Effectiveness of Scat Detection Dogs for Detecting Forest Carnivores

ROBERT A. LONG,[1,2] *Vermont Cooperative Fish and Wildlife Research Unit, University of Vermont, Burlington, VT 05405, USA*

THERESE M. DONOVAN, *United States Geological Survey Vermont Cooperative Fish & Wildlife Research Unit, University of Vermont, Burlington, VT 05405, USA*

PAULA MACKAY, *University of Vermont, Burlington, VT 05405, USA*

WILLIAM J. ZIELINSKI, *United States Department of Agriculture Forest Service, Pacific Southwest Research Station, 1700 Bayview Drive, Arcata, CA 95521, USA*

JEFFREY S. BUZAS, *Department of Mathematics and Statistics, University of Vermont, Burlington, VT 05405, USA*

ABSTRACT We assessed the detection and accuracy rates of detection dogs trained to locate scats from free-ranging black bears (*Ursus americanus*), fishers (*Martes pennanti*), and bobcats (*Lynx rufus*). During the summers of 2003–2004, 5 detection teams located 1,565 scats (747 putative black bear, 665 putative fisher, and 153 putative bobcat) at 168 survey sites throughout Vermont, USA. Of 347 scats genetically analyzed for species identification, 179 (51.6%) yielded a positive identification, 131 (37.8%) failed to yield DNA information, and 37 (10.7%) yielded DNA but provided no species confirmation. For 70 survey sites where confirmation of a putative target species' scat was not possible, we assessed the probability that $\geq$1 of the scats collected at the site was deposited by the target species (probability of correct identification; P_{ID}). Based on species confirmations or P_{ID} values, we detected bears at 57.1% (96) of sites, fishers at 61.3% (103) of sites, and bobcats at 12.5% (21) of sites. We estimated that the mean probability of detecting the target species (when present) during a single visit to a site was 0.86 for black bears, 0.95 for fishers, and 0.40 for bobcats. The probability of detecting black bears was largely unaffected by site- or visit-specific covariates, but the probability of detecting fishers varied by detection team. We found little or no effect of topographic ruggedness, vegetation density, or local weather (e.g., temp, humidity) on detection probability for fishers or black bears (data were insufficient for bobcat analyses). Detection dogs were highly effective at locating scats from forest carnivores and provided an efficient and accurate method for collecting detection–nondetection data on multiple species. (JOURNAL OF WILDLIFE MANAGEMENT 71(6):2007–2017; 2007)

DOI: 10.2193/2006-230

KEY WORDS black bear, bobcat, detection dog, fisher, *Lynx rufus*, *Martes pennanti*, scat, survey, *Ursus americanus*, Vermont.

Terrestrial carnivores are characteristically sensitive to habitat fragmentation, disturbance, and exploitation by humans (Weaver et al. 1996, Woodroffe and Ginsberg 1998, Ginsberg 2001, Woodroffe 2001) and are thus the focus of many research and conservation efforts. Unfortunately, some of the same characteristics that cause carnivores to be of conservation concern (i.e., large area requirements, low densities)—coupled with their elusive behavior—render them difficult to study. In the late 1990s, researchers in North America began to apply a systematic and replicable protocol for training detection dogs to locate scat samples from secretive and wide-ranging species (Smith et al. 2001, Wasser et al. 2004). This method was developed, at least in part, to help minimize the potential detectability biases associated with scat surveys conducted by human observers. Scats can provide information on species and individual identity (via DNA; Foran et al. 1997, Waits et al. 2001), as well as other important insights into the ecology and natural history of the target species (Arthur et al. 1989, Zielinski et al. 1999, Farrell et al. 2000, von der Ohe and Servheen 2003, Wasser et al. 2004). Because scat detection dogs are a relatively new wildlife survey technique, their effectiveness has been quantified for very few target species (Smith et al. 2001, 2003, 2005; Wasser et al. 2004; Harrison 2006).

[1] *E-mail: robert.long@coe.montana.edu*
[2] *Present address: Road Ecology Program, Western Transportation Institute, Montana State University, P.O. Box 1654, Ellensburg, WA 98926, USA*

We discuss the results of a 3-year study intended to assess the ability of detection dogs to locate scats from black bears (*Ursus americanus*), fishers (*Martes pennanti)*, and bobcats (*Lynx rufus*) throughout the state of Vermont, USA—a primarily forested and topographically complex region. To our knowledge, this project represents the first time scat detection dogs were used in the forests of eastern North America and to detect 3 such taxonomically diverse species simultaneously. Prior to our study, scat detection dogs had not been tested on fishers or bobcats in any part of their respective ranges. Our objectives were to 1) determine whether detection dog teams could locate scats from the 3 target species and distinguish them from nontarget species, 2) develop a method for quantifying confidence in declaring a site occupied by a target species when DNA confirmation was not possible, 3) estimate the probability that a detection dog team would detect a target species on a single visit, given the species' presence at the site, and 4) assess the site- and visit-specific factors that affected this probability.

