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# LONGEVITY OF SOLAR-POWERED RADIO TRANSMITTERS ON BUTEONINE HAWKS IN EASTERN COLORADO

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Abstract.—From 1982 through 1986, solar-powered radio transmitters were attached to 23 adult and seven fledgling Red-tailed Hawks (*Buteo jamaicensis*), seven adult Ferruginous Hawks (*B. regalis*) and seven adult Swainson's Hawks (*B. swainsoni*) in eastern Colorado. Transmitters were attached by means of a teflon-ribbon harness as a backpack ($n = 39$), or epoxied and sutured to the rachis of a tail feather ($n = 5$). Excluding transmitters that appeared to fail immediately after release ($n = 3$), or that were lost when tail feathers were shed prematurely ($n = 5$), the time from release to last telemetry contact (minimum life) for adult hawks ranged from 14 to 2931 d ($\bar{x} = 452$, $n = 26$). The median minimum transmitter life for adult hawks was 352 d; 15 (58%) of 26 adult hawks fitted with backpack-mounted transmitters that were not subsequently found dead on the study area ($n = 2$) were observed with functioning transmitters ≥1 breeding season subsequent to capture. Minimum life for transmitters on juvenile hawks ranged from 59 to 108 days ($\bar{x} = 73$, $n = 7$) and last telemetry contact coincided with when young dispersed from natal territories. All nine adult Red-tailed Hawks, six (86%) of seven Ferruginous Hawks, and six (100%) of six Swainson's Hawks captured and fitted with radio transmitters during the breeding season successfully raised young to banding age in the year that they were captured. In the subsequent breeding season, active nests were located in eight (89%) of nine Red-tailed Hawk, three (43%) of seven Ferruginous Hawk, and four (67%) of six Swainson's Hawk territories where adults had previously been captured. Success of these nests was 100% for Red-tailed Hawks, 67% for Ferruginous Hawks, and ≥50% for Swainson's Hawks. One Red-tailed Hawk captured as a breeding adult survived a minimum of nine breeding seasons while equipped with a transmitter and successfully raised young to banding age in ≥7 of those years.

## LONGEVIDAD DE RADIOTRANSMISORES CON BATERÍAS SOLARES COLOCADOS EN BUTEOS DEL ESTE DE COLORADO

Sinopsis.—De 1982 a 1986 se le colocaron radiotransmisores, impulsados con energía solar, a 23 adultos y siete volantones de (*Buteo jamaicensis*), siete adultos de *B. regalis* y siete adultos de *B. swainsoni*. Se montaron 39 transmisores tipo mochila, en la espalda de las aves, sujetados con un arnés construido con tirillas de teflón. A otras cinco aves se les pegó el transmisor al raquis de una de las plumas de la cola con sutura y epoxi. Excluyendo transmisores que fallaron inmediatamente luego de la liberación de las aves ($n = 3$), o que se perdieron cuando las aves mudaron las plumas de la cola prematuramente ($n = 5$), el período mínimo de funcionamiento o vida de las transmisores varió de 14 a 2931 días ($\bar{x} = 452$, $n = 26$). El período promedio mínimo de funcionamiento para los transmisores colocados en halcones adultos fue de 352 días. Quince (58%) de los 26 halcones adultos a los cuales se le colocaron mochilas, y que no se hallaron posteriormente muertos ($n = 2$), se encontraron con los transmisores funcionando una temporada reproductiva (≥1) subsiguientemente a su captura. El período mínimo de funcionamiento de transmisores colocados a halcones juveniles varió de 59 a 108 días ($\bar{x} = 73$, $n = 7$) y el último contacto radiotelemétrico coincidió con la dispersión de estos fuera de sus territorios natales. Los nueve adultos de *B. jamaicensis*, seis (86%) de los siete adultos de *B. regalis* y el 100% (seis) de los adultos de *B. swainsoni*

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a los cuales se les colocaron radiotransmisores durante la época de reproducción criaron pichones, durante ese mismo año, al menos hasta la edad en que fueron anillados. En épocas reproductivas subsiguientes se localizaron nidos activos de ocho (89%) de los *B. jamaicensis*, tres (43%) de los *B. regalis* y cuatro (67%) de los *B. swainsoni* en los territorios donde fueron capturados. El éxito de anidamiento fue de 100%, 67% y ≥ a 50% en el orden en que fueron mencionadas estas especies, respectivamente. Un *B. jamaicensis* capturado como adulto, y al cual se le colocó un radiotransmisor, sobrevivió un mínimo de nueve épocas reproductivas y crió pichones exitosamente al menos hasta la edad de anillamiento en ≥7 de los nueve años.

