commentary on the potential variation of impacts between different bird-handlers and researchers conducting the tagging, and associated study methods which may also play a role beyond the devices themselves.

As wildlife tracking technologies continue to evolve and become more broadly used, we must continue to consider trade-offs between the value of research to the conservation of species and the potential effects on the focal species and information collected. We recommend that researchers perform pilot studies on bird groups, species, or populations that have not yet undergone rigorous study using existing tracking devices, or when new devices are introduced. This will help ensure any tag effects are minimal and will not unduly affect the study animals, nor the value of the data collected.

Lastly, with a few notable exceptions (Raim 1978, Rappole and Tipton 1991, Streby et al. 2015; Warnock and Warnock 1993), there is a general lack of detailed and consistent methods and resources for affixing a variety of tracking devices to species. An effort should be made to publish detailed descriptions of tagging methods within study methods as well as produce publications and other resources describing well-established methods and protocols for the use of tracking devices on wild birds.

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Table 1. Summary of original research demonstrating impacts of different tracking devices on several study parameters

Citation	Species	Life history stage[a]	Tag mass[b]	Device type	Attachment type	Study parameter	Direction of impact
Arlt et al. 2013	Northern Wheatear	Breeding	4.0-6.0	Geolocator	Leg-loop harness	Breeding phenology	Positive
						Nest success	Negative
						Annual return rate	Negative
Bell et al. 2017	Cerulean Warbler	Breeding	avg. 3.0	Geolocator	Leg-loop harness	Brood provisioning rate	None
						Nestling growth	None
						Nest success	None
						Annual return rate	None
						Next-year arrival date	None
						Next-year recruitment	None
						Nest-year nest success	None
						Breeding phenology	None
Blackburn et al. 2016	Whinchat	Overwinter	avg. 4.1	Geolocator	Leg-loop harness	Annual return rate	None
Chan et al. 2016	Red Knot	Overwinter	3.1-4.0	Satellite	Full-body harness	Movement	None
Clewley et al. 2021	Lesser Black-backed Gull	Breeding	2.5-3.0	GPS	Wing harness	Annual survival	None
Davis et al. 2008	Hermit Thrush	Overwinter	avg. 2.4	Radio	Leg-loop harness	Heterophil-lymphocyte ratios	None
Fairhurst et al. 2015	Tree Swallow	Breeding	<5.0	Geolocator	Leg-loop harness	Feather corticosterone	None
	Barn Swallow	Breeding	≤4.5	Geolocator	Leg-loop harness	Feather corticosterone	None
Gillies et al. 2020	Manx Shearwater	Breeding	0.6	Geolocator	Leg ring	Nest success	None
						Foraging trip duration	None
						Foraging efficiency	None
						Chick provisioning	None

Citation	Species	Life history stage[a]	Tag mass[b]	Device type	Attachment type	Study parameter	Direction of impact
			4.2	GPS	Dorsal tape attachment	Nest success	None
						Foraging trip duration	Positive
						Foraging efficiency	Negative
						Chick provisioning	None
Godfrey et al. 2003b	Takahe	Non-breeding	1.4-2.3	Radio	Wing harness	Energy expenditure	Positive
Gómez et al. 2014	Tree Swallow	Breeding	<5.0	Geolocator	Leg-loop harness	Brood provisioning rate	None
						Nest attendance	None
						Nestling growth rate	None
						Nestling size	None
						Annual return rate	Negative
Gow et al. 2011	Wood Thrush	Breeding	<5.0	Radio	Leg-loop harness	Brood provisioning rate	None
						Nesting success	None
						Nest attempts	None
						Clutch size	None
						Fledging success	None
						Hatching success	None
						Plasma lipid metabolites	None
		Moult	<5.0	Radio	Leg-loop harness	β-hydroxybutyrate	Negative
						triglycerides	Positive
Haramis and Kearns 2000	Sora	Stopover	<3.0	Radio	Leg- and waist-loop harness	Annual survival	None
						Migration	None
Herzog et al. 2020	Forster's Tern	Hatchling	3.5	Radio	Sutures and glue	Growth rate	Negative
						Within-season survival	Negative
Hill et al. 1999	*Turdus* sp.	Breeding	2.0-2.5	Radio	Leg-loop harness	Clutch size	None
						Egg volume	None
						Nest survival	None
						Fledged young	None
						Brood provisioning rate	None
Homberger et al. 2021	Grey Partridge	Reintroduction	<3.5	Radio	Necklace	Plasma corticosterone	None
						Escape flight capacity	None
						Within-season survival	Negative
Kavelaars et al. 2018	Lesser Black-backed Gull	Breeding	avg. 2.3	GPS	Wing harness	Nestling growth	None
						Nestling survival	None

