EFFECTS OF RADIO TAGS ON SPOTTED OWLS

PETER W. C. PATON,[1] U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 1700 Bayview Drive, Arcata, CA 95521
CYNTHIA J. ZABEL, U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 1700 Bayview Drive, Arcata, CA 95521
DONALD L. NEAL, U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 2081 E. Sierra Avenue, Fresno, CA 93710
GEORGE N. STEGER, U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 2081 E. Sierra Avenue, Fresno, CA 93710
NANCY G. TILGHMAN,[2] U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 1700 Bayview Drive, Arcata, CA 95521
BARRY R. NOON, U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 1700 Bayview Drive, Arcata, CA 95521

Abstract: Fifteen of 47 radio-tagged northern spotted owls (*Strix occidentalis caurina*) died during a 2-year study in northern California, and 11 of 33 radio-tagged California spotted owls (*S. o. occidentalis*) died in 2.5 years in the Sierra Nevada. Female owls with 19-g radio tags had significantly lower annual survival rates than color-banded females ($P = 0.006$) after a forest fire in 1987 in the Klamath Mountains. There were no differences in annual survival rates between males with and without radio tags. In 1988, fewer radio-tagged pairs (17%) fledged young than color-banded pairs (88%) ($P < 0.001$), and in 1989 radio-tagged pairs nested (7%) less often than color-banded owls (64%) ($P = 0.0002$). We suggest that spotted owl researchers avoid using backpack-mounted radio tags.

J. WILDL. MANAGE. 55(4):617-622

The spotted owl (Strix *occidentalis)* has been the focus of numerous radio-tracking studies in recent years because of the species' association with old-growth forests (e.g., Carey et al. 1990). However, little is known about possible negative effects of radio tags on spotted owls. Dawson et al. (1987) recommended against using radio tags on juvenile spotted owls because of low survival rates among juveniles and potential adverse effects of radio tags on their flying and hunting capabilities.

Radio tags were usually attached to spotted owls with a harness-mounted backpack (Forsman 1983) prior to 1989. Harnesses used on other bird species have apparently caused reduced flight speed and increased CO_2 production (Gessaman and Nagy 1988), mass loss (Johnson and Berner 1980), reduction in high-energy activities (Hooge 1991), decreased reproductive success (Sibly and McCleery 1980), and lower survival rates (Marks and Marks 1987). Other researchers, however, found minimal impacts from harnessed radio packages on birds (Erikstad 1979).

Our objectives were to test the null hypotheses that (1) no difference existed between survival rates of male and female radio-tagged spotted owls, and (2) no differences existed between reproductive attempts, fledgling success, or survival rates of radio-tagged and color-banded owls.

We thank E. M. Adams, S. R. Avery, N. D. Bandetlini, M. A. Bias, M. E. Brennan, A. C. Chrisney, P. R. Delevoryas, B. W. Dill, B. B. Fazio, F. L. Galea, M. J. Heyne, T. L. Hines, H. E. Hollis, T. E. Hosler, D. A. Leal, J. R. Loehr, J. C. Lovio, C. V. Ogan, M. McMillian, T. E. Munton, S. L. O'Brien, K. L. Purcell, M. S. Tomosy, H. F. Sakai, J. L. Seay, R. M. Suydan, R. A. Wilson, and D. J. Vezie for helping to collect tracking data. Necropsies were done by J. A. Langenberg, J. C. Franson, and K. A. Converse of the National Wildlife Health Research Center and D. L. Hunter and D. A. Jessup of the California Wildlife Investigations Laboratory. Earlier drafts of the manuscript were reviewed by D. R. Anderson, I. J. Ball, W. M. Block, K. A. Converse, A. B. Franklin, R. Golightly, D. A. Jessup, C. J. Ralph, J. Verner, and J. R. Waters.