STUDY AREA

Our study area included the entire state of Vermont (24,963 km^2), along with a few sites located immediately west of central Vermont's border with New York. Mean elevation was 370 m, ranging from 30 m along the shores of Lake Champlain to 1,339 m at Mount Mansfield, Vermont's highest peak. Vermont's climate was classified as humid continental, with mean January temperatures ranging from

−10° C to −5.5° C, and mean July temperatures from 17.7° C to 21° C (Thompson and Sorenson 2000). Annual precipitation ranged from about 75 cm in the Champlain Valley to >180 cm along the southern Green Mountain peaks (Thompson and Sorenson 2000). Recent changes in forest patterns have been dramatic. Up to 95% of the state was forested in 1750; by 1850, almost 75% of the forests had been cleared for timber and agriculture (Thompson and Sorenson 2000). Relatively shallow and infertile soils resulted in poor farming conditions, and by 1980, roughly 79% of the state was again forested (Thompson and Sorenson 2000). At the time of our study, most of Vermont was dominated by hardwoods such as sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), paper birch (*B. papyrifera*), and American beech (*Fagus grandifolia*). The mid- and upper-slopes of the Green Mountains supported montane stands of red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*), and much of northeastern Vermont featured forests of black spruce (*P. mariana*), red spruce, balsam fir, paper birch, and white spruce (*P. glauca*; Thompson and Sorenson 2000).

METHODS

Survey Methods and Design

Scat detection dog and handler training.—During the summer of 2002, we conducted a pilot study with 3 detection dog teams to design and refine our survey protocols. Over the next 2 field seasons, 5 detection dog teams (3 in 2003, 2 in 2004) surveyed field sites throughout Vermont. Scat detection dogs were professionally trained by Packleader Dog Training (Gig Harbor, WA) with techniques similar to those used to train dogs to detect narcotics and explosives, as well for search and rescue applications (for training details see Smith et al. 2003, Wasser et al. 2004). In brief summary, dogs were selected for specific attributes (e.g., high drive, object orientation, appropriate temperament) and were initially trained to associate the scent of a single target species' scat with a reward (i.e., a tennis ball). Dogs were trained to sit or stay at the site of located scats—a conditioned behavior known as indicating. Once a given dog consistently located scat from the first target species in field trials, a second target odor was introduced. Training continued until dogs were able to locate scats from all 3 target species in field trials.

At least 20 scats from each target species (representing numerous individuals and a wide range of food items) were used to train the detection dogs. We solicited scats from wildlife researchers, agency personnel, and rehabilitators across the United States for this purpose. This protocol ensured that dogs were trained on the species' scent rather than that of individual animals or specific food items. All dogs were trained for 4–6 weeks prior to the field season at either the McNeil Island Correctional Center, McNeil Island, Washington, or at Packleader Dog Training's facilities in Gig Harbor, Washington, USA.

Each dog was paired with a handler who was also trained for ≥10 days. Handlers were trained to read and assist the dog in working to the odor's source because a dog's ability to detect odor and locate scat may vary as a function of topography, vegetation, wind, humidity, and other variables (Wasser et al. 2004). Handlers were also responsible for monitoring the dog's condition during the training and field seasons and for attending to basic needs such as food, water, and rest.

Survey site selection.—We conducted surveys on lands owned by the State of Vermont, the United States Department of Agriculture Forest Service, and the University of Vermont, along with a small number of parcels owned by private citizens. To maximize the number of individual animals detected, we attempted to locate sites ≥5 km apart. We used Geographic Information System software (ArcGIS) and Hawth's Analysis Tools (www.spatialecology.com/htools/) to generate a large set of random points across the entire area to which we had access, and we constrained these points to being >5 km apart. We randomly selected a subset of these points and generated a 2-km, diamond-shaped transect around each point. We discarded transects located in inaccessible areas (e.g., cliffs, bodies of water) or, if possible, shifted them to the closest location that could be feasibly surveyed (usually within 1 km). The resulting transects represented all major cover types and a broad gradient of human disturbance, forest fragmentation, land ownership categories, elevation, and topographic complexity. We surveyed target carnivores along the transect, which began and ended at the same point and circumscribed an area of approximately 22 ha. As we surveyed only one transect at each site, the terms site and transect are generally synonymous for our study.

Carnivore surveys.—Each transect was searched by a team consisting of a detection dog, a dog handler, and an orienteer (responsible for navigating and keeping the team on transect). We haphazardly determined the order of initial site visits, with each team working in a different region. The modeling framework we used (discussed below) allows estimation of detection probability with survey data collected from multiple visits to at least a subset of sites (MacKenzie et al. 2002). Logistical and cost constraints precluded multiple visits to all sites. Thus, we surveyed a subset of transects twice and a smaller subset 3 times. Most surveys occurred from early morning to midday, with surveys beginning near dawn on days when the predicted temperature was high. We instructed handlers to search along the transect line. We included in the analysis scats collected inside the transect line or ≤100 m outside the transect line (i.e., the detection zone; Fig. 1).

After each survey, detection teams recorded wind (i.e., calm, light, moderate, high) and rain (i.e., none, light, moderate, high) conditions during the survey period. We calculated mean temperature and humidity values for each survey from weather data recorded by the climate station closest to the survey site (National Climatic Data Center 2003). We estimated vegetation openness at each site using the mean of 16 low (0–1 m) and 16 middle (1–2 m) density board readings (Nudds 1977) taken on each transect (4

