

# Radio Telemetry for Black-footed Ferret Research and Monitoring

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## Abstract

By 1973, radio telemetry was regarded as an important potential tool for studying the elusive, nocturnal, and semi-fossorial black-footed ferret (*Mustela nigripes*), but fears of using invasive techniques on this highly endangered mammal caused delays. We began radio collaring ferrets in 1981. Use of radio telemetry on ferrets proved to be both challenging and rewarding. We document two decades of development and use that led to the present radio-tagging techniques and methods for radio tracking. The 7-g radio collar commonly used after 1992 was smaller and lighter, relative to mass and size of subjects, than collars used in studies of other *Mustela*. Other important developments were a Teflon<sup>®</sup> coating to shed mud, a highly flexible stainless steel cable for whip antennas, and a nondurable wool collar. Although collar-caused neck abrasions have continued to occur sporadically, a retrospective assessment of minimum survival rates for 724 reintroduced ferrets (392 radio tagged), using data from spotlight surveys, failed to detect negative effects of radio-collars. In a South Dakota study, ferrets that were found to have hair loss or neck abrasions when collars were removed did not exhibit movements significantly different from those of radio-tagged ferrets with no evidence of neck problems. Prototype transmitters designed for surgical implantation had insufficient power output for effective use on ferrets. Early attempts at tracking radio-tagged ferrets by following the signal on foot quickly gave way to following movements by triangulation, which does not disturb the subjects. The most effective tracking stations were camper trailers fitted with rotatable, 11-element, dual-beam Yagi antennas on 6-m masts. We used radio telemetry to produce 83,275 lines of data (44,191 indications of status and 39,084 positional fixes via triangulation) for 340 radio-collared ferrets during the reintroduction program. Tracking by hand and from aircraft augmented triangulation, allowing us to locate animals that dispersed long distances and enabling us to determine causes of mortality. Justifying further use of radio telemetry

on black-footed ferrets requires careful consideration of costs and benefits.

Key words: black-footed ferret, collar, *Mustela eversmannii*, *Mustela nigripes*, radio telemetry, radio tracking, Siberian polecat, survival, triangulation

## Introduction

Radio telemetry has been used as a tool to study vertebrates for more than 50 years (Kimmich, 1979) and *Mustela* since the mid-1970s (Erlinge, 1979). The technique is especially useful for re-locating individual animals that are highly mobile, secretive, and difficult to observe. Black-footed ferrets (*M. nigripes*) are among the most nocturnal of carnivores, and they are semifossorial, attributes that reduce our ability to monitor them with other techniques. Ferrets may be located with spotlights, a technique that is often employed for conducting annual surveys of their abundance (Campbell and others, 1985; Biggins and others, 1998a). Spotlighting, however, affects the behaviors of ferrets (Campbell and others, 1985), making it less attractive for the intensive monitoring that may be required for behavioral studies. Techniques must be matched to objectives, and the relative advantages and disadvantages of radio telemetry, spotlighting, and snow tracking for studying black-footed ferrets have been summarized elsewhere (Biggins, Godbey, Matchett, and others, this volume). This article addresses the challenges of applying radio telemetry to studies of black-footed ferrets, in part to help a potential investigator decide whether it is the appropriate tool for the goals of the project being considered.

Because of difficulties encountered by earlier researchers in studying this secretive species and because technologies were rapidly advancing, radio telemetry was recognized as a "vital" tool for future ferret investigations (commentary by E. Brigham in Linder and Hillman, 1973, p. 162). Erickson (1973, p. 156) emphasized a need to use radio telemetry on ferrets, lamenting that "the black-footed ferret is one of the least well known of all of the endangered mammals of the United States, despite 10 years of intensive research." The anticipated importance of this tool was reflected in a primary objective of the first captive breeding program for

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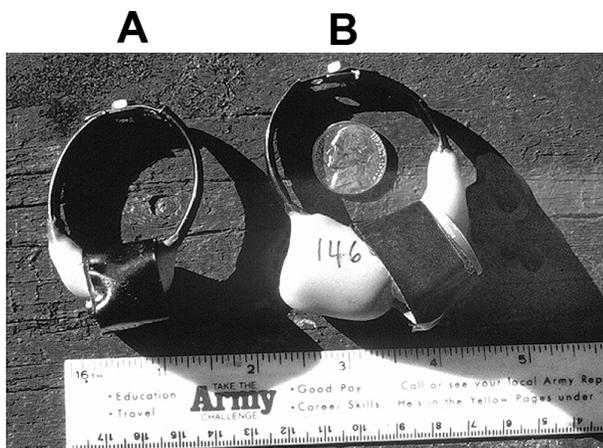
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black-footed ferrets (commencing in 1971), which was “not to produce animals for release in the wild, but to learn more about . . . safe marking methods” and “means of following their travels and home range” (commentary by R. Erickson in Linder and Hillman, 1973, p. 26). These experiences of the 1970s motivated development of prototype transmitters for black-footed ferrets, but, by the latter years of that decade, no free-ranging ferrets could be found. Our use of radio telemetry on black-footed ferrets began in 1981 with the discovery of the last known extant population west of Meeteetse, Wyo. Our intent is to review the use of radio telemetry for black-footed ferret research during the subsequent two decades. There is a particular need to document the problems and our attempts to find solutions. Detailed discussions of hardware and methods that did not work seem as important as discussion of the triumphs, if only to provide a better starting point for those who might wish to engage in improving the techniques. We review the challenges of radio tagging these animals, methods used to gather data once they have been tagged, and methods for analyzing those data.

## Radio Tagging Black-footed Ferrets

In a prophetic prediction of upcoming problems, Erickson (1973, p. 157) stated “There is no known way to safely develop and test methods of installing radio-transmitter harnesses on live ferrets in the wild.” Although the first transmitter packages intended for use on black-footed ferrets (fig. 1) were indeed tested on surrogate domestic ferrets (*M. putorius furo*; fig. 2) (C. Hillman and S. Martin, oral commun., 1980), problems developed when the collars were first used on black-footed ferrets at Meeteetse in 1981–82. Neck abrasions sometimes occurred with these 15-g collars, and they had low power output (table 1, version A-1), in part caused by the inefficient brass loop antenna that also served as a collar (fig.



**Figure 1.** The first radio collars tested for use on black-footed ferrets (*Mustela nigripes*), ca. 1979 (version A-1 of table 1). A model similar to “A” was used on ferrets. Photograph by D. Biggins.



**Figure 2.** Early transmitter packages with tuned loop antennas (version A-1 of table 1) were tested on domestic ferrets (*Mustela putorius furo*). Photograph by U.S. Fish and Wildlife Service.

1). The low power resulted in frequent loss of contact with subjects (Fagerstone and Biggins, 1986). Although a more powerful collar prototype was produced in 1982 (table 1, version B-1), it seemed too bulky for use on ferrets. That transmitter was attached to a harness, but tests on surrogate prairie dogs (*Cynomys* spp.) (fig. 3) were unsuccessful. The original packages were again used in 1982, but the brass loop collars were difficult to fit and collar loss was high (Fagerstone and Biggins, 1986). These first radio collars for ferrets transmitted on 164 MHz.

