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EFFECTS OF RADIO TRANSMITTERS ON MIGRATING WOOD THRUSHES

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Abstract.—We quantified the effects of radio transmitters on Wood Thrushes (*Hylocichla mustelina*) using 4 yr of banding and telemetry data from Piedmont National Wildlife Refuge, Georgia. Flight performance models suggest that the 1.6-g transmitter shortens the migratory range of wood thrushes by only 60 km, and the estimated migratory range is adequate to accomplish migration even with limited fat stores. We used two strengths of line, 5- and 9-kg test-strength braided Dacron, to attach the transmitters using the thigh-harness method. We recaptured 13 returning radio-marked wood thrushes, seven of which were still marked. Six of the seven birds marked with the 5-kg test harnesses lost their transmitters within 1 yr while all six of the 9-kg test harnesses were still attached up to 21 mo later. Radio-marking did not reduce the return rates of adults and immatures, and the transmitters did not cause radio-marked birds to lose more mass than banded-only birds. Wood Thrushes can successfully carry a transmitter during migration with no detectable negative effects. We recommend continued use of the thigh-harness method, but we encourage the use of 5-kg cotton line.

EFECTO DE LOS RADIOTRANSMISORES EN *HYLOCICHLA MUSTELINA* MIGRANTES

Sinopsis.—Cuantificamos el efecto de los radiotransmisores en *Hylocichla mustelina* utilizando 4 años de datos de anillaje y de telemetria del Refugio de Vida Silvestre Nacional de Piedmont, en Georgia. Los modelos de desempeño de vuelo sugieren que los radiotransmisores de 1.6-g reducen el alcance migratorio de esta especie por tan solo 60 km, y el alcance migratorio estimado es adecuado para conseguir la migración inclusive con falta de reservas de grasa. Utilizamos lineas de dacrón entrelazadas y probadas para resistencia de dos potencias de linea, de 5-y 9-kg, para ajustar los radiotransmisores utilizando el método de arnés de muslo. Recapturamos 13 aves marcadas con radiotransmisores, siete de las cuales estaban todavía marcadas. Seis de las siete aves marcadas con el arnés de 5-kg de prueba

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perdieron sus radiotransmisores el primer año, mientras que las seis aves con los arneses de prueba de 9-kg los tuvieron consigo hasta 21 meses después. Marcar con radio no redujo las tasas de retorno de adultos o inmaduros, y los radiotransmisores no causaron que las aves radio-marcadas perdieran más masa que las aves que solo fueron anilladas. Individuos de *Hylocichla mustelina* pueden transportar radiotransmisores exitosamente durante la migración sin algún efecto negativo detectable. Recomendamos el uso continuo del método del arnés en el muslo, pero recomendamos el uso de lineas de 5-kg de algodón.

Radio transmitters are an increasingly common tool in field studies of neotropical migrants (Rappole and Tipton 1991, Sykes et al. 1990). Our own studies of Wood Thrushes (*Hylocichla mustelina*) involve extensive use of transmitters on adult and juvenile birds. Most radio-marked birds are not recaptured before migration to enable the removal of the transmitter. While some transmitter attachment designs (e.g., adhesives) permit the eventual 'shedding' of the radio (Sykes et al. 1990), we were unsure whether or not a thigh harness (Rappole and Tipton 1991) of Dacron line would disintegrate before fall migration following a study season.

Wood Thrushes migrate an average of 2200 km, and the amount of fat stored for migration is likely to be related to the distance to be covered (Yong and Moore 1993, 1994). A species' flight range is believed to be limited by the ability to store fuel (Pennycuick 1975). Therefore, we were concerned about the potential negative effects of a transmitter's added mass on a migrating Wood Thrush, given the evidence of lower survival rates and behavioral changes for other radio-marked birds (Bergman et al. 1994, Brigham 1989, Burger et al. 1991, Cotter and Gratto 1995, Paquette et al. 1997, Pietz et al. 1993, Ward and Flint 1995). Transmitters decreased laboratory flight distance and negatively affected some physiological factors of pigeons (Gessaman et al. 1991). The effects of transmitters on wild passerine birds is not well-documented (Sykes et al. 1990), despite their extensive use in field studies (Cochran et al. 1967, Furrer 1979, Graber and Wunderle 1966, Rappole et al. 1989, Stouffer and Caccamise 1991, Winker et al. 1990).