Solar-powered radio transmitters have the advantages of providing more energy and potentially functioning for longer periods, relative to battery-powered transmitters of similar mass. These characteristics are especially desirable when transmitter packages must be small, and are placed on highly mobile species, such as birds of prey. Recently, Snyder et al. (1989) reported on the utility of solar-powered radio transmitters mounted as backpacks on Snail Kites (*Rostrhamus sociabilis*). They concluded that solar-powered transmitters attached as backpacks had little effect on the birds, and packages weighing 14–21 g had effective lives of from 8–21 mo. Solar-powered transmitters have been attached to other raptors, including Bald Eagles (*Halieeatus leucocephalus*) (Buehler et al. 1991a,b; Wood 1992), although except for Snail Kites (Snyder et al. 1989), evaluation of their effectiveness and potential impact on survival or reproduction has not been reported. Here, I describe attachment of solar-powered transmitters to adult and fledgling Red-tailed Hawks (*Buteo jamaicensis*), Ferruginous Hawks (*B. regalis*), and Swainson's Hawks (*B. swainsoni*) in eastern Colorado from 1982 through 1986, and evaluate their longevity and effect on subsequent behavior and reproduction.

## METHODS

*Study areas.*—Birds of prey were captured and equipped with radio transmitters on the Fort Carson Military Reservation (FCMR) in east-central Colorado from 1982 through 1983, and on the Piñon Canyon Maneuver Site (PCMS) in southeastern Colorado from 1983 through 1986. The 556-km$^2$ FCMR was located along the eastern edge of the Front Range south of Colorado Springs, Colorado, and was characterized by rolling shortgrass prairie intersected by foothills dominated by pinyon pine (*Pinus edulis*) and juniper (*Juniperus* spp.). The 1040-km$^2$ PCMS, located in Las Animas County in southeastern Colorado, was similarly characterized by rolling shortgrass prairie intersected by low bluffs and the canyon system of the Purgatoire River; both were dominated by a pinyon pine-juniper vegetative community. Topography, climate, and vegetation for the FCMR (Andersen et al. 1985, 1986) and the PCMS (Andersen and Rongstad 1989, Andersen et al. 1990, Shaw and Diersing 1990) have been described previously.

*Nest success.*—Occupied territories and active nests were located on the study areas in spring from helicopters (White and Sherrod 1973) and by searching potential territories from the ground for nest sites (Craighead and Craighead 1956). Each year after locating an active nest (1983 on the FCMR, 1984–1988 on the PCMS), I checked the previous nest site and vicinity for evidence of territory occupancy and the presence of an active nest, regardless of whether a radio-equipped bird was observed at or near the nest site. In addition, one Red-tailed Hawk territory on the FCMR was checked from 1983 to 1992 in conjunction with searching for a radio-marked bird. Terminology and definitions related to reproduction follow those of Postupalsky (1974). A nest was classified as active when young were raised or eggs were laid in the nest, or an adult was observed in incubating posture in the nest. A nest was classified as successful when young reached bandable age (approx. 3–4 wk) or were observed perched outside of the nest (e.g., on branches in the nest tree).

*Capture, transmitter specifications and transmitter attachment.*—Adult birds of prey were captured with bal-chatri traps (Berger and Mueller 1959) baited with rats, dho-gaza nets baited with a live Great Horned Owl (*Bubo virginianus*) (Hamerstrom 1963), or with noose carpets placed on the rim of active nests. In one instance, I recaptured an adult Red-tailed Hawk, which had a functioning battery-powered transmitter, at night with a spotlight and hand-held net. Fledglings were captured by hand at or near the nest. The sex of adult raptors was determined subsequent to capture on the basis of behavior at or near a nest and size relative to the other member of a breeding pair.