We also conducted comparative experiments with reception of signals emanating from underground transmitters on 30 MHz and 164 MHz, reasoning that the longer wavelengths would better penetrate soil. The lower frequencies performed no better than the higher frequencies during underground trials, but problems with transmitting and receiving antennas were exacerbated with the lower frequencies (lower frequencies need larger antennas for efficient transmission and reception). All subsequent transmitters were on 164–165 MHz at frequencies licensed to the U.S. Department of the Interior.

Early in 1983 we submitted specifications for a new transmitter collar to manufacturers of wildlife telemetry equipment, requesting their assistance in producing an improved transmitter package. Prototypes from three of the five companies that responded exceeded dimensional or weight limits. Two units (table 1, version D-1, fig. 4; table 1, version C-1, fig. 5) seemed satisfactory and were used on 10 black-footed ferrets in August 1983 (Fagerstone and Biggins, 1986). Reception range was several times greater with model D-1 than with model A-1 used in 1981–82. During 1983, however, breakage of the whip antenna was common, and sometimes accumulations of clay resulted in large increases in mass and dimensions of the transmitter package (fig. 6). The accumulations of clay likely were partially responsible for some neck injuries. Various treatments and coatings, including polished acrylic (fig. 7A), wool (fig. 7B), and Teflon® (DuPont, Wilmington, Del.) heat-shrink tubing (fig. 8), were used in laboratory trials and on prairie dogs and ferrets in the field during 1983 and 1984 to alleviate the mud accumulation problem (Fagerstone and Biggins, 1986). The Teflon tubing solved the problem of mud accumulation; however, its slippery surface seemed to

**Table 1.** Transmitter packages tested during development of radio-telemetry applications for black-footed ferrets (*Mustela nigripes*).

Version	Year	Type	Weight (g)	Antenna	Effective power <sup>1</sup>	Pulse		Battery life (days)
						Width <sup>2</sup>	Rate <sup>3</sup>	
A-1	1981	collar	15	14.0-cm loop	-35		104	100
B-1	1982	harness		44.5-cm whip	-9	14	34	
C-1	1983	collar	10	8.9-cm whip	-35	104	30	39
D-1	1983	collar	13	15.2-cm whip	-12	25	66	
E-1	1983	collar		16.5-cm whip	-40		19	
D-2	1989	collar	10	15.2-cm whip	-18	11–40	25–67	59+
A-2	1991	collar	9	20.3-cm whip			variable	variable
D-3	1992	collar	7	20.3-cm whip	-20	25	47	50
D-4	1985	implant	18	internal coil	-41		47	
D-5	1985	implant	4	whip	-37		80	
E-2	1985	implant	26	internal coil	-39		60	

<sup>1</sup>Decibels relative to 1 milliwatt (dBm).

<sup>2</sup>Milliseconds duration.

<sup>3</sup>Pulses per minute.



**Figure 3.** Capsules with high power output (Telonics, Inc., Mesa, Ariz.) (version B-1 of table 1) were attached to harnesses and tested on surrogate prairie dogs (*Cynomys* spp.) in 1982. Photograph by D. Biggins.



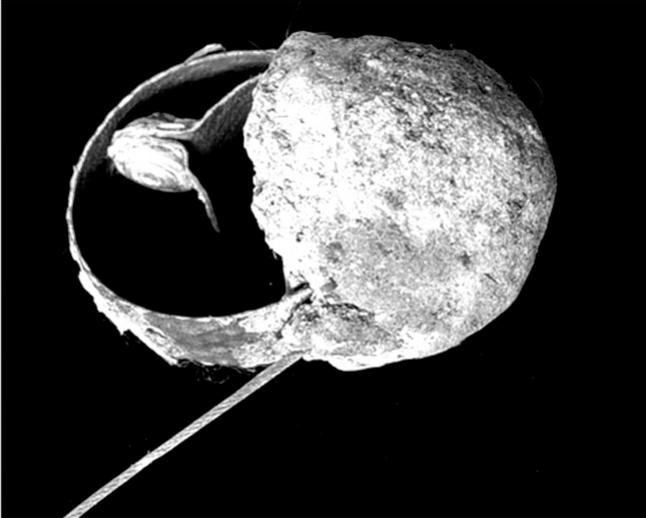
**Figure 5.** A package coated with soft plastic used on black-footed ferrets (*Mustela nigripes*) in 1983 (version C-1 of table 1). Photograph by D. Biggins.



**Figure 4.** A 13-g transmitter package (version D-1 of table 1) used on black-footed ferrets (*Mustela nigripes*) during 1983–84. Photograph by D. Biggins.

exacerbate collar loss, and there were several instances of neck abrasions.

Continued problems with collar loss in 1984 motivated additional investigation and development of transmitter attachment methods for ferrets. Disease outbreaks in Meeteetse prairie dogs and ferrets (Forrest and others, 1988; Ubico and others, 1988) ended all hope for continued research on that free-ranging population of ferrets; however, the ensuing captive breeding program and its ultimate goal of reintroductions underscored the importance of improving radio telemetry for ferrets. In trials conducted in the spring of 1985, two of three free-ranging black-tailed prairie dogs (*Cynomys ludovicianus*) developed neck sores when fitted with old-style ferret collars made of vinyl-impregnated cloth but did not seem adversely affected by neckbands of wool ( $n = 4$ ) or leather ( $n = 4$ ). Prairie dogs gained 40 percent in mass during a 3-month period. Wool collars sewed with cotton thread often wore sufficiently to be lost by prairie dogs in 3 to 6 months. Thus, a black-footed ferret with a wool

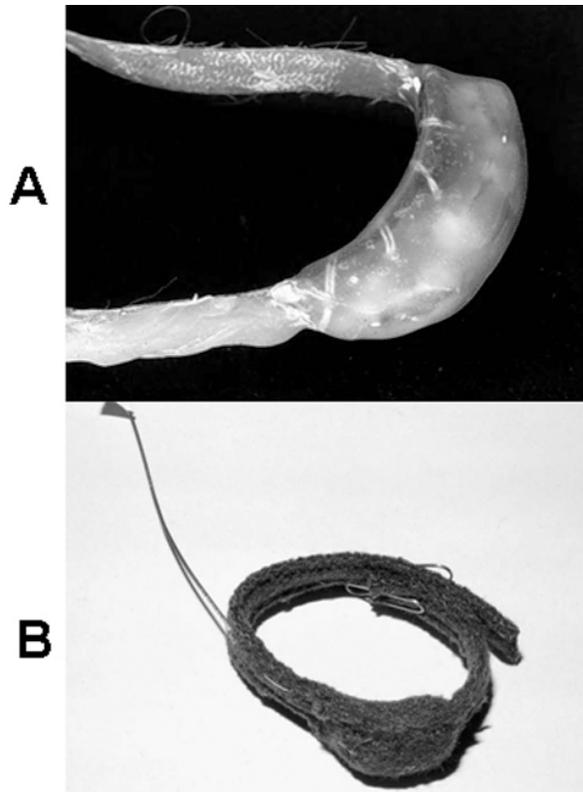


**Figure 6.** A collar from 1983 that accumulated a large buildup of clay while carried by a black-footed ferret (*Mustela nigripes*). Photograph by D. Biggins.

neckband would not be collared permanently if its radio failed prematurely and the animal could not be relocated for collar removal.