STUDY AREA

Fieldwork in the Klamath Mountains of northwestern California was initiated on northern spotted owls (*S. o. caurina*) in 1987. Eighteen owls were tracked 50 km southeast of Eu-

[1] Present address: Utah Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Utah State University, Logan, UT 84322.
[2] Present address: U.S. Forest Service, Forest Environment Research, P.O. Box 96090, Washington, D. C. 20090.

reka, Humboldt County (Mad River Ranger Dist., Six Rivers Natl. For.); 19 owls were tracked 30 km west of Happy Camp, Siskiyou County (Ukonom Ranger Dist., Klamath Natl. For.). We tracked birds at both sites from summer I987 through spring 1989. We tracked 10 owls 10 km east of Brookings, Curry County, Oregon (Chetco Ranger Dist., Siskiyou Natl. For.) from summer 1988 until fall 1989. All sites were in mountainous forests dominated by Douglas-fir *(Pseudotsuga menxiesii),* tanoak (*Lithocarpus densiflorus),* and Pacific madrone *(Arbutus menxiesii).* Elevations ranged from 0 to 1,800 m.

Data on survival rates and reproductive success of color-banded northern spotted owls were obtained from A. B. Franklin (Humboldt State Univ., Arcata, Calif., pers. commun.). Owls from the banding study were interspersed between our Ukonom and Mad River study sites in the Klamath Mountains.

A forest fire, started by lightning on 30 August 1987, burned 8,100 ha at the Ukonom study site in the Klamath Mountains. The fire was put out 50 days after it began. An inversion held a dense smoke layer close to the ground for 25 days, during which radio-tagged owls were exposed to high levels of carbon monoxide (CO) (≤ 54 ppm) and total suspended particulates ($\leq 4{,}600$ $\mu g/m^3$)(K. Corbin, Siskiyou County Air Pollut. Control Dist., pers. commun.). Ten of the color-banded owls were located in an area 10 km east of the Ukonom study site and exposed to light to moderate understory burns (A. B. Franklin, unpubl. data).

California spotted owls (*S. o. occidentalis)* were tracked in the Sierra Nevada at a site 70 km northeast of Fresno, Fresno County, from May 1987 to January 1990. Elevations ranged from 300 to 2,440 m and encompassed a variety of habitat types from oak-pine woodlands *(Quercus douglasii, Q. wislixeni,* and *Pinus sabiniana)* to mixed-conifer forests (*Abies concolor,* A. *magnifica, Pinus jeffreyi, P. lambertiana,* and *Libocedrus decurreus*). No companion data from color-banded owls were available from this area.

METHODS

Radio Tags.-We captured and fitted owls ≥ 1 year old in the Klamath Mountains with backpack-mounted radio tags with a cross-chest harness described by Forsman (1983). In 1987, the teflon harness straps were sewn together; in 1988 we switched to copper electrical clamps to fasten the harness because metal clamps expedited handling time. We used radio tags (AVM Instrument Co., Livermore, Calif.) with a 30-cm antenna and a life expectancy of 12 months. Tags (including the harness) were weighed to the nearest 0.1 g. Tags used in 1987 had a cylindrical battery (AVM model P-2), 4.5-cm length and 1.5cm diameter, with a mean mass (including harness) of 18.7 $\pm$ 0.15 (SE) g *(n* = 7). In 1988, we used rectangular tags (AVM model K-7), 5.0 x 1.8 x 0.8 cm, with a mean mass (including harness) of 18.5 $\pm$ 0.15 g (*n* = 6). Owls tracked in the Sierra Nevada were equipped with radios weighing 22-24 g (Telonics, Mesa, Ariz.) or 18-19 g (AVM); these were backpack-mounted with electrical clamps to secure the harnesses.

Owl Measurements. - Owls were weighed to the nearest 5 g when captured. Each bird was aged as an adult (≥ 3 yr old) or subadult (<3 yr old) based on the shape and amount of white at the tip of rectrices (Forsman 1981). We compared masses between age classes and sexes with *t*-tests (Zar 1984). Masses of adults and subadults did not differ, so data were pooled by sex.

We used triangulation techniques with a minimum of 3 bearings per fix to locate owls. We attempted to locate each radio-tagged owl 4 nights and 1 day per week throughout the year. If an owl's location did not change for >3 days, we visually located the bird to determine its condition. Dead owls were recovered within an estimated 1-4 days of death. Carcasses were frozen and shipped to either the California Fish and Game Department's Wildlife Investigations Laboratory in Rancho Cordova or to the U.S. Fish and Wildlife Service's National Wildlife Health Research Center in Madison, Wisconsin, for necropsy.