Captured birds were measured, banded with U.S. Fish and Wildlife Service aluminum lock-on bands, fitted with a radio transmitter and released at the site of capture. Processing individual birds took approximately 1 h. Birds were restrained by placing a falconer's hood over their heads and tying their feet together. In one instance, an individual that was captured at night was held until the next morning and returned to and released at the site of capture. Radio transmitters were attached either as backpacks (Andersen et al. 1986, Smith and Gilbert 1981), or affixed to the rachis of a central rectrix (Dunstan 1973). Backpacks consisted of woven teflon ribbon (Bally Ribbon Mills, Bally, Pennsylvania; use of company names does not imply endorsement by the U.S. Fish and Wildlife Service or the University of Wisconsin) that was attached to the bottom of the transmitter with epoxy. Attachment was similar to that described by Snyder et al. (1989), with the exception that no attempt was made to shield the transmitter from overlapping contour feathers. In five cases (Table 1), transmitters were attached on the dorsal side of a central rectrix with 5-min epoxy and surgical sutures.

One-stage, solar-powered transmitters (150–152 MHz) were obtained from Advanced Telemetry Systems, Inc. (Isanti, Minnesota) and Telemetry Systems, Inc. (Mequon, Wisconsin). Transmitter dimensions varied among years, but were approximately 4.5 × 1.5 × 1.5 cm with a 25-cm braided stainless steel antenna that exited the potting material flush with the bottom of the transmitter. Four 1 × 1 cm solar panels wired in series were located on the top of each transmitter, and all but five transmitters contained rechargeable nickel-cadmium batteries. Five transmitters placed on fledgling Red-tailed Hawks in 1983 did not contain rechargeable batteries and were powered directly by solar panels. Pulse width ranged between 25 and 30 ms, and pulse rate in transmitters with rechargeable batteries ranged from 60 to 100/min. Pulse rate in transmitters without rechargeable batteries varied widely from near 0 to >100/min, depending upon power output from the solar panels. Transmitters weighed between 12 and 18 g, and attached transmitter packages weighed approximately 15–25 g.

*Radio telemetry procedures.*—After capture and radio attachment, all birds were located using portable telemetry receiving equipment based from a vehicle, all-terrain cycles, horseback, on foot, or from aircraft (both fixed-wing and helicopters). Through 1986 on the PCMS and through 1983 on the FCMR, we searched for all birds weekly, until either they left the study area, we were unable to locate them on the study area repeatedly, or there was evidence that the bird had died, lost its transmitter or the bird's transmitter had stopped functioning. When a bird was not located after ≥2 attempts from the ground, we attempted to locate the bird from aircraft. On the FCMR in 1984, we checked for functioning transmitters from the ground during the breeding season, and on the PCMS in 1987 and 1988, birds whose fate was not known previously were searched for on the study area during the breeding season from fixed-winged aircraft and helicopter. In addition, from 1985 to 1992, the territory of one bird on the FCMR was checked from the ground once annually during the breeding season to determine whether the bird's transmitter continued to function. Most birds were also followed intensively for some period subsequent to radio attachment (e.g., Andersen et al. 1986, 1990).

## RESULTS

From 1982 through 1986, 30 Red-tailed Hawks, seven Ferruginous Hawks, and seven Swainson's Hawks were captured on the FCMR and the PCMS and equipped with solar-powered radio transmitters (Table 1). Five transmitters were attached on the tail feathers of adult Red-tailed Hawks; all other transmitters were attached as backpacks. Transmitters were placed on seven fledgling Red-tailed Hawks in 1982 ($n$ = 2) and 1983 ($n$ = 5); all other transmitters were placed on adult hawks that were members of resident pairs on the study areas.