In this paper, our objectives were to: (1) estimate the effects of the transmitter mass on the migratory range of wood thrushes, (2) determine if wood thrushes could successfully transport a radio transmitter during migration, (3) compare return rates of radio-marked and banded-only birds, and (4) compare two types of harness materials used to attach transmitters to wood thrushes.

METHODS

We captured and banded adult (AHY) and fledgling (HY) Wood Thrushes in mist nets during a 4-yr study of population dynamics at Piedmont National Wildlife Refuge (83°40′W, 33°05′N) in central Georgia during 1993–1996. We banded other HY Wood Thrushes at or near their nest at the time of fledging. We radio-marked a subsample of AHY and HY Wood Thrushes with 1.6-g radio transmitters (Holohill Systems, Ltd.) using the thigh-harness method (Rappole and Tipton 1991).

In 1993 and 1994, we used a 56-mm loop of 9-kg test-strength, braided Dacron line, and we secured the square knot with super glue. After the transmitter was situated correctly on the bird's back, we applied super glue in the attachment tubes to keep the radio from moving laterally along the string. Harnesses on smaller HY birds were shortened a few mm to fit, but they were loose enough to allow growth to AHY-size.

Fewer than five transmitters per year were removed from Wood Thrushes that we recaptured after the battery failed during the breeding season. Most Wood Thrushes were still carrying their transmitter when we lost radio contact with them during July–September.

We used Dacron line in hopes that it would rot and the transmitter would fall off the bird. In 1995, we discovered that the 9-kg line was not rotting quickly, so we began using 5-kg test-strength line to attach the transmitters.

We used Pennycuick's (1989) bird flight performance software, Program 1, Version 1.1, to calculate the migratory ranges of Wood Thrushes under various situations. We accepted the default model parameters, including zero headwind, suggested by Pennycuick (1989), with the following exceptions: 38.8-g empty body mass, 16.0-g fat payload mass, and 327-mm wing span (W. Yong, pers. comm.); 5.95 aspect ratio (median value for thrush family, Pennycuick 1989); and 0.15 body drag coefficient (C. J. Pennycuick, pers. comm.). Few data exist on how much fat is loaded prior to migration (Roth et al. 1996), but Yong and Moore (1993) estimated that 16.0 g of fat are needed to complete the trans-Gulf migration. Also, Odum (1993) provided sex-specific wet and dry body mass measurements of AHY and HY migrating Wood Thrushes killed at a television tower before attempting the trans-Gulf flight. From these measurements, we calculated the wet fat mass (HY M: body mass = 43.32 g, fat = 16.55 g; AHY M: body mass = 42.06 g, fat = 17.02 g; HY F: body mass = 40.85 g, fat = 13.18 g; AHY F: body mass = 41.89 g, fat = 13.79 g). Odum's (1993) and Yong and Moore's (1993) estimates differ slightly, and our range estimates depend largely on the body mass and fat load. By keeping these values constant, when appropriate, we can determine the proportional effect of the additional transmitter mass.

We calculated migratory ranges under the following alternative scenarios: (1) normal fat load (16.0 g) with no radio, (2) radio adds extra mass (causes no change in fat load), (3) radio causes reduction in fat load equal to mass of radio, and (4) radio interferes substantially with ability to load fat (we arbitrarily chose decreases of 6.0 and 8.5 g). We estimated the effects of the radio transmitter on migratory range under five wind conditions: still (no wind), slight headwind (5 km/h), fast headwind (25 km/h), slight tailwind (5 km/h), and fast tailwind (25 km/h).

We used Pearson's chi-square test to determine differences in return rate and mass gain between radio-marked and banded-only AHY Wood Thrushes (PROC FREQ, SAS Institute 1987). The small sample size of returning HY Wood Thrushes prevented us from using Pearson's chi-square test (SAS Institute 1987), so we calculated a 95% confidence interval for the binomial sample proportion (Burleson 1980).