One of the goals of research initiated in 1988 on Siberian polecats (*Mustela eversmannii*) and other surrogate species was to advance our proficiency in radio tagging and radio tracking *Mustela* before reintroductions of black-footed ferrets. Studies of captive Siberian polecats and of reproductively sterilized polecats released into prairie dog colonies in Colorado and Wyoming provided opportunities to develop and test equipment. Radio collars made of natural materials were first tested on 13 captive polecats at the National Zoo's Conservation & Research Center, Front Royal, Va., during September 1989. Neckbands were made of leather or wool instead of the vinyl-coated fabric used previously. Collar retention was the primary reason for preliminary testing of radio collars on captive ferrets. Wool and leather collars are somewhat elastic, and the >10 percent stretch of these materials might allow animals to slip out of the collars. Overlapping ends of wool and leather collars were glued with contact cement. The transmitter package for polecats weighed about 10 g, had a 15.2-cm whip antenna (table 1, version D-2), and was attached to a 1-cm-wide wool collar with vinyl tape (not Teflon). The 2-stage, 3-V transmitter had a mercury switch that triggered change in pulse rate, resulting in pulse intervals of about 0.9–2.4 seconds, with pulse interval inversely proportional to activity of the animal (as sensed by motion of the transmitter), and a pulse width inversely proportional to pulse interval to maintain consistent and predictable current drain. Battery longevity was about 59 days.

Both wool and leather collars were removed by some captive animals, but in most cases the shed collars were in poor condition. Captive polecats were housed in family groups and tended to chew and pull on each other's collars causing rapid wear that we did not expect to occur under field



**Figure 7.** The acrylic potting material was polished (A) or encased in wool (B) in attempts to alleviate mud accumulation. Photograph by D. Biggins.



**Figure 8.** A 13-g transmitter package (version D-1 of table 1) from Wildlife Materials, Inc. (Murphysboro, Ill.), with Teflon tubing covering most of the acrylic potting material (used on black-footed ferrets [*Mustela nigripes*] during 1984). Photograph by D. Biggins.

conditions. Wool collars were no more likely to be pulled off than were leather collars, but wool collars wore more quickly. Because the “breakaway” feature of wool was desirable, the wool collar was selected for testing on the released animals to evaluate retention and irritation. Under field conditions, only 1 of the 13 polecats removed its collar, but that animal did so twice. Whip antennas broke on collars worn by two polecats. One antenna became completely severed after 10 days on the animal, and a radio recovered from a dead polecat had several broken strands in its antenna wire. Our simple solution was to use slightly heavier wire and an extra layer of heat-shrink coating extending 1 cm above the point where the antenna protruded from the radio capsule. No sign of worn hair or neck abrasion was noted on recovered polecats; however, there were only a few days of wet weather during our polecat release study, and the soil was sandier than soil at the Meeteetse black-footed ferret study area. Therefore, the potential for mud accumulation on radio collars was not fully assessed. During a short wet period, a small amount of mud was found on the collar of one recaptured polecat, but the mud fell away easily. Poor survival of polecats hampered the evaluation of radio-collar performance in that study (Biggins, 2000a).

Additional polecats released in 1990 ( $n = 44$ ) accumulated about 600 animal days wearing the type of radio collars described above (but with the modified antennas), combining the time that animals carried radio collars during arena conditioning with monitoring time after release. The wool collars continued to function well overall. One collar deteriorated rapidly and was lost from a polecat after only 2 weeks, perhaps because that animal (no. 34, wild caught in China) was exceptionally active. Several other animals lost collars, likely in part because of rapid weight loss after release, particularly with obese animals (Biggins, 2000a). One instance of neck abrasion was noted, and again it was with animal no. 34. That animal was recollared after losing her first transmitter collar; perhaps the tendency was to fit the second collar too tightly because of the prior loss.

The polecat from China (no. 34), radio tracked until the study ended, lost 50 percent of her body mass and her radio collar during the first several weeks postrelease. Perhaps that scenario helps explain the high rate of lost radio contact with wild-caught polecats (3/5 versus 5/39 for captive-bred polecats). Other factors also can cause loss of radio contact. Two recovered radio collars were damaged, presumably by the teeth of coyotes (*Canis latrans*). The signal from one of those collars was barely audible above ground, even at short range (<100 m), suggesting the possibility of complete radio failure from bites of coyotes or badgers (*Taxidea taxus*). Radio signals also can be lost when animals are in burrows >2 m below ground. Because loss of radio contact could have been a result of predation, dispersal, or premature transmitter failures, functional longevity for collars could not be estimated.

Similar versions of these transmitters with wool collars also were used to study free-ranging Siberian polecats (fig. 9) (Zhou and others, 1994) and alpine weasels (*Mustela altaica*) in China (fig. 10). Collars of wool functioned well generally,



**Figure 9.** Additional collar tests (version D-2 of table 1) were conducted on a subspecies of free-ranging Siberian polecat (*Mustela erversmannii dauricus*) in Inner Mongolia, China. Photograph by D. Biggins.



**Figure 10.** We used smaller transmitters with wool collars to study alpine weasels (*Mustela altaica*) in Qinghai, China. Photograph by D. Biggins.

but premature collar loss and occasional neck abrasions continued to be problems. Collar loss was especially common in the alpine weasel study (Wei and others, 1996). The polecat transmitter packages with variable pulse rates used in China and the United States produced easily interpreted activity data.

Because of the effective combination of wool collars and activity-type transmitters used on polecats, this 10-g unit by Wildlife Materials, Inc., (WMI, Murphysboro, Ill.) and a similar variable-pulse rate model by AVM Instrument Company, Ltd., (Colfax, Calif.) (table 1, version A-2) were adopted for monitoring 37 of 49 black-footed ferrets released during the first reintroductions in 1991 at Shirley Basin, Wyo. (U.S. Fish and Wildlife Service, 1992). Collars were worn by ferrets for 2–4 weeks before they were released, allowing prerelease observation of animals but also expending 40–68 percent of

the expected battery life and producing noticeable wear to the wool collars.

Fluctuations in mass of animals appeared to create problems. Ferrets from the Henry Doorly Zoo (Omaha, Nebr.) were 26 percent heavier when collared than were their wild counterparts at Meeteetse ( $P < 0.001$ ) and were 37 percent heavier at 5 days postcollaring. Seven of the zoo ferrets developed neck sores while being held in cages, perhaps because of the increasingly snug fit of the collars as the ferrets gained mass. Ferrets raised at the Wyoming Game and Fish Department facility were not heavier than Meeteetse ferrets prerelease. We accumulated 460 animal days of postrelease telemetric monitoring on the 37 ferrets. Loss of mass postrelease (Biggins, 2000a) likely loosened the fit of collars and may have exacerbated premature collar loss that occurred in nine known instances involving six individual ferrets (ferrets were sometimes recollared). One free-ranging ferret had a neck laceration when recaptured, but other injuries confused determination of the cause(s). There were two known cases of mud adhering to the vinyl tape used to attach the transmitter package to the collar.