Three transmitters failed within 1–2 d of attachment, based on reobservation of non-functioning radio transmitters on territorial birds. In two other instances, birds were found dead on the study area when a signal that had not been received for a substantial period was again detected; a signal from one of these birds had not been received since 2 d post-release. In three of five cases where transmitters were mounted on tail feathers, birds either shed or chewed through the rachis of the feather to which the transmitter had been attached within approximately 1 mo. A signal from one additional tail-mounted transmitter was not received subsequent to release of the bird, and the final tail-mounted transmitter

TABLE 1. Buteonine hawks fitted with solar-powered radio transmitters on the Fort Carson Military Reservation and the Piñon Canyon Maneuver Site, Colorado from 1982 through 1986.

| Species | Age[1] | Sex[2] | Attachment method[3] | Date attached | Date last located | Minimum transmitter life (d) |
|---|---|---|---|---|---|---|
| Red-tailed Hawk | ASY | F | tail | 28 May 1982 | 14 Jun. 1982 | 17 |
| (*Buteo jamaicensis*) | ASY | F | backpack | 31 May 1982 | 9 Nov. 1982 | 162 |
| | ASY | F | tail | 18 May 1982 | 23 Jun. 1982 | 36 |
| | ASY | F | backpack | 5 Jun. 1982 | 13 Jun. 1990 | 2931 |
| | ASY | F | backpack | 8 Jun. 1982 | 21 Sep. 1982 | 105 |
| | ASY | F | tail | 21 May 1983 | 13 Jun. 1983 | 23 |
| | ASY | F | tail | 18 May 1983 | 28 Aug. 1983 | 102 |
| | ASY | M | tail | 26 May 1983 | 26 May 1983 | 0 |
| | ASY | U | backpack | 7 Jun. 1983 | 12 Dec. 1983 | 188 |
| | ASY | M | backpack | 8 Mar. 1984 | 10 Mar. 1984[4] | 2 |
| | ASY | M | backpack | 5 Mar. 1984 | 1 Mar. 1985 | 362 |
| | ASY | M | backpack | 26 Sep. 1984[5] | 20 Nov. 1984 | 55 |
| | ASY | F | backpack | 24 Feb. 1984 | 8 Nov. 1986 | 988 |
| | ASY | F | backpack | 7 Jun. 1984 | 20 Nov. 1984[4] | 166 |
| | ASY | F | backpack | 8 Jun. 1984 | 6 Nov. 1985 | 517 |
| | ASY | F | backpack | 10 Jun. 1984 | 13 Dec. 1985 | 552 |
| | ASY | F | backpack | 16 Jun. 1985 | 17 Jun. 1985[6] | 2 |
| | ASY | F | backpack | 22 Jun. 1985 | 22 Feb. 1987 | 611 |
| | ASY | M | backpack | 10 Feb. 1986 | 11 Feb. 1987 | 367 |
| | ASY | M | backpack | 13 Feb. 1986 | 8 May 1987 | 450 |
| | ASY | M | backpack | 31 May 1986 | 30 Oct. 1986 | 152 |
| | ASY | F | backpack | 5 Jun. 1986 | 24 Nov. 1986 | 172 |
| | ASY | F | backpack | 12 Jun. 1986 | 14 Jun. 1986[6] | 2 |
| | L | U | backpack | 4 Jul. 1982 | 13 Aug. 1982 | 89 |
| | L | U | backpack | 16 May 1982 | 1 Sep. 1982 | 108 |
| | L[7] | U | backpack | 14 Jun. 1983 | 21 Aug. 1983 | 68 |
| | L[7] | U | backpack | 16 Jun. 1983 | 19 Aug. 1983 | 64 |
| | L[7] | U | backpack | 16 Jun. 1983 | 19 Aug. 1983 | 64 |
| | L[7] | U | backpack | 23 Jun. 1983 | 21 Aug. 1983 | 59 |
| | L[7] | U | backpack | 17 Jun. 1983 | 17 Aug. 1983 | 61 |

TABLE 1. Continued.