RESULTS

We banded 283 AHY and 67 HY Wood Thrushes during 1993–1996. We radio-marked 110 AHY and 38 HY Wood Thrushes (Table 1). We recaptured 11.8% of the radio-marked birds, while 6.9% of the banded-only sample was recaptured in subsequent years ($\chi^2 = 2.06$, df = 1, $P = 0.151$). The total sample of returning Wood Thrushes included 25 AHYs, 23 of which returned to their original banding area (usually within 200 m of the previous location). No radio-marked HYs were recaptured, but two banded HYs (6.9%, 95% CI from −2.3% to 16.1%) did return to the refuge. Although the confidence interval of the radio-marked HYs was not estimable, the inclusion of zero by the confidence interval of the banded-only HYs indicates that the return rates of the two groups were not different. One HY returned to its natal banding area, and the other returned to a location approximately 4 km from its natal area.

Migratory range estimation.—We estimated that the migratory range of Wood Thrushes, without radio transmitters, was 2360 km (Table 2). The addition of a 1.6-g radio decreased this range by 60 km. In fact, under all levels of possible fat loading that we tested, the addition of a radio only decreased the total range by 3% (Fig. 1). Hatch-year birds loaded slightly less fat than adults (Odum 1993) and had lower migratory range estimates (Table 3). Females of both age classes loaded much less fat than males and had correspondingly lower migratory range estimates.

Under the alternative hypothesis that the presence of a radio would cause a decreased fat load, the range was reduced considerably, depending on the amount of reduction in fat load (Table 2). If a Wood Thrush can only carry a maximum, fixed payload, the 1.6-g radio would lower the amount of fat loaded from 16 g to 14.4 g. Migratory range would be decreased by 10.6% (Table 2). These rates varied for each age and sex group (Table 3).

With a 25-km/h headwind, migratory range of a non-marked bird would be decreased by 46%. Ironically, a radio-marked bird's range would only decrease by 41% (Table 2), because in order to counter the effect of the added mass, a radio-marked bird should increase its speed (C. J. Pennycuick, pers. comm.). We estimated that non-radio-marked birds fly at 15.1 m/s while radio-marked birds fly at 16.8 m/s. A tailwind of 5 or 25 km/h would make up for much of the migratory range lost from lowered fat load (Table 2).

Recaptured radio-marked birds.—We recaptured 10 AHYs in 1995 and 1996 that were radio-marked in 1993–1995 (three were marked and returned more than once). In 1995, all six of the returning Wood Thrushes were still carrying their transmitters (one with a radio from 2 yr before). The birds did not show any signs of calluses, wounds, extreme feather loss, or other adverse effects from prolonged transmitter attachment. The 9-kg Dacron string appeared quite strong after either 9 or 21 mo of wear.

TABLE 1. Numbers of Wood Thrushes banded,[a] radio-marked, and returned at the Piedmont National Wildlife Refuge in central Georgia, 1993–1996.

	n banded/radio-marked				Returns from banded/radio-marked sample											
					n 1993				n 1994				n 1995			
Year	M	F	HY	U	M	F	HY	U	M	F	HY	U	M	F	HY	U
1993	16/11	11/3	6/0	10/0	—[b]	—	—	—	—	—	—	—	—	—	—	—
1994	24/19	18/15	18/12	1/0	0/0	1/0	0/0	0/0	—	—	—	—	—	—	—	—
1995	34/17	4/15	4/15	1/0	1/0	0/1	0/0	0/0	2/5	1/0	2/0	0/0	—	—	—	—
1996	32/15	10/15	1/11	0/0	2/0	0/0	0/0	0/0	1/0	0/0	0/0	0/0	4/5	0/2	0/0	0/0

[a] Banded sample size does not include radio-marked birds, although each radio-marked bird was fitted with a USFWS aluminum band.
[b] Returns not possible.