Survival Analyses.-We used the program MICROMORT (Heisey and Fuller 1985) to calculate survival estimates for radio-tagged owls during the breeding season (1 Mar-31 Aug), the nonbreeding season (1 Sep-28 Feb), and annually based on daily survival estimates. Annual survival estimates were compared with a Z-test statistic, as outlined in Heisey and Fuller (1985). We found no difference in survival rates among radio-tagged owls at the Klamath Mountain study sites in 1987 (*P* = 0.25) or 1988 (*P* = 0.45), so data were pooled from all 3 sites for further analyses.

Using model A (the standard Jolly-Seber model) with the computer program JOLLY (Brownie et al. 1986), A. B. Franklin (unpubl. data) calculated Jolly-Seber survival estimates for color-banded owls during 1987 and 1988. These estimates were based on 1986-89 capture histories of 203 banded owls, with subadults and adults combined. Color-banded owls were assumed to be dead when they were either replaced on their territory by another owl or were not detected for 2 years. We know of no data to suggest that color bands adversely affect reproductive behavior or survival rates of a nocturnal species such as the spotted owl, although effects have been reported for diurnal species which use visual cues during courtship (Ratcliffe and Boag 1987). Therefore, we assumed that banding had little impact compared to placing radio tags on owls.

Reproduction Analyses. - To assess the effects of radio tags on reproductive success, we used Fisher's exact test (Zar 1984) to compare the number of pairs that laid eggs between radio-tagged and color-banded owls. Using only pairs that had initiated incubation, we then compared fledging success between the 2 groups. Radio-tagged pairs were included in these analyses only if at least 1 member of the pair (either sex) carried a radio tag prior to 1 March of the breeding season.

RESULTS

Mass

Female spotted owls weighed more than males in the Klamath Mountains (t = -5.00, 45 df, P < 0.0001) and the Sierra Nevada (t = -6.2, 29 df, P < 0.0001) (Table 1). Radio tags weighed from 2.8-4.1% of an owl's mass (Table 1).

Mortality Factors

Klamath Mountains. - Fifteen of 47 (32%) radio-tagged owls died: 4 of 22 males and 11 of 25 females (4 subad and 7 ad). Birds died from 41 to 258 days after radio tag attachment ($\bar{x}$ = 155 ± 16 days), with 2 dying in <100 days. Two owls survived wearing their first radio for a year, but died 100 and 135 days after their second radio was attached.

None of the mortalities could be directly attributed to the radio tag or harness. Feather wear was minor at points where the harness could be abrasive. No birds were entangled in vegetation due to the harness or showed indications of entrapment in the harness. The most common symptom associated with death was emaciation, with indications of dehydration and anemia (6 of 15 deaths). Emaciated owls had no subcutaneous or coronary fat, had sustained severe pectoral muscle reduction, but had no signs of external trauma. These birds had lost at least 20% of their original capture body mass ($\bar{x}$ = 33 ± 4%, max. = 42%). One nesting pair that died 4 days apart from one another were diagnosed as emaciated. Poor post-mortem condition of thesebirds precluded detection of some undetermined contagious disease that may have caused their deaths.

Table 1. **Relationship between mass of spotted owls and radio tags, California, 1987-89.**

Location/sex	Owl mass (g) n	$\bar{x}$	SE	Radio tag (% of $\bar{x}$ owl mass)
Klarnath Mountains				
M[a]	17	591	7.3	3.2
F[b]	25	662	18.0	2.8
Sierra Nevada				
M[c]	17	563	8.0	4.1
F[d]	17	632	6.5	3.6

[a] All adults.
[b] 8 subadults and 17 adults.
[c] 4 subadults and 13 adults.
[d] 2 subadults and 15 adults.

The second most common cause of death was avian predation (3 of 15 deaths). A circle of plucked feathers around 1 carcass suggested northern goshawk *(Accipiter gentilis)* predation; 2 carcasses had missing heads and few plucked feathers suggesting predation by great-horned owls *(Bubo virginianus)*. We suspected avian predation in a fourth death for which we found only rectrices and a talon at the base of a tree and the radio tag lodged high in the tree.