| Species | Age[1] | Sex[2] | Attachment method[3] | Date attached | Date last located | Minimum transmitter life (d) |
|---|---|---|---|---|---|---|
| Ferruginous Hawk | ASY | M | backpack | 31 May 1984 | 27 Jun. 1984 | 27 |
| (*Buteo regalis*) | ASY | M | backpack | 24 Jun. 1985 | 21 Oct. 1985 | 119 |
| | ASY | M | backpack | 26 Jun. 1985 | 23 May 1987 | 697 |
| | ASY | M | backpack | 27 Jun. 1985 | 5 Aug. 1986 | 405 |
| | ASY | F | backpack | 25 Jun. 1985 | 24 Jun. 1986 | 365 |
| | ASY | F | backpack | 1 Jul. 1985 | 15 Jul. 1985 | 14 |
| | ASY | M | backpack | 23 Jun. 1986 | 17 Jul. 1986 | 24 |
| Swainson's Hawk | ASY | M | backpack | 28 Jun. 1985 | 3 May 1986 | 310 |
| (*Buteo swainsoni*) | ASY | F | backpack | 5 Jul. 1985 | 19 Jun. 1987 | 715 |
| | ASY | F | backpack | 6 Jul. 1985 | 20 Aug. 1986[6] | 411 |
| | ASY | M | backpack | 9 Jul. 1985 | 24 Aug. 1985 | 46 |
| | ASY | M | backpack | 29 Jun. 1985 | 17 Jun. 1987 | 354 |
| | ASY | F | backpack | 29 Jun. 1986 | 29 Jun. 1986[6] | 0 |
| | ASY | F | backpack | 11 Jul. 1986 | 25 Jun. 1987 | 350 |

[1] ASY = after second year, L = local (Anonymous 1977).
[2] U = unknown, F = female, M = male.
[3] Transmitters were attached as a backpack or epoxied to a tail feather as described in text.
[4] Subsequently found dead with transmitter attached.
[5] Battery-powered transmitter replaced with solar-powered transmitter on 26 Sep. 1984.
[6] Immediate failure; bird subsequently observed with non-functioning transmitter attached.
[7] Transmitters on fledglings that did not contain rechargeable batteries.

was not recovered. Data from these birds have been removed from further analyses.

Minimum transmitter life ranged between 14 and 2931 d for all adult hawks ($\bar{x}$ = 438, SD = 563, $n$ = 26), 105–2931 d for adult Red-tailed Hawks ($\bar{x}$ = 581, SD = 748, $n$ = 13), 14–697 d for adult Ferruginous Hawks ($\bar{x}$ = 236, SD = 261, $n$ = 7), 46–719 d for adult Swainson's Hawks ($\bar{x}$ = 364, SD = 214, $n$ = 6) and 59–108 d for juvenile Red-tailed Hawks ($\bar{x}$ = 73, SD = 18, $n$ = 7). The median minimum transmitter life for all adult hawks (excluding immediate transmitter failures and birds that died and were subsequently recovered, Table 1) was 352 d (Fig. 1). Fifteen (58%) of 26 adult hawks with backpack-mounted transmitters were observed with functioning transmitters on the study areas ≥1 breeding season after they were captured and equipped with transmitters: eight (57%) of 14 Red-tailed Hawks, three (43%) of seven Ferruginous Hawks and four (80%) of five Swainson's Hawks.

On the PCMS, nine adult Red-tailed Hawks were captured as members of reproducing pairs during the breeding season. All nine (100%) raised young to banding age. The year following capture, I located active nests in eight (89%) of these territories, and all eight (100%) nests produced young that reached banding age. In addition, four adult Red-tailed Hawks that were members of resident pairs were captured prior to the breeding season. Three (75%) of these birds attempted nesting in the year they were captured, but only one (33%) successfully raised young to banding age. In the subsequent breeding season, I located active nests in three (75%) of these territories: one (33%) produced young that reached banding age, one (33%) nest failed and the fate of one (33%) nest was not determined conclusively. On the FCMR, one Red-tailed Hawk was located with a functioning transmitter 2931 d after it was captured (Table 1). That individual nested successfully the year that it was captured, and in at least six of the eight subsequent breeding seasons (Table 2) that it carried a functioning transmitter.

Seven adult Ferruginous Hawks were captured on the PCMS as members of reproducing pairs during the breeding season. Six (86%) of these birds raised young to banding age the year that they were captured. The year following capture, active nests were located in three (43%) of these territories, and two (67%) of these nests produced young that reached banding age. Six adult Swainson's Hawks were captured during the breeding season on the PCMS, and all six (100%) raised young to banding age. Active nests were located in four (67%) of these territories the subsequent breeding season; two (50%) of these nests produced young that reached banding age, one (25%) nest failed and the fate of one (25%) nest was not determined conclusively.

