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INFLUENCE OF RADIO TRANSMITTERS ON PRAIRIE FALCONS

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Abstract.—We examined the effects of backpack radio transmitters on Prairie Falcon (*Falco mexicanus*) reproduction (percentage of occupied territories producing young and number of nestlings produced) over four years. In addition, we observed falcon aeries during brood-rearing to determine attendance at the nest and in the territory, prey delivery rates, and prey composition. We found no effect of radio tagging on Prairie Falcon productivity (nesting success and brood size) among years, although productivity varied significantly among years. The sex of the falcon tagged did not affect productivity. Radio-tagged members of pairs did not differ significantly from un-tagged members of pairs in territory attendance, nest attendance, prey delivery rates, or caching rates. Nestlings raised by radio-tagged parents attained masses similar to those reared by control parents. During low prey years, radio-tagged males brought a greater proportion of small birds and reptiles, and fewer mammals to the nest area than control males.

LA INFLUENCIA DE LOS RADIOTRANSMISORES EN *FALCO MEXICANUS*

Sinopsis.—Por cuatro años examinamos el efecto de los radiotransmisores de tipo arnés en la reproducción (porciento de territorios ocupados produciendo crías y número de pichones producidos) de *Falco mexicanus*. En adición, observamos los vuelos de la especie durante la crianza de los hijos para determinar su presencia en el nido y en el territorio, las tasas de entrega de presas y la composición del banco de presas. No encontramos ningún efecto de tener radiotransmisores en la productividad de la especie (exito de anidaje y tamaño de la camada) entre años, aunque entre años la productividad varió significativamente. El sexo del ave marcada no afectó su productividad. Las aves radiomarcadas de una pareja no mostraron diferencias significativas de sus parejas en presencia en su territorio, atención al nido, tasas de entrega de presas y tasas de colección. Pichones criados por padres con radiotransmisores adquirieron masas similares a las de aquellos criados por padres control. Durante años de escasez de presas, los machos con radiotransmisores trajeron una mayor proporción de aves pequeñas y reptiles, y menos mamíferos al área del nido que los machos control.

Use of radiotelemetry to mark and relocate animals has emphasized the need to identify any effects of tagging before making inferences about an animal's biology (Hiraldo et al. 1994, Wanless 1992). Species respond differently to radio tagging (Anderson 1994, McCrary 1981, Paton et al. 1991, Sodhi et al. 1991, Taylor 1991, Ward and Flint 1995). Radio tagging can adversely affect condition and behavior by abrading skin, influencing time budgets, decreasing foraging efficiency, increasing metabolic costs,

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or causing desertion of eggs or nestlings (Foster et al. 1992, Gessaman and Nagy 1988, Hooge 1991, Massey et al. 1988). Few studies have examined the influence that environmental variables have on the magnitude of a radio-tagging effect over several years (Peitz et al. 1993). Some effects may not be evident during mild weather or high prey abundance.

We examined the influence of radio tagging on Prairie Falcons (*Falco mexicanus*) in the Snake River Birds of Prey National Conservation Area (NCA) from 1991–1994. Our goal was to determine the effect of radio tagging on reproduction and associated behaviors. We also hoped to identify other factors that may have interacted with radio tagging to either increase or decrease the magnitude of the effect.

METHODS

Study area and subjects.—During March and April, we captured and radio tagged falcons at randomly selected nesting areas (cliffs where nests are found each year, but where no more than one pair has ever bred at one time) in the NCA. From 1991–1994, we radio tagged 28, 34, 36, and 31 falcons, respectively. We attempted to tag falcons throughout the study area and to tag approximately equal numbers of male and female falcons each year. We weighed and measured each captured falcon and determined sex by wing chord (USDI 1977). Transmitters were designed to last for 9 mo and harnesses were designed to be shed after 1–2 yr. Therefore, each year we trapped and radio tagged a new sample of falcons. All captured birds were banded to allow individual identification in subsequent years.

We randomly selected control Prairie Falcon nesting areas from the same sample as treatment nesting areas. For controls, we excluded sites where we confirmed that a falcon had been previously radio tagged. From 1991–1994, we monitored 51 control nesting areas uniquely selected each year. Control and treatment nesting areas were interspersed along the Snake River Canyon.