One nonbreeding adult female died of pneumonia and pulmonary edema 41 days after her radio was attached. A subadult female that died of avian cholera *(Pasteurella multocida* [serotype 3]) weighed only 5 g less than her capture mass.

Of 5 birds that died following the forest fires at the Ukonom site, 2 were emaciated and 1 died of avian predation. No carcasses were found for 2 birds; only the intact harnesses with radio tags attached were recovered. Necropsies of the 2 emaciated birds did not reveal any direct signs suggesting death from smoke inhalation or from other fire effects. Only 1 death occurred during the fires; the others occurred up to 7 weeks after the fires were extinguished.

Sierra Nevada. - Eleven of 33 radio-tagged birds died: 5 of 16 males (3 subad and 2 ad) and

Table 2. Annual survival rates (Heisey and Fuller 1985) for radio-tagged spotted owls in the Klamath Mountains and the Sierra Nevada, California. Jolly-Seber annual survival rates, calculated from the program JOLLY (Brownie et al. 1986), are presented for color-banded owls in the Klamath Mountains (data from A. B. Franklin, pers. commun.).

	Radio-tagged owls										Color-banded owls				
	Klamath Mountains					Sierra Nevada					Klamath Mountains				
Yr/sex	Tagged	Died	Survival rate	95% CI	P[a]	Tagged	Died	Survival rate	95% CI	P[a]	Tagged	Died	Survival rate	95% CI	P[b]
1987															
M	13	1	0.921	0.78–1.00		8	1	0.681	0.47–1.00		60	4	0.935	0.86–1.00	0.94
F	12	7	0.342	0.15–0.76	0.0002	5	1	0.803	0.52–1.00	0.64	54	6	0.890	0.79–0.99	0.006
1988															
M	21	3	0.822	0.66–1.00		10	2	0.849	0.62–1.00		65	11	0.820	0.73–0.92	0.99
F	18	4	0.832	0.68–1.00	0.94	9	2	0.709	0.44–1.00	0.53	60	10	0.823	0.73–0.93	0.96
1989															
M						12	2	0.847	0.67–1.00						
F						13	3	0.743	0.53–1.00	0.53					

[a] Z-test between male and female radio-tagged owls within each study area.
[b] Z-test between radio-tagged and color-banded owls in the Klamath Mountains.

6 of 17 females (1 subad and 5 ad). Of the 11 deaths, no cause was determined for 7 birds, 2 were emaciated, and 2 were killed by avian predation. Six of 11 deaths occurred < 100 days after radio tag attachment, with 5 dying in <50 days. After carrying radio tags for almost a year, 2 owls died < 40 days after their first radio tags were replaced, suggesting the second harness might have caused problems. However, one of these owls had an eye injury, which probably lead to its death.

Survival Rates

Klamath Mountains. There were no differences in survival estimates between radio-tagged and color-banded males either year (Table 2). Survival estimates for radio-tagged females, however, were significantly lower than those for color-banded females in 1987 (P = 0.006), but were not different in 1988. Five of 15 (33%) deaths occurred during the breeding season, and 10 (67%) occurred during the nonbreeding season. We found no significant differences between seasons for males or females. Therefore, we pooled data from the 2 seasons by sex to calculate annual survival rates. Annual survival rates based on daily survival estimates of radio-tagged owls indicated that females had significantly lower survival rates than males in 1987 (P = 0.0002), but no difference (P = 0.94) was observed between sexes in 1988 (Table 2).

Due to the large proportion of females that died after the fires at Ukonom (4 of 5), these data were excluded from the 1987 analysis to reduce any bias of fire impacts on survival estimates. Results from Mad River showed that females had lower survival rates than males in 1987 (3 of 7 F and 0 of 7 M died) (Z = 3.63, P < 0.001).

Sierra Nevada. - Seven of 11 deaths occurred during the breeding season and 4 during the nonbreeding season. We found no differences in survival rates between seasons for any year (P = 0.33), so data were pooled to calculate annual survival rates. Survival estimates between radio-tagged males and females were not different for any of the 3 years (Table 2).