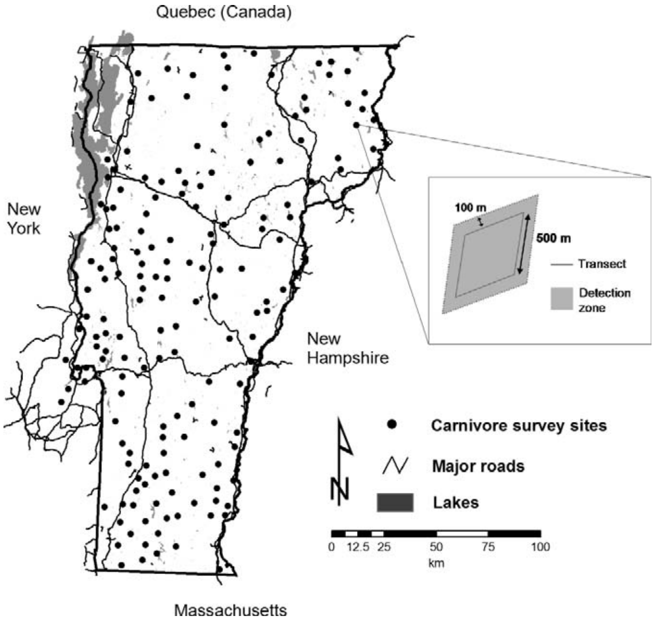

Figure 1. Map of 168 sites in Vermont and New York, USA, we surveyed for target carnivores using detection dogs during May–August of 2003 and 2004. Inset shows transect size, shape, and assumed detection zone for detection dog surveys.

readings/level at 2 locations/transect). We counted unobstructed grid cells on the density board such that sites with less vegetation density (i.e., more openness) had higher values.

Survey Assessment

Objective 1: ability to locate scats and distinguish between target and nontarget species.—Detection teams recorded both total numbers of scats and independent scat events. We assigned a unique scat identification number to scats that were >15 m apart or to scats that were <15 m apart but appeared to vary in age or content. These scats were presumably deposited at different times or from different individuals, and we recorded them as independent events. We presumed multiple scats <15 m apart that appeared to be of consistent age, size, and contents to be deposited by one individual during one event, and we assigned them a common identification number. We hereafter refer to each independent event as a scat, regardless of whether there were single or multiple scats at the location.

Team members collected all scats detected by dogs and assigned each scat a putative species identification based on morphological characteristics. Detection teams also assigned the species identification a confidence level (i.e., high, medium, low) based on the dog's behavior, scat morphology, relative age of scat, and amount of scat degradation. We presumed scats receiving a high confidence score to be from a target species, medium scores indicated some uncertainty, and low scores were typically reserved for scats that were old, degraded, or otherwise ambiguous. Although it was impossible to determine the exact age of scats from any of our target species, we consistently assigned black bear scats a relative age based on interior or exterior moistness, odor, texture, presence or absence of mold and insects, contents, and comparisons with known-age scats (many fisher and bobcat scats were too desiccated or degraded to allow for even relative aging). Age classes consisted of 1–2 days, 3 days–1 week, 1 week–1 month, >1 month, and last season. In an effort to ensure that we did not fail to detect a species that was present at a site, teams occasionally collected scats suspected to have been deposited by a nontarget species, or for which the dog gave a weak indication, and assigned these scats a low confidence rating. Given this protocol, we expected that some low confidence scats may have been deposited by nontarget species.

At each scat site, detection teams subjectively evaluated (i.e., very low, medium, high) the chance that they would have located the scat without assistance from the dog, thus providing some idea of how many scats might have been found by 2 human surveyors working without a dog. Scat locations were recorded via a Garmin Etrex handheld Global Positioning System receiver employing a North American Datum 1983 reference system, with an estimated accuracy of ± 20 m. We collected samples and immediately deposited 5–10 mL of each scat in 95% ethanol for subsequent genetic analysis.

In the Northeast, fresh black bear scats are generally unambiguous in terms of species identification, primarily because there are no sympatric species with which intact (i.e., high confidence) scats might be confused. Thus, we did not subject high confidence bear scats to genetic analysis for species confirmation unless we found only one high confidence bear scat on the transect. For all other species-confidence level combinations, we attempted to confirm species identification via genetic analysis for ≥ 1 scat from each target species for each transect visit.

We sent scats to Wildlife Genetics International (Nelson, BC, Canada) for species identification. Using the Qiagen QiaAmp Mini Stool Kit (Qiagen Inc., Valencia, CA), DNA was extracted from samples. The species test consisted of a sequence-based analysis of the 16S ribosomal ribonucleic acid (rRNA) mitochondrial gene (e.g., Johnson and O'Brien 1997). Results were compared to a library of known-species reference samples. A second round of analyses was performed whenever results from the first were weak or the sample failed to yield sufficient DNA for species identification.

Objective 2: establishing detection versus nondetection at sites.—We used an occupancy modeling framework (see objectives 3–4 below) that assumes a species is never falsely detected at a site (MacKenzie et al. 2002). Because laboratory methods for extracting DNA from feces are still being refined (Foran et al. 1997, Murphy et al. 2001), species confirmation via genetic methods is not always possible. Further, given the large numbers of scats located by our detection teams and the substantial cost of DNA analyses, it was not economically feasible to analyze each scat collected. To address these issues, we coupled the results of conclusive DNA analyses with a formula for compounding probabilities to evaluate the probability that ≥ 1 scat from a given site was deposited by the putative target species. First, we used DNA-confirmed scats to estimate correct classification rates for each combination of confidence level and species. We then applied these rates to the number and confidence levels of scats from a putative target species on a given transect to calculate the overall probability that detection teams correctly assigned ≥1 scat per transect from that species correctly (P_{ID}):

$$P_{ID} = 1 - \prod_{i=1}^{3}(1 - cc_i)^{n_i}$$

where cc_i is the correct classification rate for scats of a given confidence level i (where $i = 1$, 2, or 3 for low, medium, and high confidence scats, respectively), and n_i is the number of scats with the ith confidence level. This approach produces a single probability value between zero and one. It was therefore necessary to assign a P_{ID} cutoff level below which we would not be sufficiently confident that ≥1 of the collected scats was deposited by the putative target species (i.e., the species was not sufficiently detected). By setting the cutoff at a relatively high level ($P_{ID} \geq 0.90$), we assumed that we included very few false detections in our analyses.