Transmitter application.—We applied transmitters as backpacks using a Teflon® ribbon harness (after the "Y design" in Buehler et al. 1995) modified with a leather breast-patch. To construct the harness, we threaded two lengths of ribbon through slits cut across the corners of a 13 $\times$ 19 mm leather patch. We then threaded the ribbons through opposite ends of tubes epoxied onto each end of the transmitter to form an anterior and posterior loop meeting at the leather patch. Loops were passed over the bird's body so that the wings stuck out between the posterior and anterior loop.

Once placed on a bird, we individually fitted each harness. We continually adjusted the transmitter position so it remained centered over the spine and below the front edge of the wing where it meets the body. We checked the posterior loop of the harness to ensure the ribbon passed above the hip. We then used a blunt rod, probed gently under the feathers, to move feathers from under the ribbon. We tightened the harness until two fingers could slide beneath the anterior end of the transmitter, and one finger could slide beneath the posterior end. We re-checked the position of the leather patch and transmitter and the fit of the harness after birds were allowed to flap their wings.

A transmitter with harness weighed 14 g, less than 3% of body mass for male falcons ($n = 69$, $\bar{x} \pm SE = 561.6$ g $\pm$ 4.7), and less than 2% of body mass for female falcons ($n = 62$, $\bar{x} \pm SE = 943.8$ g $\pm$ 8.7).

Productivity and behavior.—We observed falcon aeries several times per week from below cliffs to determine nesting success or failure. When chicks were approximately 30-d old, we rappelled to aeries to obtain brood counts and estimated the ages of nestlings using a photographic guide (Moritsch 1983). We banded and weighed nestlings, and measured seventh primary length, footpad length, and tarsus width. We also estimated crop fullness and general nestling condition (pectoralis development, activity, and presence of ectoparasites). We considered nesting attempts to be successful if at least one nestling reached an estimated age of 30 d, 80% of fledging age (Steenhof 1987). We confined analysis of nesting success to occupied nesting areas with known fates (control and radio-tagged, respectively: 1991, $n = 42$ and 26; 1992, $n = 47$ and 29; 1993, $n = 47$ and 31; 1994, $n = 44$ and 27). Analysis of productivity was confined to occupied nesting areas where we made complete counts of 30-d-old young (control and radio-tagged, respectively: 1991, $n = 32$ and 24; 1992, $n = 37$ and 23; 1993, $n = 46$ and 31; 1994, $n = 43$ and 24).

We monitored reproductive behaviors of radio-tagged Prairie Falcons at nesting areas accessible by vehicle and near each other ($n = 12$, 14, 5 and 10; 1991–1994, respectively). We observed falcon behavior at aeries from blinds or vehicles (Holthuijzen 1990) placed to optimize view and minimize disturbance. Distances from observer to aerie ranged from 72–300 m ($\bar{x} = 132$ m). Teams of two observers, each on a half-day shift, observed behaviors from 20 min before sunrise to 15 min after sunset, using 15–45× spotting scopes and 10 × 50 binoculars. We tried to reduce observer bias among years by following the same training protocol, which included watching videos of Peregrine Falcons (*Falcon peregrinus*) bringing prey to young and visiting Prairie Falcon aeries for practice sessions before we began regular observations. Within-year observer bias was reduced by having the same observers visit nesting areas with radio-tagged males and radio-tagged females. We used the un-tagged mates of radio-tagged falcons as controls for analysis of behavior differences. We believed this method was conservative, because some studies have indicated increased attendance and prey delivery rates for mates of radio-tagged birds (Wanless et al.1988, Wright and Cuthill 1989). We observed each site at least once during both early brood-rearing (nestlings <21-d old) and late brood-rearing (nestlings 21–40-d old). We quantified the amount of time falcons spent at the nest and the amount of time they were visible in the nesting area (a measure of attendance). We determined delivery rates of fresh prey items to the nest area and prey caching rates. In 1991, we did not classify prey deliveries as fresh to the nest area, nor did we record prey caching rates. We attempted to identify all prey items, at least to class. We classified prey items as Townsend's ground squirrels (*Spermophilus townsendii*), kangaroo rats (*Dipodomys* spp.), unidentified mammals, birds, reptiles, and unidentified prey.