Reproduction

The number of pairs that laid eggs was significantly higher for color-banded (64%) compared to radio-tagged owls (7%) in the Klamath Mountains in 1989 (P = 0.0002), but there was no difference in 1988 (P = 0.14) (Table 3). The number of pairs that successfully fledged young was lower for radio-tagged (17%) than color-banded owls (88%) in 1988 (P = 0.001), but not in 1989 (Table 3). In June 1988, a cold rain storm apparently killed young at 3 of 4 active radio-tagged nests at the Mad River site. Among pairs with radio tags in 1989, the only pair that laid eggs had a female with no radio tag.

Two of 6 (33%) radio-tagged pairs laid eggs in 1988 at Ukonom, 6 months after the fires, but only 1 pair successfully fledged young (17%). In contrast, 9 of 10 color-banded owls with territories in the center of the fire survived, and 3 of 5 (60%) pairs fledged young in 1988 (A. B. Franklin, pers. commun.).

Table 3. Number of radio-tagged spotted owl pairs initiating clutches and fledging young compared to color-banded pairs in California. Data for color-banded pairs are from Franklin et al. (1990).

	No. pairs				
Yr/treatment	Total	Laid eggs	P[a]	Fledged young	P
1988					
Radio-tagged	11	6		1	
Color-banded	45	33	0.14	29	0.001
1989					
Radio-tagged	14	1		0	
Color-banded	56	36	0.002	27	0.25

[a] Fisher's exact test.

DISCUSSION

The relationship between survival estimates and the sex of radio-tagged owls was not consistent across study areas or years. However, demographic studies of color-banded spotted owls in the Klamath Mountains also indicated that females had lower survival probabilities than males (Franklin et al. 1990). Because female spotted owls weigh more than males, one might expect radio tags to have a greater impact on males. However, energetic studies have shown the relative costs of carrying radio tags are greater for larger birds (Caccamise and Hedin 1985). In addition, radio tags might be more difficult for female owls to transport, as females are less maneuverable than males due to greater wing loading (Earhart and Johnson 1970). It is unclear, however, whether these energetic arguments can explain the differences in survival rates between the sexes during 1 year of our study.

Survival estimates from other radio-tracking studies of spotted owls in California were also relatively low. Annual survival rates, based on daily survival estimates (Heisey and Fuller 1985), ranged from 0.44 (95% CI = 0.21-0.90, n = 18) (Laymon 1988) to 0.57 (0.30-1.00, n = 9) (Call 1990) in the Sierra Nevada, and 0.80 (0.52-1.00, n = 8) in the Klamath Mountains (Solis 1983, Sisco 1990). These data indicate that low survival rates for harnessed radio-tagged owls were not confined to our study.

Our study was not designed to separate effects of radio tag mass from effects of the harness per se. However, adverse impacts from radio tags on spotted owls could have partially been due to the method of attachment, as has been noted in other species. For example, Hooge (1991) compared the activities of acorn woodpeckers (*Melanerpes formicivorus*) with harness-mounted radio tags to those of birds with tags glued onto the back without harnesses. Woodpeckers with harnesses had significant reductions in 2 high-energy behaviors, and significantly higher preening and perching rates. Gessaman and Nagy (1988) found that harnesses with no radio tag significantly reduced flight speeds of homing pigeons (*Columba livia*) by 15%.

Exactly how the harness or radio tag affects reproduction and survival needs further research. For example, the antenna could interfere with copulation or courtship behavior, although some types of back-mounted antennas have been shown to not interfere with copulation (Kalas et al. 1989). Harnesses that are either too loose or too tight could cause discomfort and therefore additional stress. The additional energetic cost of carrying the mass of the tag could indirectly affect reproduction. The breeding effort involves the highest levels of energy expenditure throughout the year (Wijnandts 1984), and radio tags could reduce the amount of excess energy available for females to produce eggs.

We conclude that data from harnessed, radio-tagged spotted owls should not be used for annual reproduction or survival estimates, as has been recommended for other species (Marks and Marks 1987). Furthermore, 18-24-g backpack radio tags should no longer be used on spotted owls. In addition, based on our results and work by Gessaman and Nagy (1988) and Hooge (1991), we think that researchers should be wary of the use of any type of backpack-mounted radio tag on spotted owls.