Continued problems with collars in 1991 resulted in a more conservative approach to collar configurations used for ferret studies in subsequent years. Beginning in 1992, ferrets were collared with smaller transmitter packages, and Teflon heat-shrink tubing became the standard method for attaching the transmitter to the double- or triple-layered wool collar (fig. 11). The WMI transmitter had a 20.3-cm flexible steel whip antenna (table 1, version D-3). We located an improved type of stainless steel wire for whip antennas (designed for operating prosthetic limbs) that further reduced the problem of breakage resulting from metal fatigue. The 1.5-V battery gave an estimated 45–150 days of transmitting, depending on power output desired. The completed package weighed 6.0–7.2 g (usually  $< 1$  percent of the subject's mass). We believe that miniaturization of the transmitter-collar assembly reduced



**Figure 11.** Fitting a lightweight (6–7 g) transmitter collar (version D-3 of table 1) to a black-footed ferret (*Mustela nigripes*). This style of collar has been used since 1991. Photograph by R. Reading.

problems of collar loss and neck abrasion in black-footed ferrets. See appendix for instructions on final assembly of these collars and the procedure for fitting them to ferrets.

Serious neck injuries may be caused by improper fit of radio collars; abrasions on radio-collared black-footed ferrets in 1991 fueled controversy over effects of collars on survival of ferrets. Oakleaf and others (1993), using data generated from spotlight searches after the second ferret release in 1992, stated that “survival indices are significantly ( $P = 0.002–0.055$ ) greater for black-footed ferrets released without telemetry compared to ferrets released with telemetry collars.” These authors presented four criteria that should be met to enhance comparability of collared and noncollared groups in future studies. Data for their analyses were generated under conditions that violated two of their criteria, similarity in habitat quality and equal accessibility for spotlight searches in areas where radio-collared and noncollared ferrets are released. Radio-collared ferrets were released on lower quality habitat, as measured by densities of prairie dog burrows, than were noncollared ferrets, and the areas with collared ferrets were less easily searched via spotlighting. Prior recognition of the possibility of confounding can be inferred from the hypothesis generated before the 1992 release of ferrets, which stated that “survival of ferrets released in best habitat, without telemetry and with good logistics for spotlight surveys is higher than survival in habitat that is possibly less than the best, with telemetry, and possibly poorer conditions for spotlighting” (B. Oakleaf, quoted in Miller and others, 1996, p. 129). Regarding habitat quality, mounting evidence demonstrates a negative correlation between ferret dispersal and density of prairie dog burrows (Biggins and others, 1999; Biggins, 2000b), and ferrets prefer areas with high burrow density (Biggins, Godbey, Matchett, and Livieri, this volume).

Confounding of collar effect and other variables was problematic in the 1992 sample involving 89 ferrets but became less troublesome as sample size increased because the potentially confounding variables were not consistently associated with the same primary treatment groups. Thus, it may be revealing to examine a much larger data set of reencounters, resulting from spotlight surveys about 1 month postrelease, for 724 ferrets released in four States during 12 years (table 2). For all States except Wyoming, cage-reared ferrets were excluded from the analysis because ferrets that lack preconditioning in outdoor pens have relatively poor survival rates (Biggins and others, 1998a). We could not categorize rearing status for some of the ferrets released in Wyoming; thus, we pooled rearing categories in Wyoming (similar to the analysis of Oakleaf and others, 1993). A multivariate general model (with site-year and mark category) and competing nested submodels were evaluated with program SURVIV (White, 1983). Comparisons of Akaike's Information Criteria (AIC) associated with these models (table 3) favored either the submodel that pooled collared and noncollared ferrets (AIC = 52.86) or the general model (AIC = 51.14). Not surprisingly, reencounter rates (the product of probabilities of survival and capture) for sites-years were likely different. Although

**Table 2.** Numbers of black-footed ferret (*Mustela nigripes*) kits released with and without radio collars. Assessment included only preconditioned kits (except in Wyoming).

Year	Montana		South Dakota		Utah		Wyoming		Total
	No radio	Radio	No radio	Radio	No radio	Radio	No radio	Radio	
1991							12	37	49
1992							52	37	89
1993							48		48
1994		17	7	6			37		67
1995		35		37					72
1996	28			39					67
1997			2	57					59
1998			41	42					83
1999				30	35	18			83
2000					27	29			56
2001					35	8			43
2002					8				8
Total	28	52	50	211	105	55	149	74	724

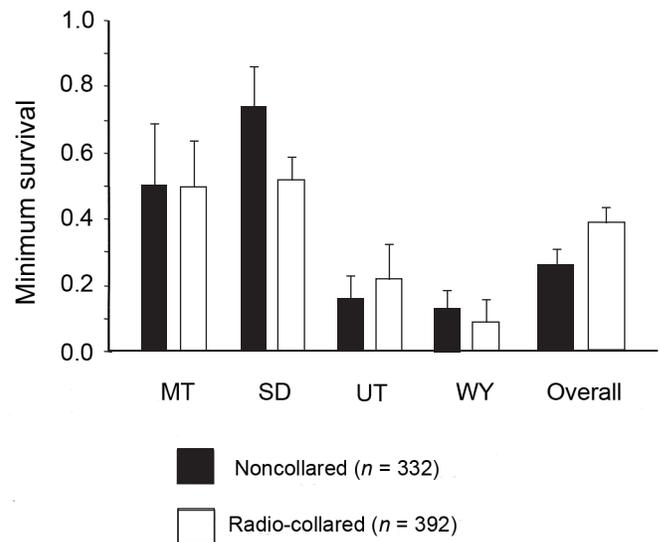
**Table 3.** Modeling minimum short-term (1 month) survival rates of 392 radio-collared and 332 noncollared black-footed ferrets (*Mustela nigripes*) released in Montana, South Dakota, Utah, and Wyoming.

Model	Log-likelihood	np <sup>a</sup>	AIC <sup>b</sup>
General	-17.534357	8	51.06871
All same	-92.542614	1	187.08523
Collaring same	-22.228649	4	52.45729
Sites-years same	-85.786658	2	175.57332

<sup>a</sup>np = number of parameters.

<sup>b</sup>AIC = Akaike’s Information Criterion.

evidence was somewhat equivocal regarding collars, the most parsimonious model of the two with low AIC values suggested no effect of collars (fig. 12). Regardless of improvements in sample size and reduced confounding potential, this remains a post hoc analysis of data from experiments designed to test other hypotheses. Interactions are probable (fig. 12) and the unbalanced design (table 2) allows numerous possible explanations to account for the disparate results for different sites and years. Nevertheless, these data do not support the contention that radio collars negatively affect reencounter rates of released black-footed ferrets. Perhaps cases of management intervention enabled by radio telemetry help compensate for potentially negative influences of collars. On a few occasions, ferrets that dispersed from suitable habitat were captured and translocated; other interventions (also rare) included capture, rehabilitation, and rerelease of ferrets that were injured or in poor condition.



**Figure 12.** Minimum survival rates of preconditioned black-footed ferret (*Mustela nigripes*) kits at about 1 month postrelease.

In a study of translocated ferrets conducted in South Dakota in 1999 (Biggins and others, 2000a), neck abrasions that ranged from minor hair loss to a case of severe ulceration were noted on 10 radio-tagged black-footed ferrets (of 36 released) when animals were reobserved during the study or recaptured for collar removal at the end of the study. A categorical variable (abrasion, no abrasion) for neck condition was evaluated during statistical modeling to assess movements and dispersal of the primary treatment groups (released captive-reared versus wild-born ferrets). There was no evidence that

neck abrasions affected any of the attributes of movements examined ( $P > 0.19$  for all models), even though the experimental design and statistical analyses were sufficiently powerful to detect significant effects of several other variables.