Analyses.—We used a three-factor (treatment, year, fate) log-linear model to test for the effect of radio tagging on nesting success (number of pairs successful/occupied territory) of falcons among years. We also analyzed data for sex-specific radio effects on falcon nesting success using a three-factor (sex tagged, year, fate) log-linear model.

To determine the effects of year and radio tagging on falcon productivity, we used a two-factor (year and treatment) ANOVA to compare the number of 30-d-old nestlings for successful pairs with and without radios. We did not compare the number of young produced by all control and radio-tagged falcon pairs, because the large numbers of zeros, fours, and fives resulted in non-normal data and essentially replicated the success-fail categorical data. We analyzed the productivity of radio-tagged falcons using a two-factor (year and treatment) ANOVA to compare the number of nestlings produced by either radio-tagged sex.

We compared radio-tagged and control falcon attendance and prey delivery rates using a two-factor (year and treatment) ANOVA with one repeated measure (nestling stage). We analyzed differences in prey types brought to the territory by radio-tagged and control males using a three-factor (treatment, year, prey type) log-linear model. We combined prey types into two groups: all mammals combined (Townsend's ground squirrels, unidentified mammals, and kangaroo rats) and birds and reptiles combined. We did not include unidentified prey in the analysis because it is not a mutually exclusive category, but we reported proportions of unidentified prey delivered each year for treatment and controls.

We compared Prairie Falcon nestling masses between control and treatment broods using a two-factor (year and treatment) ANOVA with seventh primary length, footpad length, and brood size as covariates. Before analysis, we separated nestlings into large (female) and small (male) groups based on footpad lengths > or <86 mm (Marzluff et al. 1991), and adjusted masses for fullness of crop (BLM, unpublished data). Masses used in the analysis were the mean mass per brood for each sex to reduce dependency of the data.

RESULTS

Radio-tagged Prairie Falcons had similar nesting success as control falcons (Fig. 1; $G_3 = 3.8$, $P = 0.28$), but nesting success differed among years ($G_3 = 46.18$, $P < 0.001$). Success was lowest in 1993 for both radio-tagged and control falcons, and radio-tagged falcons tended to have lower success than controls in that year, but this difference was not significant ($G_1 = 2.75$, $P = 0.097$). Sex of the tagged bird did not affect nest success (Fig. 2, $G_3 = 1.34$, $P = 0.72$).

Successful radio-tagged falcons had similar brood sizes as control falcons (Fig. 1; $F_{1,137} = 0.06$, $P = 0.81$), and brood sizes did not differ significantly among years between treatment and control groups ($F_{3,137} =$