## DISCUSSION

The potential advantages of solar-powered radio transmitters have been recognized for some time (e.g., Aucouturier et al. 1977, Church 1979, Patton et al. 1973), although their efficiency in the field has rarely been

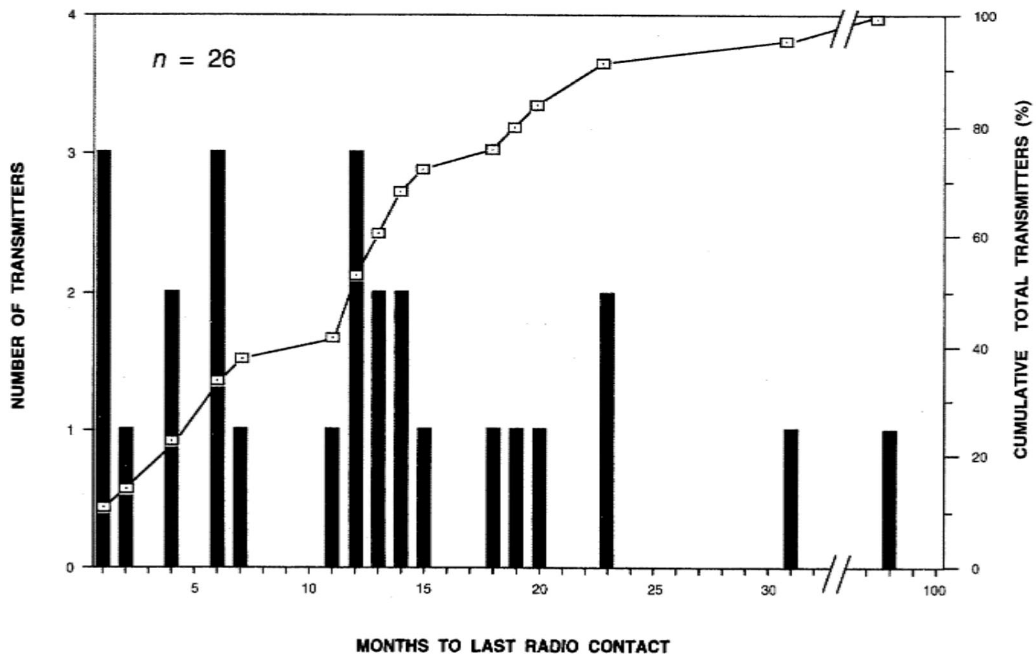


FIGURE 1. Frequency and cumulative frequency distributions of the time to last radio contact from solar-powered transmitters attached as backpacks to 26 adult Red-tailed, Ferruginous and Swainson's Hawks in eastern Colorado 1982–1986. Transmitters that failed within 1–2 d of attachment ($n = 3$) and transmitters recovered from birds that died ($n = 2$) are not included (see text).

reported (see Herman 1981, Silvy et al. 1979, Snyder et al. 1989). For relatively long-lived species such as many raptors, the ability to monitor the movements and behavior of individuals over several years provides the opportunity to address ecological and management questions at a time scale longer than would be possible with shorter-lived transmitters. In addition, repeatedly capturing individuals is difficult for many species of raptors; thus in long-term studies it is often desirable to attach transmitters with the maximum potential life, rather than depend upon recapturing individuals and replacing transmitters when batteries fail. Mounted as backpacks on Red-tailed, Ferruginous and Swainson's Hawks in eastern Colorado, solar-powered transmitters weighing 12–18 g functioned for up to 8 yr, and >50% functioned for ≥2 breeding seasons. In one instance, an individual Red-tailed Hawk carried a functioning solar-powered transmitter for a minimum of 8 yr, which included nine breeding seasons and ≥7 nesting attempts (Table 2). These results indicate that at least in some environments, solar-powered transmitters have the potential to function for several years and at the same time, remain below mass and size constraints for medium-sized raptors.