TABLE 2. Migratory range (km) of Wood Thrushes, estimated for five headwind (HW) and tailwind (TW) conditions (km/h). Range was calculated for five treatments, including four possible effects of the radio on fat load: (1) W. Yong's (pers. commun.) calculated normal fat load, 16.0 g, no radio, (2) 1.6-g transmitter, no effect on fat load (16.0 g), (3) transmitter lowers fat load to 14.4 g, (4) transmitter lowers fat load to 10.0 g, and (5) transmitter lowers fat load to 7.5 g.

	Migratory range				
Treatment	HW = 0	HW = 5	HW = 25	TW = 5	TW = 25
1	2360	2143	1274	2577	3446
2	2300	2110	1349	2490	3251
3	2110	1935	1237	2285	2983
4	1580	1447	914	1713	2246
5	1180	1080	680	1280	1680

In 1996, only one of the seven returns from 1995 (fitted with the 5-kg test line) was wearing its radio. Nine of the 10 returning thrushes were re-marked, and their behaviors, including the ability to fly, mate, and produce successful young, were not unusual (L. A. Powell, unpubl. data).

Transmitters did not cause unusual mass loss between years. In fact,

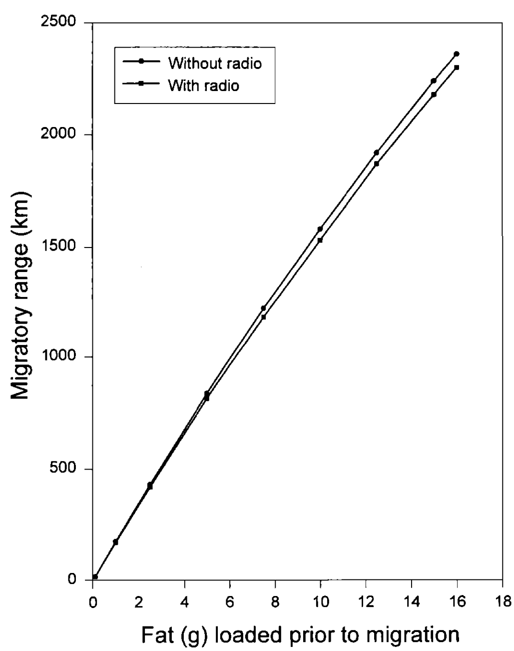

FIGURE 1. Migratory ranges (km), under still conditions, of Wood Thrushes with and without radio transmitters for various levels of fat loading prior to migration. See text for other parameter values used in Pennycuick's (1989) flight performance model.

TABLE 3. Sex-specific estimates of migratory range (km) of adult (AHY) and hatch-year (HY) Wood Thrushes, using data from Odum (1993). Range was calculated for five treatments, including four possible effects of the radio on fat load: (1) Odum's (1993) estimated fat load of migrating thrushes, no radio, (2) 1.6-g transmitter, no effect on fat load, (3) transmitter lowers fat load by 1.6 g, (4) transmitter lowers fat load by 6.0 g, and (5) transmitter lowers fat load by 8.5 g. Reductions of Odum's (1993) estimated fat load in treatments 3–5 are equal to reductions made in Table 2.

	Migratory range			
Treatment	HY M	AHY M	HY F	AHY F
1	2170	2290	1900	1930
2	2130	2240	1860	1880
3	1950	2060	1660	1690
4	1440	1540	1080	1130
5	1130	1220	723	789

69.2% of radio-marked birds ($n = 13$ between-year intervals) gained mass or remained the same between years, while 58.3% of banded-only birds ($n = 12$) did not lose mass ($\chi^2 = 0.32$, df = 1, $P = 0.571$).

DISCUSSION

Wood Thrushes successfully carried a 1.6-g radio transmitter for 2 yr with no apparent negative effects. However, we do not know if the transmitter caused other problems during migration. Yong and Moore (1993, 1994) found that migratory and feeding activity of thrushes captured on the coast following spring migration were related to condition and energy reserves. The returning Wood Thrushes in our study had ample time to replenish fat reserves before reaching our study site, and we did not capture Wood Thrushes immediately after they returned. If the birds were affected by the transmitter, it may have increased migration time or caused the thrushes to deplete an excess "margin of safety fat" (Yong and Moore 1994), both of which would have been difficult to detect with our study.