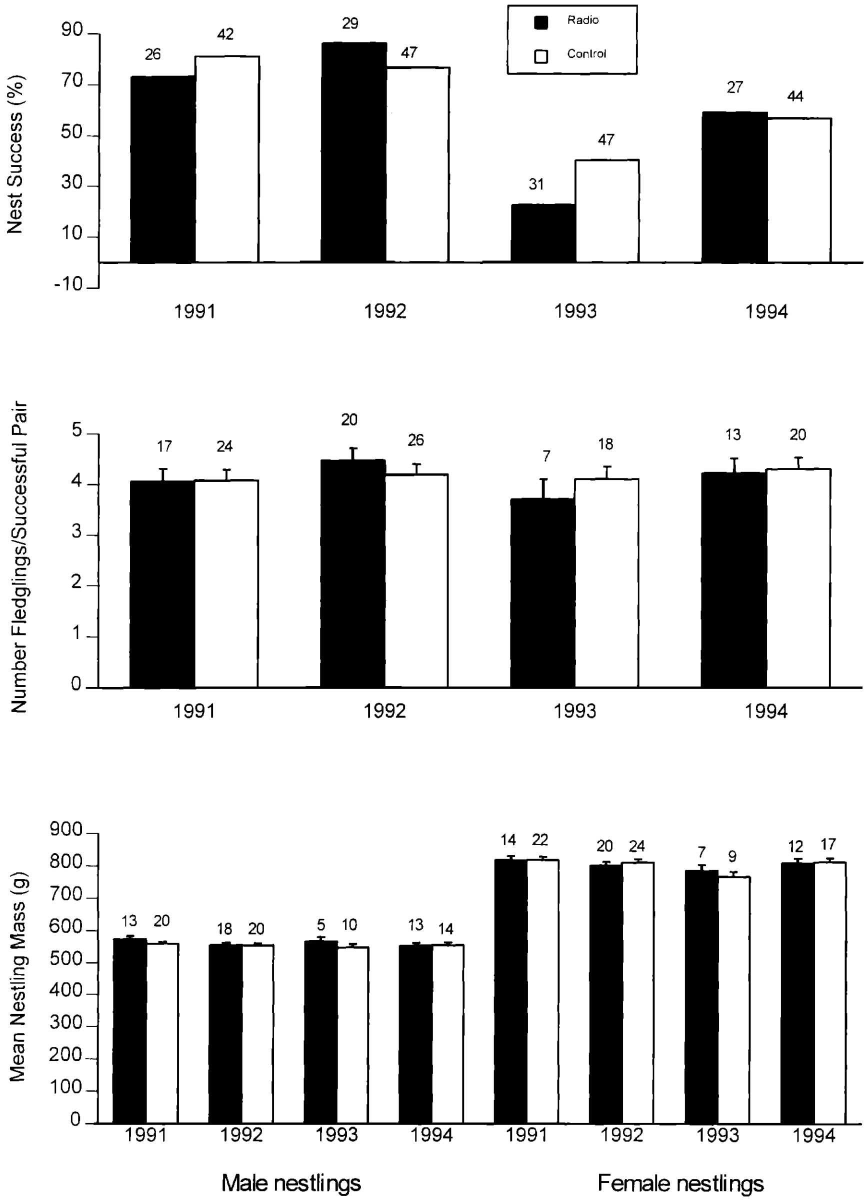

FIGURE 1. Radio-tagged and control Prairie Falcon nesting success for all occupied nesting areas, mean (±SE) brood size of successful pairs, and mean (±SE) mass of male and female nestlings. Sample sizes are given above error bars.