LITERATURE CITED

BROWNIE, C., J. E. HINES, AND J. D. NICHOLS. 1986. Constant parameter capture-recapture models. Biometrics 42:561-574.

CACCAMISE, D. F., AND R. S. HEDIN. 1985. An aerodynamic basis for selecting transmitter loads in birds. Wilson Bull. 97:306-318.

CALL, D. 1990. Home range and habitat use by California spotted owls in central Sierra Nevada. M.S. Thesis, Humboldt State Univ., Arcata, Calif. 83pp.

CAREY, A. B., J. A. REID, AND S. P. HORTON. 1990. Spotted owl home range and habitat use in southern Oregon Coast Ranges. J. Wildl. Manage. 54: 11-17.

DAWSON, W. R., J. D. LIGON, J. R. MURPHY, J. P. MYERS, D. SIMBERLOFF, AND J. VERNER. 1987. Report of the scientific advisory panel on the spotted owl. Condor 89:205-229.

EARHART, C. M., AND N. K. JOHNSON. 1970. Size dimorphism and food habits of North American owls. Condor 72:251-264.

ERIKSTAD, K. E. 1979. Effects of radio packages on reproductive success of willow grouse. J. Wildl. Manage. 43:170-175.

FORSMAN, E. D. 1981. Molt of the spotted owl. Auk 98:735-742.

———. 1983. Methods and materials for locating and studying spotted owls. U.S. For. Serv. Gen. Tech. Rep. PNW-12. 8pp.

FRANKLIN, A. B., J. A. BLAKESLEY, AND R. J. GUTIERREZ. 1990. Population ecology of the northern spotted owl *(Strix occidentalis caurina)* in northern California: preliminary results, 1989. Calif. Dep. Fish and Game Nongame Tech. Rep. 1990-9. 35pp.

GESSAMAN, J. A., AND K. A. NAGY. 1988. Transmitter loads affect the flight speed and metabolism of homing pigeons. Condor 90:662-668.

HEISEY, D. M., AND T. K. FULLER. 1985. Evaluation of survival and cause-specific mortality rates using telemetry data. J. Wildl. Manage. 49:668-674.

HOOGE, P. N. 1991. The effects of radio weight and harnesses on time budgets and movements of acorn woodpeckers. J. Field Ornithol. 62:230-238.

JOHNSON, R. N., AND A. H. BERNER. 1980. Effects of radio transmitters on released cock pheasants. J. Wildl. Manage. 44:686-689.

KALAS, J. A., L. LOFALDLI, AND P. FISKE. 1989. Effects of radio packages on great snipe during breeding. J. Wildl. Manage. 53:1155-1158.

LAYMON, S. A. 1988. Ecology of the spotted owl in the central Sierra Nevada, California. Ph.D. Thesis, Univ. California, Berkeley. 285pp.

MARKS, J. S., AND V. S. MARKS. 1987. Influence of radio collars on survival of sharp-tailed grouse. J. Wildl. Manage. 51:468-471.

RATCLIFFE, L. M., AND P. T. BOAG. 1987. Effects of colour bands on male competition and sexual attractiveness in zebra finches *(Peophila guttata)*. Can. J. Zool. 65:333-338.

SIBLY, R. M., AND R. H. MCCLEERY. 1980. Continuous observation of individual herring gulls during the incubation season using radio tags: an evaluation of the technique and a cost-benefit analysis of transmitting power. Pages 345-352 in C. J. Amlaner, Jr. and D. W. Macdonald, eds. A handbook on biotelemetry and radio tracking. Pergamon Press, Oxford, U.K.

SISCO, C. L. 1990. Seasonal home range and habitat ecology of spotted owls in northwestern California. M.S. Thesis, Humboldt State Univ., Arcata, Calif. 81pp.

SOLIS, D. M. 1983. Summer habitat ecology of the northern spotted owl. MS. Thesis, Humboldt State Univ., Arcata, Calif. 169pp.

WIJNANDTS, H. 1984. Ecological energetics of the long-eared owl (*Asio otus*). Ardea 72:1-92.

ZAR, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, N. J. 620pp.

Received 9 May 1990.
Accepted 16 May 1991.
Associate ***Editor: Morrison.***