Objectives 3 and 4: estimating probability of detection and evaluating factors affecting detectability.—Recent advances in likelihood-based occupancy modeling (e.g., MacKenzie et al. 2002, 2005; Tyre et al. 2003; Moore and Swihart 2005; Wintle et al. 2005) allow the estimation of both site occupancy (ψ) and probability of detection (p), given presence, from detection–nondetection data collected during repeat surveys at sites. We used data from all sites, with each site visited 1, 2, or 3 times, to evaluate the effects of site- and visit-specific covariates on scat detection by detection dog teams and also to estimate the probability of detecting each target species (given presence) during a single survey of a site.

Based on published studies, field experience, and input from detection dog trainers, we identified a number of variables that might affect the ability of a detection team to locate a target scat. We considered the following explanatory variables in our analysis: 1) survey visit number (VISIT), identified as 1, 2, or 3; 2) topographic ruggedness index (TRI; Riley et al. 1999), an index of elevation change across the transect calculated using ArcGIS 9; 3) vegetation openness (OPEN); 4) year of the survey (YEAR), corresponding to either 2003 or 2004; 5) detection dog team (TEAM) used for the survey; 6) mean air temperature (TEMP) during the hours of the survey; 7) mean humidity (HUMID) during the hours of the survey; 8) wind (WIND), a categorical variable defined as none, light or moderate, or strong; and 9) precipitation (PRECIP), a categorical variable defined as none, light or moderate, or high. We standardized continuous covariates prior to analysis.

The occupancy-likelihood framework considers both detection and occurrence simultaneously, resulting in a dependency between estimates of these parameters. We modeled detectability by fitting a set of candidate models for this parameter while including a standard set of potential occurrence covariates that were constant across all models. Our a priori candidate models included combinations of explanatory variables that might plausibly affect detectability, and we fit these models to the detection–nondetection data for each species using the occupancy estimation option in the Program MARK Version 5.1 (White and Burnham 1999). We eliminated from the candidate set models that did not result in convergence—or for which convergence was suspect because of inestimable parameters. We ranked models using the small-sample correction to Akaike's Information Criterion (AIC_c; Burnham and Anderson 2002).

We used Akaike weights (Buckland et al. 1997, Burnham and Anderson 2002) to evaluate the weight of evidence in favor of a given model providing the best fit to the data. To address model uncertainty, we averaged results from the 99% model confidence set (i.e., models that contributed to the top 99% of summed model wt; Burnham and Anderson 2002) using program MARK Version 5.1 (White and Burnham 1999) and spreadsheet software designed by B. Mitchell (www.uvm.edu/~bmitchel/software.html).

We evaluated model fit by comparing the observed Pearson chi-square statistic from the most general model with chi-square statistics from 10,000 simulated parametric bootstrap datasets to assess whether the observed statistic was unusually large (MacKenzie and Bailey 2004). We conducted goodness-of-fit analyses with program PRESENCE (Proteus Wildlife Research Consultants, Dunedin, New Zealand). We addressed cases of poor model fit (i.e., the model chi-square value was >95% of the bootstrap values) by estimating an overdispersion factor ($\hat{c}$), inflating standard errors by a factor of $\sqrt{\hat{c}}$, and using a quasi-corrected AIC_c ($QAIC_c$) for model selection (Burnham and Anderson 2002).

RESULTS

During May–August 2003 and 2004, 5 detection dog teams surveyed 168 sites (Fig. 1) a total of 220 times. The number of teams, sites surveyed, and single- and multiple-site visits varied by year (Table 1). Mean distance between transects was 6.9 km. Mean time required to survey a site was 4.1 hours ($n = 206$ surveys, SE = 0.10 hr, min. = 1.0 hr, max. = 10.8 hr) and depended largely on 1) the density of scats, 2) topographic ruggedness, 3) the density of vegetation, and 4) temperature and humidity. The mean density of putative target scats from all 3 target species on transects where ≥1 scat was detected was 4.24 scats/km of transect searched (SD = 3.51 scats/km, min. = 0.50 scats/km, max. = 22.00 scats/km).

Objective 1: Ability to Locate Scats and Distinguish Between Target and Nontarget Species

We detected 728 scats in 2003 and 868 scats in 2004, resulting in an overall average across sites, visits, and species of 7.2 scats/transect (3.6 scats/km of transect surveyed). There were substantially more putative black bear ($n = 747$) and fisher ($n = 665$) scat detections than putative bobcat scat

Table 1. Number of sites surveyed for scat by detection dog teams and number of multiple visits to sites in Vermont and New York, USA, during May–August 2003 and 2004.