The transmitter, approximately 4% of the Wood Thrush body mass, did not affect either survival or behavior. Although the transmitter is an additional load during migration, it does not seem to be significant. Indeed, our estimates of migratory range only decreased by 3% under the added mass of a radio transmitter, and thrushes under the extra demands of the transmitter had similar patterns of mass maintenance between years to banded-only birds.

Passerines may be better suited for telemetry research than larger species, such as waterfowl or Gallinaceous birds. Caccamise and Hedin (1985) found that small birds, such as passerines, can carry proportionately heavier loads than large birds. Also, transmitter size, design, and attachment method in our study may have been responsible for the lack of adverse effects that some avian species have shown from radio-marking (e.g., Burger et al. 1991, Cotter and Gratto 1995, Paquette et al. 1997, Pietz et al. 1993, Ward and Flint 1995). The Wood Thrushes were able to preen the transmitters under their feathers, allowing for virtually no drag during flight. Larger, bulkier transmitters could add mass and increase drag (Obrecht et al. 1988, Pennycuick 1989, Sykes et al. 1990).

Migration was unaffected by the additional mass of our transmitters, or Wood Thrushes compensated by increasing the amount of fat needed to reach their "set point" (Yong and Moore 1993) before making the trans-Gulf flight. However, increased fat loading may not be necessary. The Wood Thrushes' estimated migratory range is more than enough to make the approximately 1000-km trans-Gulf flight under still conditions and moderate reductions in fat-loading. The range for females and HY thrushes drops below 1000 km under the most drastic reduction of fat loading that we simulated (Table 3). Because we do not know the actual effect of the transmitter on fat loading, we suggest further study of the effects of radio transmitters on female and HY birds.

Our research shows that Wilson's (1975) principle of stringency may be applicable to migrating birds. Wilson (1975) predicted that organisms evolve to prepare for unpredictable events such as random reductions in food supply (Ettinger and King 1980) or changes in wind direction during migration. Leberg et al. (1996) reported that most Wood Thrushes arriving in the U.S. after the spring migration were not seriously fat depleted, suggesting that the birds began their migration with a heavier load than necessary for an "average" trip. Migratory birds may possess the energetic flexibility to contend with a wide range of contingencies encountered during migration, which may enable them to cope with the added weight of a transmitter.

Our Wood Thrush research may contradict some commonly held migratory assumptions. Migration requires sufficient caloric acquisition to allow for significant, non-stop flights including long distances over the Gulf (Alerstam and Lindström 1990, Moore et al. 1995, Pennycuick 1975, Yong and Moore 1993). But if Wood Thrushes can successfully complete migration with an additional 1.6-g mass attached, perhaps the mass of fat loaded before fall and spring migrations by Wood Thrushes is less critical than previously thought. Moore et al. (1995) provided several examples of large variability among individuals in fat loading and behaviors prior to fall migration, and Leberg et al. (1996) reported that most Wood Thrushes, Swainson's Thrushes (*Catharus ustalatus*), and Summer Tanagers (*Piranga rubra*) had not depleted their fat reserves to critical levels following spring migration. Other short- and medium-distance migrants may show analogous trends, and we suggest similar research on other species.

Our recapture data also provide evidence of the effectiveness, mechanically and energetically, of the Rappole and Tipton (1991) thigh harness attachment method. None of the returning Wood Thrushes, including an individual which was recaptured 21 mo after the original attachment, showed any adverse effects of the transmitter on body condition. Radio-marked AHY Kirtland's Warblers (*Dendroica kirtlandii*) had a significantly lower return rate than banded-only birds (P. Sykes and C. Kepler cited in Samuel and Fuller 1996: 388), but our radio-marked sample of AHY Wood Thrushes tended towards ($P = 0.15$) a higher return rate than the banded-only samples. We are satisfied that our transmitters, attached with the Rappole and Tipton (1991) harness method, did not have an overtly negative effect on the radio-marked Wood Thrushes.

We recommend continued use of the Rappole and Tipton (1991) harness method, but we encourage the use of 5-kg test-strength braided Dacron line. This line is strong enough to keep the transmitter on during the breeding season, but it shows evidence of rotting in less than 9 mo.

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