Citation	Species	Life history stage[a]	Tag mass[b]	Device type	Attachment type	Study parameter	Direction of impact
Lees et al. 2019	Masked Lapwing	Hatchling	<5	Radio	Glue	Within-season survival	None
	Red-capped Plover	Hatchling	<5	Radio	Glue	Within-season survival	None
	Hooded Plover	Hatchling	<5	Radio	Glue	Within-season survival	None
Matyjasiak et al. 2016	Barn Swallow	Breeding	avg. 3.5	Geolocator	Leg-loop harness	Flight maneuverability	None
						Flight velocity	None
						Flight acceleration	None
Mong and Sandercock 2007	Upland Sandpiper	Breeding	avg. 2.4	Radio	Glue	Within-season survival	None
						Annual return rate	None
					Leg-loop harness	Within-season survival	None
						Annual return rate	Negative
Morganti et al. 2018	Common Swift	Breeding	<3.0	Geolocator	Full-body harness	Annual return rate	Negative
	Pallid Swift	Breeding	<3.0	Geolocator	Full-body harness	Annual return rate	Negative
Musseau et al. 2021	European Kingfisher	Breeding	avg. 3.0	GPS	Leg-loop harness	Body mass	None
Naef-Daenzer et al. 2001	Great Tit	Post-fledging	2.4-3.3	Radio	Glue or leg-loop harness	Within-season survival	None
						Distance covered	None
	Coal Tit	Post-fledging	4.2-5.8	Radio	Glue or leg-loop harness	Within-season survival	None
						Distance covered	None
Neudorf and Pitcher 1997	Hooded Warbler	Breeding	7-8.5	Radio	Leg-loop harness	Brood provisioning rate	None
Nicoll et al. 2022	Gadfly Petrel	Breeding	avg. 1.0	Geolocator	Tarsus ring	Within-season survival	None
						Annual return rate	None
Peterson et al. 2015	Golden-winged Warbler	Breeding	avg. 5.7	Geolocator	Leg-loop harness	Annual return rate	None
						Territory fidelity	None
						Body mass	None
Powell et al. 1998	Wood Thrush	Migration	avg. 4	Radio	Leg-loop harness	Annual return rate	None
						Body mass	None

Citation	Species	Life history stage[a]	Tag mass[b]	Device type	Attachment type	Study parameter	Direction of impact
Rae et al. 2009	Savannah Sparrow	Post-breeding, pre-migration	<3.0	Radio	Leg-loop harness	Body mass Fat free dry mass Muscle depth Fat mass	None None None None
Raybuck et al. 2017a	Cerulean Warbler	Breeding	3.6-4.0	Geolocator	Leg-loop harness	Within-season survival Brood provisioning rate Nest survival Annual return rate	None None None Negative
Rodriguez-Ruiz et al. 2016	European Roller	Breeding	≤2.6	Geolocator	Back-mounted or leg-loop harness	Brood mass Annual return rate	Negative Negative
Scandolara et al. 2014	Barn Swallow	Breeding	<5.0	Geolocator	Leg-loop harness	Annual return rate Reproductive phenology Clutch size Nestling mass Fledging success	Negative Positive Negative None None
Seward et al. 2021	Arctic Tern	Breeding	<3.0	GPS	Glue	Nest attendance Brood provisioning rate	Negative None
Snijders et al. 2017	Great Tit	Breeding	avg. 7.6	Radio	Leg-loop harness	Breeding propensity Brood provisioning rate Chick mass	Negative None None
Stantial et al. 2018	Piping Plover	Breeding	avg. 2.0	Radio	Glue	Nest survival Chick survival	None None
Stantial et al. 2019	Piping Plover	Breeding	Unknown	Radio	Glue	Annual return rate	None
Stantial and Cohen 2020	Piping Plover	Breeding	avg. 2.0	GPS	Leg-loop harness	Within-season survival Nest survival Chick survival Annual return rate	None None None Negative
Streby et al. 2013	Golden-winged Warbler	Breeding	3.9-4.3	Radio	Leg-loop harness	Clutch size Hatching success Brood size	None None None

Citation	Species	Life history stage[a]	Tag mass[b]	Device type	Attachment type	Study parameter	Direction of impact
						Incubation-stage length	None
						Nestling-stage length	None
						Fledging success	None
						Number of fledglings	None
						Fledgling survival	None
							None
							None
Suedkamp Wells et	Dickcissel	Breeding	Unkn-	Radio	Leg-loop	Acute fecal glucocorticoid	Positive
Taff et al. 2018	Common Yellowthroat	Breeding	3.9-4.7	Geolocator	Leg-loop harness	Annual return rate	Negative
Tomotani et al. 2018, 2021	Great Tit	Captivity	6.0-7.5	Radio	Leg-loop harness	Escape flight capacity	Negative
van Wijk et al. 2016	Eurasian Hoopoe	Breeding	avg. 1.9	Geolocator	Leg-loop harness	Annual return rate	None
						Baseline CORT	None
						Stress-induced CORT	None
						Adult body mass	None
						Territory occupancy	None
						Breeding phenology	None
						Brood success	None
						Number of fledglings	None
						Fledgling weight	None
						Brood provisioning rate	None
Williamson and Witt 2021	Giant Hummingbird	Breeding	Unknown	Geolocator	Three-loop body harness	Mass change	None
Zenzal et al. 2014	Ruby-throated Hummingbird	Migration	avg. 6.0-6.3	Radio	Glue	Flight time	Negative
						Flight range	Negative
			avg. 5.5-5.8	Radio	Glue	Flight time	None
						Flight range	Negative

[a] Life history stage during tagging
[b] Tag mass as percent body mass

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