In summary, collar-caused mortality of ferrets has not been documented, and there is no evidence of negative effects of radio telemetry on ferret populations or average behaviors within groups of ferrets. Nevertheless, collaring can at times negatively impact individual ferrets. Moreover, it seems best to assume, even without the latter evidence, that an unnatural protuberance of any sort will influence a free-ranging animal's behavior to some degree, even if that influence is not detectable statistically. Such influences may be acceptable, particularly if it can be reasonably assumed that they equally affect all treatment groups of an experiment. Decisions on whether or not to use this monitoring tool may rest with cost/benefit analyses. If information potentially gained could enhance success of future conservation of the ferret, risk to individuals may be warranted. The arguments, however, appear similar to those discussed with reference to releasing adult ferrets (Biggins, Godbey, Livieri, and others, this volume), wherein "some conservationists and ethicists may justify extreme means to achieve the goal of preservation and recovery" of a species, while "others may set inviolate moral standards regarding the welfare of individuals."

Compared to other recent studies of *Mustela* that have involved radio telemetry, our present collars have rather conservative dimensions and mass. Considering *Mustela* of sizes similar to black-footed ferrets, 27-g and 25-g collars were fitted to feral domestic ferrets in New Zealand (Moller and Alterio, 1999; Byrom, 2002), collars of 25–35 g were placed on European polecats (*M. putorius*) in Italy (Marcelli and others, 2003), and endangered European mink (*M. lutreola*) were tagged with collars of about 13 g in Spain (Zabala and others, 2003). Collars weighing 10 g (likely 4–6 percent of body mass) were placed on stoats (*M. erminea*) in New Zealand (Moller and Alterio, 1999). Although Jedrzejewski and others (2000) tagged least weasels (*M. nivalis*) in Poland with collars of only 3.5–4.5 g, that mass was about 4 percent of the body mass of their subjects. Realizing the sensitivity of these animals to handling and collaring, the latter investigators placed the weasels into an enclosure for several days of observation before final release at the location of capture. We are aware of problems of collar loss and neck abrasion caused by radio collars in other studies of radio-tagged *Mustela*, although discussions of such difficulties are seldom published.

Problems with collars precipitated evaluations of intraperitoneal and subcutaneous implants for black-footed ferrets. Surgically implanted transmitters have been used effectively in several other mustelids such as river otters (*Lutra canadensis*; Hoover, 1984), badgers (Minta, 1993; Goodrich and Buskirk, 1998), and American mink (*Mustela vison*; Stevens and others, 1997). In 1985, we solicited prototype implantable transmitters suitable for ferrets from radio-telemetry equipment suppliers. Two of these units were designed for intraperito-

neal use (table 1, versions D-5 and E-2), and a smaller unit (table 1, version D-4) was to be used subcutaneously. All had disappointingly low power output, leading us to believe that the problems we had in 1991 with loss of contact with ferrets would be worse with the implanted transmitters. Power output of the implants was initially lower than even that of the first radio collars used (table 1) and could be expected to be further degraded after implanting by signal attenuation caused by the ferret's body. Thus, we did not proceed to the next planned step in tests, which was to surgically implant the transmitters into surrogate Siberian polecats.

We did, however, use intraperitoneal and subcutaneous implants in American badgers at the Meeteetse study area in 1984. The dorsally implanted subcutaneous units with 15.2-cm implanted whip antennas radiated more powerful signals than did intraperitoneal units in the same animals, but abscesses that developed around the subcutaneous transmitters resulted in their premature loss. Compared to signals from the radio-tagged ferrets, which were then carrying relatively powerful transmitters (table 1, version D-1), signals from the subcutaneous implants in badgers were about as easily received from our fixed stations, but the intraperitoneal implants in badgers were much more difficult to track. Allowing that technology might have improved during the subsequent decade, we repeated the process of acquiring prototype implantable transmitters for ferrets in 1997, with generally similar results. Relatively poor reception range is a well-known attribute of implantable transmitters, in part because of the compromises necessary with transmitter antennas, which can translate into reduced precision and accuracy of data (Koehler and others, 2001). In our case, low power output resulted in rejection of implant technology before it was necessary to weigh the additional risks and costs of the surgeries needed for implanting and removing the transmitter. It also would have been necessary to consider the possible impact of implants on fertility of females and the possibility that implanted ferrets might not be locatable when it was time to remove the transmitter.

## Radio-tracking Strategies

We quickly realized after radio tagging the first black-footed ferret in 1981 that signal-following techniques using hand-held tracking equipment were unlikely to generate the type, quality, and volume of data we were seeking. Much time was wasted searching for the subjects given the combination of relatively inefficient receiving antennas and low power output from the transmitters. Aside from the partial solution of developing more powerful transmitters (discussed above), it also was necessary to use much more directional and sensitive receiving antennas in order to maintain contact with the ferrets. Also, our signal-following attempts at night often appeared to disturb the ferrets. Thus, we decided to develop several stations of varying mobility equipped with larger antenna arrays from which tracking could be remotely

accomplished via triangulation. Camper trailers with dual-beam 11- or 12-element, rotatable Yagi antennas (fig. 13) became the mainstay of the tracking system, augmented by more mobile truck-mounted receiving equipment (fig. 14). The relatively high receiving efficiency of these stations resulting from the larger antennas was further enhanced by increasing the heights of the arrays with masts of 4.5–6.0 m and by placing the stations on hilltops whenever possible. Although reception range was highly variable for these stations and the transmitters that were developed later (table 1, version D-3), we commonly radio-tracked ferrets at distances of 0.5–2.0 km and received signals from as far as 26.0 km on occasion (Biggins and others, 1999).

Knowing the exact locations of stations is a prerequisite for accurate triangulation. These data were produced (in Universal Transverse Mercator coordinates) by using traditional survey techniques (transit and chain) in the 1980s, followed by location data from a differentially corrected Global Positioning System in later years. Meticulous accuracy testing of each station improved the data in two ways. First, such tests allowed assessment of bias patterns inherent in each station and development of correcting algorithms to improve accuracy of data during processing. Second, the residual variation in bearings from stations, after bias was corrected, allowed estimates of accuracy to be associated with each esti-



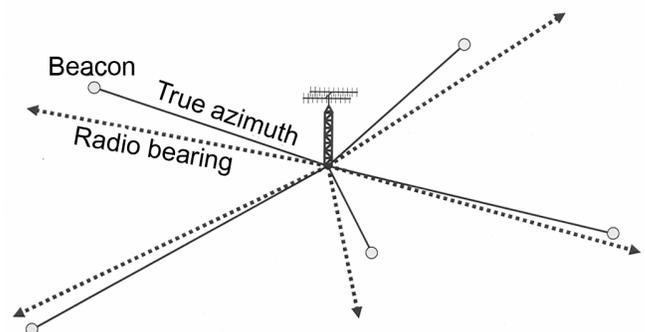
**Figure 13.** Camper trailer fitted with rotatable, 11-element, dual-beam Yagi array, used to radio track black-footed ferrets (*Mustela nigripes*) at the Meeteetse, Wyo., study area in 1983–84. Photograph by D. Biggins.