Yr	No. of teams	No. of site visits 1	2	3	Total visits	Total sites
2003	3	71	8	13	126	92
2004	2	64	6	6	94	76
Total	5	135	14	19	220	168

detections ($n = 153$; Table 2). An additional 31 scats were too degraded or too ambiguous to assign a putative species. Of the scats that we assigned a confidence level, we rated 985 (62%) high, 395 (25%) medium, and 208 (13%) low (Table 2). Of scats that we assigned a likelihood of being located without canine assistance, we rated 1,283 (83%) very unlikely, 170 (11%) moderately likely, and 101 (6%) highly likely.

We attempted to confirm (via DNA analysis) the source species for 347 scats, 338 of which we tentatively assigned to black bears ($n = 32$), fishers ($n = 189$), or bobcats ($n = 117$) in the field. Of the 347 DNA-tested scats, 132 (38%) resulted in failure to extract or amplify DNA, and 21 (6.0%) provided a mixed or unknown result (where we could identify no single species). We identified another 16 (4.6%) samples as potential prey species, such as white-tailed deer (*Odocoileus virginianus*), cow (*Bos taurus*), or red squirrel (*Tamiasciurus hudsonicus*). These scats, which were morphologically consistent with those of target carnivores, may have been deposited by target carnivores but yielded DNA from only prey items within the scat. Thus, we excluded them from the accuracy analysis. We analyzed few putative black bear scats because most black bear scats received a high confidence rating (Table 2).

Of 178 genetically identified scats included in the accuracy analysis, the proportion of scats confirmed from putative target species (i.e., the correct classification rate) was 1.00 and 0.50 for high and medium confidence black bear scats, respectively; 0.93, 0.94, and 0.77 for high, medium, and low confidence fisher scats, respectively; and 0.90, 0.29, and 0.13 for high, medium, and low confidence bobcat scats, respectively (Fig. 2). Other species identified via DNA analysis included coyote (*Canis latrans*), red fox (*Vulpes vulpes*), northern raccoon (*Procyon lotor*), house cat (*Felis catus*), and long-tailed weasel (*Mustela frenata*). We detected differences in correct classification rates by scat confidence levels (based on nonoverlapping 95% CIs) only for bobcat scats—and only between high and medium and between high and low confidence ratings (Fig. 2). Applying the estimates of correct classification by species and confidence level to the raw scat counts from the 2 survey seasons, we estimated that our teams located 710 black bear, 594 fisher, and 42 bobcat scats.

Objective 2: Establishing Detections

Failed or inconclusive DNA analyses resulted in an inability to confirm a given target species' presence for 70 survey sites on which we detected putative target scats. We thus used the species- and confidence-specific correct classification rates, along with scat counts and the formula for compounding probabilities, to calculate P_{ID} for each site. Using a P_{ID} cutoff value of 0.90 for these sites, we detected black bears at 96/168 sites (57.1%), fishers at 103/168 sites (61.3%), and bobcats at 21/168 sites (12.5%). We used these detection data in the analyses for objectives 3 and 4. Actual (as opposed to putative) scat counts, estimated using correct classification rates, averaged 3.7 scats/visit for bears, 2.9 scats/visit for fishers, and 1.0 scats/visit for bobcats on transects with confirmed detections or $P_{ID} \geq 0.9$.

Objectives 3 and 4: Estimating Probability of Detection and Evaluating Factors Affecting Detectability

We developed and attempted to fit 50 detection models (Table 3) for each species, with every model for a given species containing the same general set of covariates for ψ

Table 2. Number of scats located by detection dog teams from target carnivore species (by yr, putative species, and confidence level) during May–August 2003 and 2004 on sites in Vermont and New York, USA.

Yr	Putative species	Confidence level High	Medium	Low	Not recorded	Total
2003	Bear	357	31	6	0	394
	Fisher	106	69	33	0	208
	Bobcat	11	53	53	0	117
	Not assigned	0	0	8	1	9
	2003 subtotal	474	153	100	1	728
2004	Bear	317	31	5	0	353
	Fisher	189	198	67	3	457
	Bobcat	5	12	19	0	36
	Not assigned	0	1	17	4	22
	2004 subtotal	511	242	108	7	868
Both yr		985	365	208	8	1,596

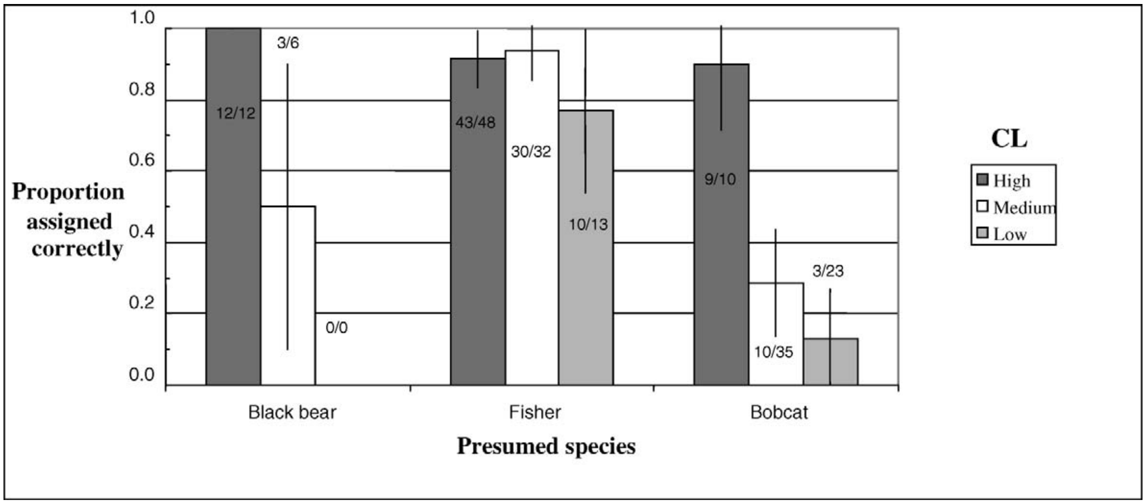

Figure 2. Proportion of putative target species' scats collected on sites in Vermont and New York, USA, May–August of 2003 and 2004, confirmed by genetic analysis, grouped by confidence level. Numbers above bars show fractions from which we calculated proportions. Bars represent 95% confidence intervals.