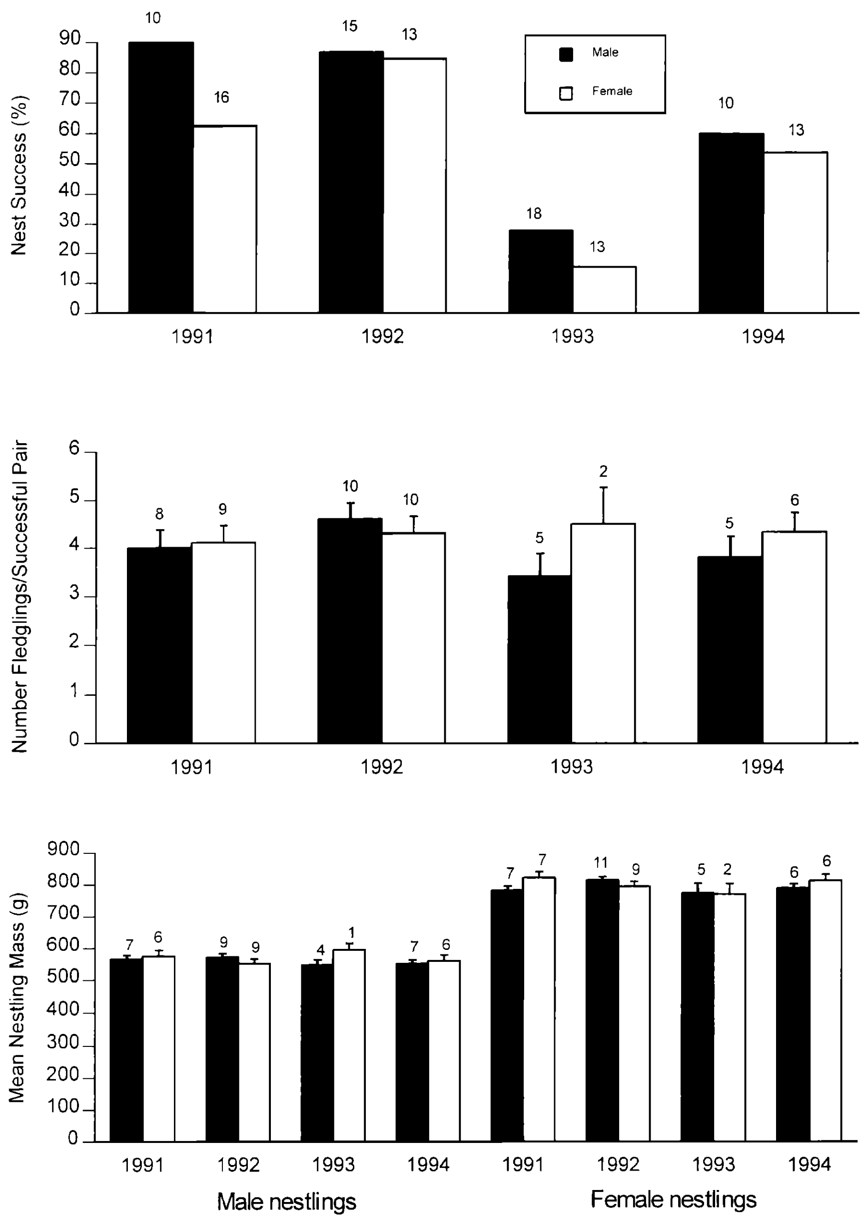

FIGURE 2. Radio-tagged male versus female Prairie Falcon nesting success for all occupied nesting areas, mean (±SE) brood size of successful pairs, and mean (±SE) mass of male and female nestlings. Sample sizes are given above error bars.

0.47, $P = 0.70$). Brood size did not vary among years ($F_{3,137} = 0.89$, $P = 0.45$).

The number of 30-d-old young produced by successful falcons did not depend upon which sex was radio tagged (Fig. 2; $F_{1,47} = 1.23$, $P = 0.27$), and there was no interaction between the sex tagged and year ($F_{3,47} = 0.80$, $P = 0.50$). The number of nestlings produced by successful radio-tagged falcons did not differ among years ($F_{3,48} = 0.63$, $P = 0.60$).

Radio-tagged falcons did not differ significantly from un-tagged falcons in any of our measures of behavior (Table 1). Radio-tagged males were observed in the territory ($F_{3,30} = 0.60$, $P = 0.62$) and at the nest ($F_{3,31} = 0.82$, $P = 0.49$) for similar periods of time, and delivered fresh prey to the territory at rates similar to un-tagged males ($F_{2,21} = 0.47$, $P = 0.63$). Radio-tagged females were observed for similar periods of time as untagged females in the territory ($F_{3,30} = 1.23$, $P = 0.32$) and at the nest ($F_{3,31} = 0.06$, $P = 0.98$). Delivery rates of fresh prey items to the territory by radio-tagged and un-tagged females did not differ ($F_{2,21} = 0.21$, $P = 0.81$). Radio-tagged females also cached prey at rates similar to un-tagged females ($F_{2,21} = 0.10$, $P = 0.91$).