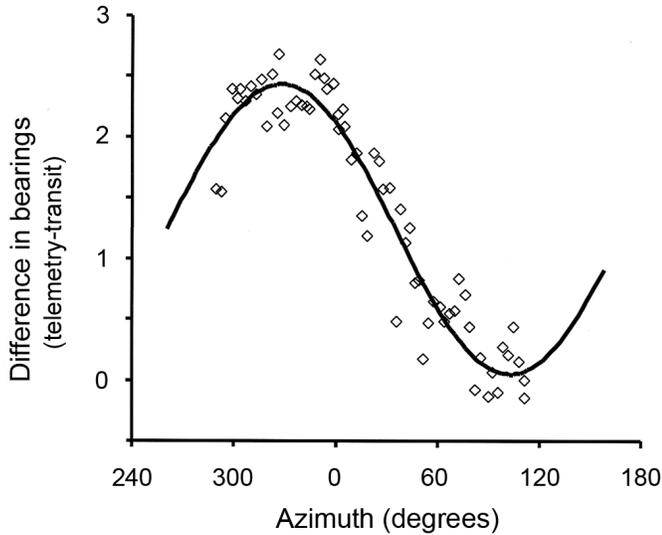
**Figure 14.** Truck-mounted, collapsible, 5-element Yagi array used to radio track black-footed ferrets (*Mustela nigripes*) at Meeteetse, Wyo., during 1982–84. Photograph by D. Biggins.

ated location for a ferret. Tests were conducted by contrasting telemetric bearings to 60–100 beacon transmitter locations surrounding the tested station with a set of known bearings to those beacon locations measured with a surveyor's transit (fig. 15). We employed a split sample technique to analyze test data, using half of the sample to derive the bias corrections and the second half to assess residual variation after the corrections were applied (fig. 16).

A second prerequisite for accurate triangulation is the ability to reference bearings from the antenna. Bearings can be usefully processed only when they are relative to a known



**Figure 15.** Accuracy testing and referencing involve comparison of true azimuths and radio bearings to beacon transmitters.



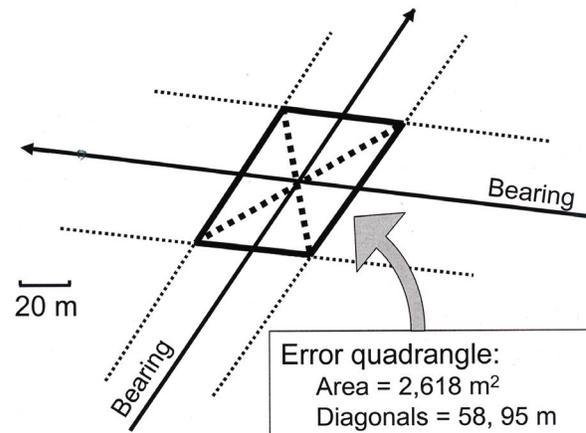
**Figure 16.** An accuracy test done at station 4, UL Bend National Wildlife Refuge, Mont., 1994. In this case, bias was corrected by using a formula defining the sine curve plotted. Residual variation produced a bias-adjusted accuracy estimate of  $\pm 0.63^\circ$  (90% confidence) for future bearings from this station.

entity, such as grid north. One could simply align the main beam of the antenna to north with a compass and set the compass rose to zero. This method is rather crude (White and Garrott, 1990); at least two problems cause variable results. First, the physical and electronic alignment of antennas is seldom absolutely parallel. Second, there is considerable variation in the electronic aiming (fig. 16). If one could successfully get the aim exactly right at one particular point on the compass rose, then it would still not be correct for many other points around the compass rose. Some sort of averaging is needed. To solve these problems, we used reference transmitters placed at known points in the study area. Actual azimuths to the beacons were known for each station and were compared to the telemetric bearings to those transmitters (fig. 15), taken at the beginning of each tracking session. The compass rose inside a station was set so that zero was approximately at grid north (e.g., using a compass), and then readings to multiple beacons were used to provide an average correction that was applied to each subsequent bearing on an animal. Bias adjustment was applied before the referencing correction was made, the same as the process used when animals were tracked. Because the accuracy of this procedure affects all subsequent data, we cannot overemphasize the care needed in referencing. It would be nice to have many beacon transmitters (e.g., 50)! In practice, we used three to six beacons to avoid allowing referencing to become the dominant feature of a tracking session.

Although it is possible to plot triangulation data from pairs of these stations directly on maps to ascertain the whereabouts of the ferrets being tracked, it is more accurate and faster to process these data via computer. Advantages of conducting at least some of this processing while radio track-

ing include the following: (1) station selection can be adjusted as animals being tracked move about; (2) radio-tracking errors can be detected in time to correct them; (3) instances of mortality can be recognized quickly, resulting in better diagnoses of causes; (4) ferret dispersal can be detected in time to allow remedial action, if desired; and (5) in the case of lost radio contact, the last location calculated gives a starting point for searches. A computer program written by one of us (DEB) to accomplish these field processing tasks assisted the technicians with radio tracking ferrets at Meeteetse. The program was used on a programmable calculator in 1982 and was adapted to the first laptop computers that became widely available in 1983. That program evolved into TRITEL (Biggins and others, 2000b), which has been repeatedly modified since 1983 to accomplish referencing and bias corrections, convert azimuth data into coordinates, calculate error estimates for each telemetric fix (fig. 17), and store resulting data.

Procedures for radio tracking and processing data are detailed in a separate report (Biggins and others, 2000b). We have relied on intensive triangulation from these kinds of stations to produce large volumes of data. Although we have at times recollared ferrets to extend data gathering over several months, all telemetric studies were relatively short term. To monitor reintroductions, ferrets often were radio tracked for just 2–4 weeks postrelease, but stations were usually occupied during all hours of the day or during all hours of darkness, with fixes generated by occupants at two or more stations coordinating their tracking with two-way radio communication. Intensity of re-location for individual ferrets varied (3–60 minutes between consecutive fixes on an individual), depending mostly on how many individual animals were being monitored. During the reintroduction phase of black-footed ferret recovery (1989–2000), we used this tracking strategy



**Figure 17.** An example of a telemetric fix and error quadrangle (black-footed ferret [*Mustela nigripes*] no. 26, South Dakota, 10/23/97, 0148 h) produced by intersecting bearings and their associated error arcs from two tracking stations.

to monitor 340 radio-tagged ferrets and polecats, accumulating 83,275 lines of data that included 44,191 indications of status and 39,084 estimates of location (fixes). Data on status demarked beginning and ending points of tracking sessions, activity of animal (active, inactive) as determined by variation in signal strength, and pulse interval records when transmitters with variable pulse rates were used. Status data were recorded with fixes but were the only data recorded when triangulation was not possible (e.g., when only a single station received an adequate signal).

Radio-telemetry data from triangulation allows many options for analyses (summarized by White and Garrott, 1990). For black-footed ferrets, we have used radio telemetry to examine survival rates (Biggins, 2000a), linear movements (Biggins and others, 1999), dispersal (Biggins, Godbey, Livieri, and others, this volume), habitat preferences (Biggins and others, 1985; Biggins, Godbey, Matchett, and Livieri, this volume), indices of spatial use (Biggins and others, 1998b), and activity cycles (Biggins and others, 1986; Biggins, 2000a). The examples noted above are not exhaustive, and other options for use of the large data sets generated during multiple studies are currently being pursued. We believe that several features of analyzing telemetric data for ferrets, however, are worthy of emphasis here.