The potential effect of the marker on an animal is of concern in any study that involves attaching markers to animals. This is especially true in radio-telemetry studies where the behavior of individuals is of interest and where the animals being studied are highly mobile. Few tests of the

TABLE 2. Breeding and telemetry history of an adult female Red-tailed Hawk equipped with a solar-powered radio transmitter on the Fort Carson Military Reservation in east-central Colorado 1982–1992.

| Year | Date last located | Nesting status | # young surviving to banding | Signal received | Observations |
|---|---|---|---|---|---|
| 1982 | 1 Dec. | captured at nest | 1 | yes | fitted with transmitter 5 Jun. 1982 |
| 1983 | 19 Sep. | nesting | 1 | yes | radio tracked regularly |
| 1984 | 29 May | nesting | 2 | yes | transmitter antenna "kinked" |
| 1985 | 19 Jun. | nesting | 1 | yes | transmitting |
| 1986 | 10 Jun. | nesting | 3 | yes | transmitting |
| 1987 | 21 Jun. | nesting | ≥2 | yes | transmitting |
| 1988 | not checked | — | — | — | — |
| 1989 | 13 Jun. | on territory | unknown | yes | transmitting |
| 1990 | 13 Jun. | nesting | ≥2 | yes | transmitting |
| 1991 | not located | — | — | no | ground search of previous nesting territories |
| 1992 | not located | — | — | no | ground search of previous nesting territories |

effect of radio transmitters on raptors have been conducted. Foster et al. (1992) concluded that radio transmitters mounted as backpacks on Spotted Owls (*Strix occidentalis*) had no significant effect on survival and that owls did not appear to lose weight after being equipped with transmitters. They noted, however, a tendency for radio-equipped owls to produce fewer young than owls marked with color bands. Snyder et al. (1989) concluded that transmitters mounted as backpacks on Snail Kites had little effect on survival of birds marked as either adults or nestlings. McCrary (1981) concluded that Red-shouldered Hawks (*Buteo lineatus*) equipped with battery-powered transmitters mounted as backpacks exhibited marked behavioral changes for the first few hours after release, but that behaviors returned to normal by the following day. Similarly, Smith and Gilbert (1981) tested several backpack designs on Eastern Screech-Owls (*Otus asio*), and concluded that after a short adjustment period, behavior and flight performance were not impaired. I was unable to compare the behavior of radio-marked birds to that of unmarked birds, although reproductive success of radio-marked birds was comparable to that of unmarked birds on the study areas. Similarly, the probability that territories where birds were radio-marked contained active nests the year subsequent to marking was similar to reoccupancy rates of territories with unmarked birds (D. E. Andersen, unpubl. data).

Compared to battery-powered transmitters, solar-powered transmitters have the advantage of the potential for substantially longer life. The potential effects of attaching solar-powered transmitters are similar to those for battery-powered transmitters, and on many raptors appear minimal. In at least some field settings, solar-powered transmitters mounted as backpacks on raptors provide an attractive alternative to battery-powered transmitters, especially when studies are long term.

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## LITERATURE CITED

Andersen, D. E., and O. J. Rongstad. 1989. Surveys for wintering birds of prey in southeastern Colorado: 1983–1988. J. Raptor Res. 23:152–156.

———, ———, and W. R. Mytton. 1985. Line transect analysis of raptor abundance along roads. Wildl. Soc. Bull. 13:533–539.

———, ———, AND ———. 1986. The behavioral response of a Red-tailed Hawk to military training activity. Raptor Res. 20:65–68.

———, ———, AND ———. 1990. Home-range changes in raptors exposed to increased human activity levels in southeastern Colorado. Wildl. Soc. Bull. 18:134–142.

ANONYMOUS. 1977. North American bird banding manual. Volume II: bird banding techniques. U.S. Dept. Int., Fish and Wildlife Service and Dept. Fisheries and the Environ., Canadian Wildlife Service.

AUCOUTURIER, J. L., A. CHAILLOU, G. NICOLAS, R. CANIVENC, R. GOVAERTS, R. MERTENS, F. LAUWERS, R. J. VAN OVERSTRAETEN, M. MARGUES, AND A. KOCSIS. 1977. Biotelemetry and radiotracking of wild birds: portable device using solar cells power supply. Pp. 45–49, *in* F. M. Long, ed. Proc. First Int. Conf. on Wildl. Biotelemetry. Univ. Wyoming, Laramie, Wyoming.