(Long 2006). Nonsensical parameter estimates and those that failed to converge (e.g. estimates >100, SE > 1,000, or SE = 0) were likely the result of too few sample points for the number of parameters being estimated. For bobcats, no models containing detection covariates provided plausible parameter estimates. We were limited, therefore, to evaluating detection probability for this species using only 2 models for p (i.e., the null model and a model containing VISIT), each with a reduced set of occupancy covariates.

We detected no evidence of overdispersion in the fisher or bobcat data (model χ^2 < 60% and <45% of bootstrapped values, respectively). Evidence of overdispersion (model χ^2

Table 3. The 50 candidate models we used to estimate the probability of detecting black bears, fishers, and bobcats using detection dogs on survey sites during May–August 2003 and 2004 in Vermont and New York, USA.

Model no.	Model name	Model no.	Model name
1	Null[a]	37	VISIT + TRI + TEAM
2	VISIT[b]	38	VISIT + OPEN + TEAM
3	TRI[c]	39	VISIT + TEMP + TEAM
4	OPEN[d]	40	VISIT + HUMID + TEAM
5	YEAR[e]	41	VISIT + WIND + TEAM
6	TEAM[f]	42	VISIT + PRECIP + TEAM
7	TEMP[g]	43	VISIT + TEMP + HUMID
8	HUMID[h]	44	VISIT + TRI + OPEN + TEAM
9	WIND[i]	45	TEMP + HUMID + WIND + PRECIP
10	PRECIP[j]	46	VISIT + WIND + PRECIP + TEAM
11–18	VISIT + TRI/OPEN/YEAR/TEAM/TEMP/ HUMID/WIND/PRECIP	47	VISIT + TEMP + HUMID + TEAM
19–24	TEAM + TRI/OPEN/TEMP/HUMID/ WIND/PRECIP	48	VISIT + TEMP + HUMID + WIND + PRECIP
25	TRI + OPEN	49	VISIT + TEMP + HUMID + WIND + PRECIP + TEAM
26–32	YEAR + TRI/OPEN/PRECIP/WIND/ HUMID/TEMP/TEAM	50	FULLY PARAMETERIZED MODEL
33	TEMP + HUMID		
34	TEMP + HUMID + PRECIP		
35	VISIT + TRI + YEAR		
36	VISIT + YEAR + TEAM		

[a] Model containing no covariates.
[b] First, second, or third visit to site with dog team.
[c] Topographic ruggedness index.
[d] Openness of the site.
[e] Yr of the survey.
[f] Dog team that conducted the survey.
[g] Temp during the survey.
[h] Humidity during the survey
[i] Amt of wind during the survey.
[j] Amt of precipitation during the survey.

Table 4. Highest ranking models from Akaike Information Criterion (AIC)-based model selection of detection probability for black bears, fishers, and bobcats developed with data collected during May–August 2003 and 2004 in Vermont and New York, USA. Information presented for each model includes AIC_c (small-sample correction to AIC) or $QAIC_c$ (quasi-corrected AIC_c used with overdispersed data), AIC_c difference (Δ_i; difference between model AIC_c and the lowest AIC_c), Akaike wt (w_i; the wt of evidence in favor of a given model providing the best fit to the data), number of parameters in model (K), and −2log-likelihood ($-2\log(\mathcal{L})$).

Model, by species	AIC_c	Δ_i	w_i	K	$-2\log(\mathcal{L})$
Black bear					
Null[a]	120.89	0.00	0.183	14	184.23
YEAR[b]	122.11	1.22	0.099	15	181.66
TRI[c]	122.61	1.72	0.077	15	182.71
PRECIP[d]	122.91	2.03	0.066	15	183.35
WIND[e]	123.09	2.21	0.061	15	183.73
TEMP[f]	123.17	2.28	0.059	15	183.89
OPEN[g]	123.29	2.40	0.055	15	184.14
Fisher					
TEAM[h]	263.81	0.00	0.158	21	215.48
VISIT[i] + TEAM	264.31	0.50	0.124	23	210.64
TEAM + TEMP	264.84	1.03	0.095	22	213.86
TEAM + OPEN	265.23	1.41	0.078	22	214.25
TEAM + WIND	265.78	1.97	0.059	22	214.80
VISIT + TEAM + WIND	265.85	2.04	0.057	24	209.46
VISIT + TEAM + OPEN	265.89	2.07	0.056	24	209.49
Bobcat					
Null	132.79	0.00	0.500	10	111.39
VISIT	132.79	0.002	0.500	8	115.89

[a] Model containing no covariates.
[b] Yr of the survey.
[c] Topographic ruggedness index.
[d] Amt of precipitation during the survey.
[e] Amt of wind during the survey.
[f] Temp during the survey
[g] Openness of the site.
[h] Dog team that conducted the survey.
[i] First, second, or third visit to site with dog team.