Prey type brought to the territory differed significantly among years and between radio-tagged and control males (3-way interaction between year, tagging, and prey type: $G_2 = 21.84$, $P < 0.001$). In 1992, radio-tagged and control males delivered similar proportions of mammals ($n = 100$, 85.5%; $n = 62$, 83.8%), but radio-tagged males delivered fewer birds and reptiles ($n = 0$, 0%) than did control males ($n = 5$, 6.8%). The proportion of unidentified prey was similar ($n = 17$, 14.5%; $n = 7$, 9.5%) between the two groups. In 1993, falcons delivered fewer mammals than in 1992, and radio-tagged and control males delivered similar proportions ($n = 33$, 67.35%, $n = 44$, 63.8%). Radio-tagged males delivered more birds and reptiles ($n = 11$, 22.5%) than did control males ($n = 1$, 1.5%) in 1993. However, more prey types were unidentified for control males ($n = 24$, 34.8%) than for radio-tagged males ($n = 5$, 10.2%), making the difference in the proportions of birds and reptiles delivered suspect. In 1994, proportions of mammals delivered by both radio-tagged and control males were again lower than in 1992 ($n = 50$, 56.8%; $n = 33$, 71.7%), and radio-tagged males delivered more birds and reptiles ($n = 21$, 23.9%) than control males ($n = 2$, 4.4%). The proportion of unidentified prey types delivered by radio-tagged males was similar to that of control males ($n = 17$, 19.3%; $n = 11$, 23.9%).

Radio-tagged and control falcons raised young to similar masses at 30 d of age (Fig. 1; male nestlings: $F_{1,102} = 1.75$, $P = 0.19$; female nestlings: $F_{1,114} = 0.02$, $P = 0.89$), and there was no effect of tagging and year on masses (male nestlings: $F_{3,102} = 0.77$, $P = 0.51$; female nestlings: $F_{3,114} = 0.36$, $P = 0.78$). The sex of the falcon radio tagged had no effect on the masses of 30-d-old males (Fig. 2; $F_{1,38} = 0.94$, $P = 0.34$) or females ($F_{1,42} = 0.47$, $P = 0.50$), and there was no effect of the sex tagged and year on masses (male nestlings: $F_{3,38} = 1.52$, $P = 0.23$; female nestlings: $F_{3,42} = 1.25$, $P = 0.30$).

TABLE 1. Prey delivery and caching rates, and attendance activity of radio-tagged falcons using un-tagged mates as controls.

	Nestlings <21-d-old						Nestlings 21–40-d-old					
	Radio-tagged			Control			Radio-tagged			Control		
	n	x̄	SE	*n*	x̄	SE	*n*	x̄	SE	*n*	x̄	SE
1991												
Attendance at nest[a]												
Males	9	16.7	2.8	3	19.5	4.8	9	11.7	1.7	3	6.9	2.9
Females	3	33.1	8.0	9	39.4	4.7	3	12.6	3.2	9	18.2	1.9
Attendance in territory[a]												
Males	9	29.0	2.8	2	33.2	6.0	9	32.7	3.0	2	30.3	6.3
Females	2	45.1	6.9	9	47.5	3.3	2	34.8	8.3	9	41.9	3.9
1992												
Prey Delivery (items/h)												
Males	8	0.23	0.04	6	0.26	0.05	8	0.31	0.04	6	0.23	0.05
Females	6	0.11	0.03	8	0.04	0.03	6	0.17	0.05	8	0.09	0.04
Prey Caching (items/h)												
Females	6	0.10	0.03	8	0.05	0.03	6	0.03	0.02	8	0.02	0.02
Attendance at nest[a]												
Males	8	17.1	2.9	6	17.3	3.7	8	8.0	1.7	6	2.9	2.3
Females	6	35.9	6.2	8	41.0	4.8	6	10.0	2.5	8	9.6	1.9
Attendance in territory[a]												
Males	8	43.1	2.9	6	44.3	3.8	8	39.3	3.1	6	30.2	4.0
Females	6	54.7	4.3	8	61.2	3.4	6	50.2	5.2	8	46.2	4.0
1993												
Prey Delivery (items/h)												
Males	2	0.26	0.08	3	0.27	0.05	2	0.19	0.08	3	0.15	0.07
Females	3	0.08	0.04	2	0.14	0.05	3	0.15	0.07	2	0.25	0.08
Prey Caching (items/h)												
Females	3	0.16	0.04	2	0.07	0.05	3	0.05	0.03	2	0.03	0.03
Attendance at nest[a]												
Males	2	18.1	5.7	3	12.3	4.7	2	9.6	3.5	3	12.5	2.8
Females	3	51.0	7.9	2	51.3	9.5	3	12.3	3.1	2	11.8	3.8
Attendance in territory[a]												
Males	2	32.0	5.8	3	28.1	4.8	2	33.5	3.5	3	33.9	5.0
Females	3	65.0	5.5	2	55.8	6.7	3	37.3	6.6	2	37.3	8.0
1994												
Prey Delivery (items/h)												
Males	6	0.24	0.05	4	0.20	0.06	6	0.17	0.05	4	0.13	0.06
Females	4	0.15	0.04	6	0.13	0.03	4	0.16	0.06	6	0.12	0.05
Prey Caching (items/h)												
Female	4	0.09	0.04	6	0.09	0.03	4	0.01	0.03	6	0.03	0.02
Attendance at nest[a]												
Males	6	13.5	3.3	4	12.3	4.7	6	9.2	2.0	4	12.5	2.9
Females	4	37.4	7.0	6	36.6	5.5	4	16.7	2.8	6	14.7	2.2
Attendance in territory[a]												
Males	6	32.0	3.4	4	23.4	4.3	6	33.8	3.5	4	23.8	4.5
Females	4	62.1	4.9	6	46.6	6.9	4	45.2	5.9	6	35.8	4.6