First, the inevitable errors that occur during triangulation must be detected and eliminated to the extent possible. Our system for handling data from triangulation, consistent with a pattern noted by Kenward (1987), has resulted in a series of custom computer programs for manipulating the output from TRITEL and screening for errors (Breck and Biggins, 1997). Similar to the BIOCHECK routine of White and Garrott (1990), our error screening involves searches for nonsensical data entries (e.g., unreasonable dates or times) and for data that fall outside limits set by a priori knowledge of ferret behaviors (e.g., maximum speed of movement). Errors are either corrected by referral to original data sheets, or offending lines are removed.

Second, estimates of ferret locations derived from triangulation are subject to direction-finding variation, as noted above. Estimates of such error associated with each fix ("error quadrangles" when two stations are used) are stored with each fix when TRITEL is used to process bearings. Our error screening process removes data lines with error estimates exceeding specified limits for lengths of diagonals or area of the quadrangle. Just as importantly, we have used these attributes of error as covariates in multivariate statistical analyses and often retain them in statistical models as "control" variables even if their estimated effect is small or not statistically significant. Although tracking error is nuisance variation when one is attempting to assess other treatments, it often accounts for significant variation (Biggins and others, 1998b, 2000a; Biggins, 2000a). If, however, a response variable is already known to be positively correlated to tracking error, then the use of tracking error as a covariate is not warranted. An example is dispersal. Because error is in part a function of distance separating station and subject, sizes of the error

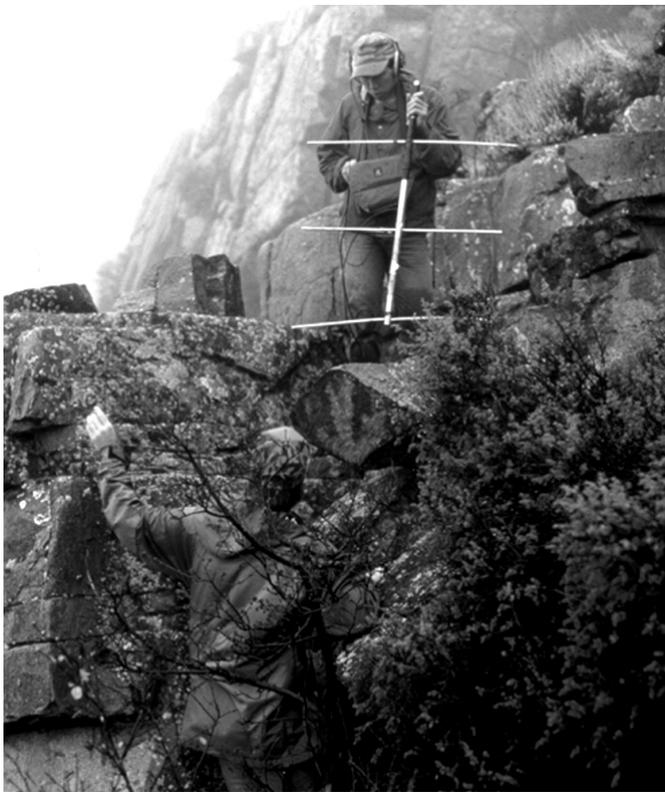
quadrangles increase as ferrets disperse away from tracking stations. Unlike other movements within the monitored area, radio-tracking error should not be used to explain variation in dispersal by ferrets because increased tracking error is an expected consequence of dispersal.

Third, the ferret data we have generated are serially correlated because of short interfix intervals; each telemetric fix cannot be considered independent (Swihart and Slade, 1985). The level of detail present in our data sets allows powerful behavioral comparisons (see examples cited above), but caution must be exercised in analyzing these data when independent observations are required (e.g., home range estimation; see White and Garrott, 1990).

The close association between black-footed ferrets and prairie dog colonies facilitates the radio tracking of ferrets from fixed tracking stations. Ferrets often remain within predictable boundaries where radio tracking coverage was nearly complete with careful placement of multiple stations (e.g., the Montana study of Biggins, Godbey, Matchett, and Livieri, this volume). Nevertheless, if we would like to monitor every animal in our sample with equal intensity and accuracy, triangulation from fixed stations is problematic (not unlike data from any other method of radio tracking or monitoring). Signal quality and accuracy of fixes vary with range and topography, and positioning of stations interacts with these factors to create uneven trackability of animals throughout any study area. The movements of some animals may be described more accurately and completely than the movements of others, and probabilities of detecting mortality cases may vary accordingly. Animals that disperse away from fixed stations may be tracked with lower intensity, lower accuracy, or not at all. Attributes such as cumulative movements are affected by frequency and accuracy of relocations. The consequences can be serious if the goal is to characterize the behaviors of the species. When comparing treatment groups (e.g., sexes, ages, rearing treatments), the consequences are more benign if we can reasonably assume that animals are distributed in the study area in such a way that members of each group are about equally trackable on average. The possibility of group-specific biases should be carefully considered for each case. For example, if dispersal is the attribute of interest, it may or may not be logical to rely on data from fixed-station triangulation. If dispersal distances have been artificially truncated by reception range of the tracking system, power of a comparative experiment may be reduced and dispersal distances will be underestimated to the greatest degree for groups whose members tend to disperse most frequently and farthest. Nevertheless, radio tracking from fixed stations has enabled us to detect significant between-group differences in dispersal (Biggins and others, 1998b, 1999). A germane statistical adage might be "if the tree falls, the axe was sharp enough" (Martin and Bateson, 1990, p. 126).

We have augmented triangulation with hand tracking, automated signal monitoring and data logging, and tracking from aircraft. Hand tracking, usually with a hand-held receiver and a 3-element Yagi antenna, was often used to investigate

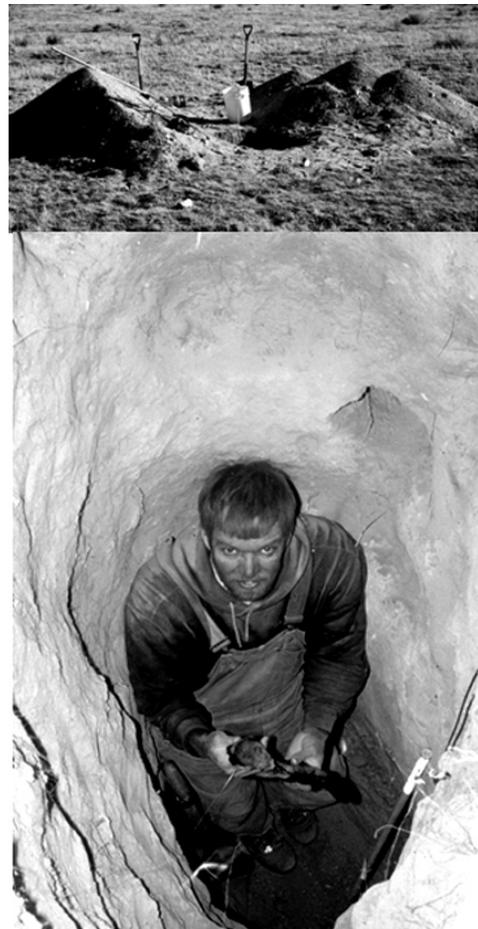
ferrets whose transmitters (a) were in unusual locations, (b) had moved rapidly, (c) had not been detected for long periods, (d) were stationary above ground at night, or (e) were above ground during daytime. These circumstances often led to re-location of ferrets that had dispersed (fig. 18) or to ferrets that had been killed by predators (fig. 19; Biggins, Godbey, Livieri, and others, this volume). We attempted to visit the location of the last fix if contact with a transmitter was lost for 2 or more days; listening for a radio signal while walking a narrowly spaced grid (ca. 2-m spacing) sometimes allowed detection of the transmitter belowground to depths of >4 m. Signal strength was correlated with depth of the transmitter; weakest signals could be received only when the operator was almost directly above the transmitter with the Yagi antenna pointing vertically downward (Biggins, 2000a). Signals seldom emanated from burrow entrances (contrary to the predictions of some electronic engineers). Remains of badger-killed ferrets were located by careful searches and excavated (fig. 20). Lost contact with transmitters also precipitated aerial searches at some sites. Each aircraft was equipped with a pair of 4-element Yagi antennas (affixed to each wing strut) and a switch to allow the operator to listen to the signal from each antenna separately. Homing on the source of a signal was accomplished by equalizing the null from each antenna (Gilmer and others, 1981). Radio-tracking flights helped locate ferrets that dispersed to different prairie dog colonies, especially when the flights were at night when ferrets are