> 96% of bootstrapped values) in the bear data, however, mandated the use of $QAIC_c$, an adjustment of $\hat{c}$ to 2.1, and an inflation of standard errors by a factor of $\sqrt{\hat{c}} = 1.45$ for model selection and standard error estimation.

For bears, a detection model without covariates (null model) received the most support, followed by a model containing YEAR, which received about half the Akaike weight of the top model (Table 4). Of the other models 23 were included in the 99% confidence set, indicating substantial model uncertainty. The high ranking of the null model, along with model-averaged coefficient estimates near zero (Table 5), suggests that the site- and visit-specific variables we explored had little effect on the probability of detecting a bear at a given site.

The model with the greatest support for estimating detectability of fishers included only TEAM (Table 4). Models containing TEAM with various combinations of all other variables (Table 4) received only slightly less support. The 99% model set contained 17 models, indicating significant model uncertainty. Only model-averaged coefficient estimates for TEAM, specifically team 3, suggested effects on the probability of detecting fishers (Table 5).

Both models considered for estimating bobcat detectability—the null model and a model containing VISIT—received approximately equal support (Table 4). However, 95% confidence intervals around coefficients for VISIT strongly overlapped (Table 5), suggesting that detection did not vary significantly by visit. As we were unable to include visit- or site-specific covariates in the bobcat models, it is unclear if variables such as TEAM or weather-related variables might have affected probability of detection.

Given the level of model selection uncertainty for all species, we extracted the 99% model confidence set for each species, recalculated model AIC weights, and calculated detection probability estimates via model averaging over the entire 99% confidence set. Because survey-specific characteristics affected detectability of fishers, and to some extent bears, detectability estimates varied (i.e., each site and survey had its own unique estimate of detectability for a given target species). Mean estimated detection probability on an average site for the first visit was 0.86 for black bears, 0.95 for fishers, and 0.40 for bobcats (Table 6). For fishers, model-averaged probabilities of detection (SE) during the first visit for the 5 teams (in team order) were 0.82 (0.10), 0.78 (0.09), 0.41 (0.11), 0.93 (0.06), and 0.95 (0.05).

DISCUSSION

Our study demonstrates that detection dogs can be very effective at locating scats from 3 target carnivore species while largely ignoring nontarget species, and that the probability of detecting each species at a site can be estimated via occupancy modeling. We were also able to quantify the effects of site- and visit-specific factors on detectability, and we developed an approach for confidently

Table 5. Model-averaged estimates, unconditional standard errors, and 95% confidence interval of standardized logit coefficients of covariates occurring in detection (with dog team) models for black bears, fishers, and bobcats based on data collected during May–August 2003 and 2004 in Vermont and New York, USA. Models shown comprise the 99% confidence set for each species. Coefficients and standard errors are in logit (log odds) space and relate to covariates transformed into z-scores.

Covariate, by species	$\hat{\beta}$	SE $\hat{\beta}$	Lower CL $\hat{\beta}$	Upper CL $\hat{\beta}$
Black bear				
VISIT[a] 1 INTERCEPT	1.850	0.807	0.269	3.432
VISIT 2 INTERCEPT	1.787	0.705	0.405	3.170
VISIT 3 INTERCEPT	1.830	0.750	0.360	3.299
TRI[b]	0.076	0.310	−0.531	0.684
OPEN[c]	−0.026	0.182	−0.383	0.330
YEAR[d]	0.394	0.720	−1.018	1.806
TEMP[e]	−0.023	0.182	−0.379	0.333
HUMID[f]	−0.015	0.210	−0.427	0.396
WIND[g]	0.086	0.551	−0.994	1.166
PRECIP[h]	−0.105	0.432	−0.952	0.742
Fisher				
VISIT 1 INTERCEPT	3.027	1.075	0.920	5.133
VISIT 2 INTERCEPT	2.367	0.914	0.577	4.158
VISIT 3 INTERCEPT	2.514	0.969	0.615	4.413
TRI	0.067	0.245	−0.413	0.548
OPEN	−0.075	0.213	−0.493	0.344
TEAM[i] 1	−1.416	1.004	−3.383	0.552
TEAM 2	−1.721	0.980	−3.642	0.200
TEAM 3	−3.401	1.112	−5.580	−1.222
TEAM 4	−0.344	1.121	−2.542	1.853
TEMP	−0.032	0.125	−0.276	0.212
HUMID	0.015	0.092	−0.165	0.195
WIND	−0.109	0.405	−0.902	0.685
PRECIP	−0.020	0.232	−0.474	0.434
Bobcat				
VISIT 1 INTERCEPT	−0.431	0.801	−2.000	1.139
VISIT 2 INTERCEPT	−1.394	0.834	−3.029	0.841
VISIT 3 INTERCEPT	−1.152	1.017	−3.146	0.841

[a] First, second, or third visit to site with dog team.
[b] Topographic ruggedness index.
[c] Openness of the site.
[d] Yr of the survey.
[e] Temp during the survey.
[f] Humidity during the survey.
[g] Amt of wind during the survey.
[h] Amt of precipitation during the survey.
[i] Dog team that conducted the survey.

declaring a site occupied or unoccupied when DNA confirmation was not possible.