[a] Attendance means are the square root of the arcsine of the percent time spent at the nest or in the territory.

DISCUSSION

Radio tagging did not affect the nesting success of Prairie Falcons, despite significant differences in success for all pairs among years that paralleled a decline in primary prey (Townsend's ground squirrel) abundance during our study (Van Horne et al. 1994). Nesting success of radio-tagged and control falcons was high in years of high ground squirrel densities (1991 and 1992) and lower in years of low or moderate (1993 and 1994) density. Radio-tagged pairs had slightly, but not significantly, lower success than control pairs during one low prey year (1993), but there was no such pattern during a second low prey year (1994). Radio-tagged Prairie Falcons appeared to compensate for low prey densities by increasing their foraging range (Marzluff et al. 1994) and delivering a greater proportion of alternate prey (birds and reptiles) to nestlings without decreasing prey delivery rates (McFadzen and Marzluff, unpubl. data).

Although we did not find differences in prey delivery rates, we did find significant differences in prey types delivered between radio-tagged and control males among the three years. Interpretation of these results are made with caution due to long viewing distances and differing proportions of unidentified prey. During years of low ground squirrel densities, radio-tagged males delivered a greater proportion of birds and reptiles than control males. Feathers from prey remains we found at nests often included pin feathers from nestlings, and observations of prey deliveries suggested that many of the birds delivered were nestlings or fledglings. Young birds may represent an easily captured prey source for falcons hindered by a backpack harness (Gessaman and Nagy 1988) and limited by low densities of ground squirrels. Alternatively, decreases in speed and agility caused by the added weight of a transmitter (Caccamise and Hedin 1985) may subject radio-tagged falcons to increased piracy of large, mammalian prey items.

The sex of the falcon radio tagged did not affect productivity or any of the behaviors we measured. The greatest sex-related differences were observed in 1991 when pairs with radio-tagged females tended to have lower productivity than pairs with radio-tagged males. This may have been due to radio tagging gravid females in 1991. In subsequent years, we continued to capture females throughout all stages of breeding, but we quickly released gravid females without attaching radio tags. The trend for higher success among pairs with radio-tagged males compared to pairs with radio-tagged females (Fig. 2), while not significant, was consistent. This could be related to the timing of our behavioral observations. Radio tagging may affect female behaviors that increase the likelihood of early nest failure that we were unable to quantify.

Using backpack-mounted radio transmitters, we have gathered long-term data on Prairie Falcon home ranges and foraging habitat use. Alternate forms of attachment, particularly tail-mounted transmitters which may have less influence (Hiraldo et. al 1994), were not practical for use during our study, as Prairie Falcons molt during brood-rearing. Although the effect of tagging has been minimal in this study, our home range and habitat use analyses could have been seriously influenced by the effects of radio tagging if we had conducted the study primarily during sub-optimal breeding conditions. Researchers should be aware of environmental variables that may exacerbate radio-tagging effects and understand that tagging biases may be present in some years, but not others. Awareness of biases and their influence on results can only make research conclusions and management and conservation recommendations stronger.

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