BERGER, D. D., AND H. C. MUELLER. 1959. The bal-chatri: a trap for the birds of prey. Bird Banding 30:8–26.

BUEHLER, D. A., T. J. MERSMANN, J. D. FRASER, AND J. K. D. SEEGAR. 1991a. Nonbreeding bald eagle communal and solitary roosting behavior and roost habitat on the northern Chesapeake Bay. J. Wildl. Manage. 55:273–281.

———, ———, ———, AND ———. 1991b. Differences in distribution of breeding, nonbreeding, and migrant Bald Eagles on the northern Chesapeake Bay. Condor 93: 399–408.

CRAIGHEAD, J. J., AND F. C. CRAIGHEAD, JR. 1956. Hawks, owls and wildlife. Stackpole Co., Harrisburg, Pennsylvania, and The Wildlife Management Institute, Washington, D.C. 443 pp.

CHURCH, K. E. 1979. Expanded radio tracking potential in wildlife investigations with the use of solar transmitters. Pp. 247–249, *in* C. J. Amlaner, Jr. and D. W. Macdonald, eds. A handbook on biotelemetry and radio tracking. Pergamon Press Ltd., Oxford, England.

DUNSTAN, T. C. 1973. A tail feather package for radio-tagging raptorial birds. Inland Bird Banding News 45:3–6.

FOSTER, C. C., E. D. FORSMAN, E. C. MESLOW, G. S. MILLER, J. A. REID, F. F. WAGNER, A. B. CAREY, AND J. B. LINT. 1992. Survival and reproduction of radio-marked adult spotted owls. J. Wildl. Manage. 56:91–95.

HAMERSTROM, F. 1963. The use of Great Horned Owls in catching Marsh Hawks. Proc. Int. Ornithol. Congr. 13:866–869.

HERMAN, M. F. 1981. The use of solar-powered radios on spruce grouse in Montana. Pp. 80–89 *in* F. M. Long, ed. Proc. Third Int. Conf. on Wildl. Biotelemetry. Univ. Wyoming, Laramie, Wyoming.

MCCRARY, M. D. 1981. Effects of radio-tagging on the behavior of Red-shouldered Hawks. N. Am. Bird Bander 6:138–141.

PATTON, D. R., D. W. BEATY, AND R. H. SMITH. 1973. Solar panels: an energy source for radio transmitters on wildlife. J. Wildl. Manage. 37:236–238.

POSTUPALSKY, S. 1974. Raptor reproductive success: some problems with methods, criteria and terminology. Pp. 21–32, *in* F. N. Hamerstrom, Jr., B. E. Harrell, and R. R. Olendorff, eds. Management of raptors. Raptor Res. Rep. No. 2.

SHAW, R. B., AND V. E. DIERSING. 1990. Tracked vehicle impacts on vegetation at the Pinyon Canyon Maneuver Site, Colorado. J. Environmental Quality 19:234–243.

SILVY, N. J., C. R. HOPKINS, J. D. HORKEL, AND R. S. LUTZ. 1979. Field evaluation of solar-powered radio-telemetry transmitters. Pp. 219–227, *in* F. M. Long, ed. Proc. Second Int. Conf. on Wildl. Biotelemetry. Univ. Wyoming, Laramie, Wyoming.

SMITH, D. G., AND R. GILBERT. 1981. Backpack radio transmitter attachment success in Screech Owls (*Otus asio*). N. Am. Bird Bander 6:142–143.

SNYDER, N. F. R., S. R. BEISSINGER, AND M. R. FULLER. 1989. Solar radio-transmitters on Snail Kites in Florida. J. Field Ornithol. 60:171–177.

WHITE, C. M., AND S. K. SHERROD. 1973. Advantages and disadvantages of the use of rotor-winged aircraft in raptor surveys. Raptor Res. 7:97–104.

WOOD, P. B. 1992. Habitat use, movements, migration patterns, and survival rates of subadult bald eagles in north Florida. Ph.D. diss. Univ. Florida, Gainesville, Florida.

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