**Figure 18.** Hand tracking enabled us to locate black-footed ferrets (*Mustela nigripes*) that had dispersed into unusual habitats. Photograph by M. Albee.



**Figure 19.** Siberian polecat (*Mustela eversmannii*) killed by a predator. Photograph by D. Biggins.



**Figure 20.** Hand-held tracking equipment enabled location of transmitters below ground, necessitating excavation to determine fate of animals such as this Siberian polecat (*Mustela eversmannii*) killed by a badger (*Taxidea taxus*). Photographs by D. Biggins.

most active above ground (Biggins and others, 1986; Biggins, 2000a). The most common product of flights, however, was detection of lost collars and cases of aboveground predation on ferrets that had dispersed (or their transmitters had been dispersed by the predator) beyond signal reception range of tracking stations. In short, these follow-up techniques, although arguably less technologically demanding than the radio tracking by triangulation, have provided the critically important details on fates of animals that other strategies cannot produce.

We used signal monitoring both with automated chart recorders and with computer loggers in attempts to collect information on aboveground activity of ferrets and polecats (Biggins, 2000a). The technique was useful to supplement data from triangulation, particularly on animals that were beyond the boundaries of the area that could be effectively monitored by tracking stations; however, the relative insensitivity of automated systems to detection of weak signals, coupled with the large activity areas of black-footed ferrets, limits the utility of automated tracking for ferrets.

## Summary

The wide range of problems and accomplishments accompanying the use of radio telemetry on ferrets provides an opportunity for both detractors and proponents to present powerful arguments. Although success was never close to total, failures were not devastating to data or the ferrets. We would like to reemphasize that radio telemetry is an expensive and labor-intensive method for monitoring black-footed ferrets and that attaching radio transmitters to ferrets poses risks to the animals. It is essential, therefore, to carefully consider the objectives of a study to ascertain whether other tools would suffice. Justifications for use of radio telemetry on ferrets include unexplained lack of success in establishing a ferret population and tests of hypotheses that have large-scale management implications and require behavioral information. Cost/benefit analyses regarding use of telemetry should include as costs the potential future losses of ferrets if a perceived need for information remains unfulfilled. In some cases, short-term recovery objectives may become subordinate to learning objectives that could advance long-term recovery goals.

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Materials, Inc. We appreciate the dedication of the many technicians over a 20-year period that assisted with setting up, testing, and operating tracking stations.

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## Appendix. Notes on Radio Collaring Black-footed Ferrets

Collars that we are presently using are considerably more fragile than their predecessors and are intentionally designed to lack durability. Most black-footed ferrets (*Mustela nigripes*) shed the collars within 2 months (often much sooner). Use of more durable collars seems to increase the risk of neck sores. Presently, collars 1 cm wide are made of 100 percent wool, folded into three layers and sewn with 100 percent cotton thread. The edges are not bound, so the wool will fray rapidly. After sewing the wool into long strips of uncut collars, we prestretch the material. It is soaked in water and hung to dry with a 200-g weight clamped to the lower end. Collars are then cut to 15–18 cm lengths. To attach a collar to the transmitter unit, both are inserted into a 2.5-cm length of Teflon® heat-shrink tubing (1.25 cm diameter), and a heat gun (or other heat source such as a gas stove or propane torch) is used to shrink the tubing. Overheating the transmitter packages can cause malfunctions. High temperature for a short duration works better than less heat applied for longer times. The object is to heat the tubing without overheating the transmitter and battery. After shrinking the tubing, the package is cooled rapidly by wrapping it in a cool, wet sponge. Equipment and supplies needed to attach these collars to ferrets include scissors, a hemostat clamp, contact cement, a telemetry receiver, and a hair dryer. Mustelids characteristically have little neck constriction, making exact collar fit important. The attachment procedure for black-footed ferrets may be accomplished in the following steps:

1. Remove the magnet and check transmitter operation.
2. Restrain ferrets with a light dose of ketamine/diazepam (about 17–20 mg per kg of body weight) for this noninvasive procedure (Thorne and others, 1985). Recently, we have been using isoflurane gas anesthesia, which is more controllable (Biggins, Godbey, Matchett, and others, this volume). New innovations in gas anesthesia (e.g., sevoflurane; Gaynor and others, 1997) have additional advantages but require different vaporizers. The U.S. Fish and Wildlife Service requires ferret handlers to be trained in anesthesia and handling procedures.
3. As soon as the animal is tranquil enough to handle, make a trial fit of the collar and mark the length needed, allowing about 1-cm overlap of ends. Mark the area of overlap that will be glued, but do not trim excess from the long end of the collar until later. The extra length makes it easier to fit on the animal and can be trimmed at the end of the process.
4. Coat the inside of one end and the outside of the other end with contact cement. We use the Weldwood® (DAP® Products, Inc., Baltimore, Md.) version that has a toluene solvent, which seems to work better than the versions with other solvents. The glue-drying process takes 3–10 minutes. A hair dryer speeds drying. The first coat of cement normally penetrates the wool. Unless the glue is quite thick, the first coat must be dried completely and a second coat applied and dried until tacky.
5. Wrap the collar around the animal's neck and press a tiny portion of the glued strip together lightly. This process allows a final check for snugness before the final gluing is done. Collar fit is critical; it should be snug but not tight. The collar should rotate fairly easily around the neck. Also, a small closed hemostat or small scissors should slide easily between the neck and collar, but if you can insert your little finger, the collar is probably too loose.
6. If the fit seems satisfactory, press the glued ends together firmly. Use the hemostat to clamp the ends, repeatedly clamping and releasing until the entire overlap area has been pressed together firmly. Trim excess wool from the long end of the collar. We know of only one occasion when the glue joint failed, and that was when a technician did not realize that he had to let the glue dry before pressing the ends together. In fact, we have not been able to separate the final joint by pulling the ends apart—the material always tears. It may even be difficult to separate the ends during the trial fitting if they have made too much contact.