Of scats located by our detection dog teams, we judged only 6% highly likely, and 11% moderately likely to have been detected by human searchers alone. Although subjective, these data suggest that the use of detection dogs in our surveys may have hypothetically increased the number of scats detected 5- to 15-fold over researchers searching without a dog. Even in more structurally simple, grassland-scrub habitats, Smith et al. (2003) estimated that their poorest performing detection dog was as successful at locating kit fox (*Vulpes macrotis mutica*) scats as a trained human searcher and that their best performing dog had detection rates >12 times greater than those of human searchers.

Table 6. Model-averaged estimates, unconditional standard errors, and 95% confidence intervals for p, the probability of detecting, when present, black bears, fishers, and bobcats, on sites ($n = 168$) in Vermont and New York, USA, during a single visit with a detection dog, May–August 2003 and 2004.

Species	p	SE	Lower CL	Upper CL
Black bear	0.862	0.073	0.651	0.954
Fisher	0.948	0.045	0.751	0.991
Bobcat	0.397	0.190	0.122	0.757

Morphologically similar scats from sympatric species are often challenging for researchers to differentiate by sight (Halfpenny 1986, Foran et al. 1997, Davison et al. 2002). For example, we found that coyote and bobcat scats were difficult or impossible to distinguish by morphology alone and that raccoon scats could resemble small bear scats. Further, Kohn et al. (1999) found that coyote scats could be confused with those of gray fox (*Urocyon cinereoargenteus*), bobcat, and badger (*Taxidea taxus*), and expert naturalists in Scotland failed to reliably distinguish scats from pine marten (*Martes martes*) and red fox (Davison et al. 2002). Detection dogs can help facilitate scat identification in the field. DNA analyses conducted on a subset of our high confidence scats determined that 12/12 were correctly identified as bear, 43/

48 as fisher, and 9/10 as bobcat. Similarly, detection dogs were consistently accurate at distinguishing kit fox scats from those of sympatric carnivores such as coyote, striped skunk (*Mephitis mephitis*), and badger at 2 field sites in central California (Smith et al. 2001, 2003).

Selection of the null model as the best model for predicting the probability of detecting black bears suggests that the ability of dogs to detect this species in Vermont was quite robust and minimally affected by the variables we explored. There is no evidence to suggest that different teams had varying probabilities of detecting this species. The model-averaged probability of detecting a bear scat, when present, on an average site was very high. Bear scats are typically large and appear to break down relatively slowly over time. In addition, we detected bears on almost half of all transects, and most bear scats were readily identified by researchers in the field. These characteristics allowed handlers to accurately and repeatedly reinforce dogs for bear detections, possibly perpetuating the consistency with which we detected bear scats.

Although the probability of detecting fisher scats was also very high, detection rates varied by team. The low estimated probability of detection of fishers by team 3 may have been related to handler inexperience. The handler for this team was the only handler having no previous detection dog field experience. Furthermore, this team's detection dog was prone to distraction by eastern chipmunks (*Tamias striatus*) and red squirrels, which may have affected the dog's performance. Despite the relatively high detection rates of the 4 other teams, it is clear that between-team differences in detection rates occurred in this study and have the potential to affect survey results. Careful attention should thus be directed towards both dog and handler training whenever detection dogs are to be used for wildlife research purposes. An appropriate study design that incorporates random assignment of detection teams to survey sites should help to mitigate the effects of between-team differences (Wasser et al. 2004).

The failure of our bobcat models to accommodate detection-related covariates, and the large standard error associated with the estimate of detection probability (Table 6), likely resulted from the generally low detectability of bobcats and the dearth of instances when bobcats were detected during more than one survey at a site (D. MacKenzie, Proteus Wildlife Research Consultants, personal communication). Indeed, the proportion of sites with bobcat detections (0.12) was much lower than that for black bears (0.57) or fishers (0.61). Simulation studies indicate that both low detection rates and low probability of detection can lead to inaccurate and biased occupancy estimates and suggest that a minimum of 2–3 surveys be conducted at each site to accurately estimate detection probability and occupancy (Tyre et al. 2003, Wintle 2003, MacKenzie and Royle 2005). We surveyed most sites only once or twice.

The low detectability and scat detection rates observed for bobcats may suggest that bobcats (relative to black bears and fishers) 1) occur at low densities, 2) have low defecation rates, 3) deposit scats that degrade quickly or are consumed by other species, 4) deposit scats in areas that are difficult to survey (e.g., cliff and ledges), 5) tend to deposit scats in clumped patterns that may be more difficult to detect with systematically arrayed transects, or 6) are less detectable because they sometimes bury their scats. Although low detectability requires more revisits to achieve a given probability of detection, surveys for rare species need not be ruled out simply because of low detectability—as long as detectability can be estimated. Interestingly, MacKenzie and Royle (2005) found that it is more efficient to survey a greater number of sites less intensively (i.e., fewer repeat surveys) for rarer species and fewer sites more often for common species.

We did not detect effects of precipitation, temperature, wind, or humidity in our black bear or fisher analyses. Although weather-related variables are known to affect a dog's scenting ability (Syrotuck 2000), and likely affect scat detection dog performance (Wasser et al. 2004), we suspect that the large numbers of scats (in the case of fishers) and the large volume of scat material (in the case of bears) enabled our detection teams to locate scats across the range of weather conditions we experienced. Further, because species detection was our goal, it was only necessary to find a single, high quality scat to confirm presence. Had we modeled numbers of scats or some other more sensitive performance metric, we may well have found that weather variables affected dog performance.

The costs associated with using detection dogs for wildlife field surveys can vary greatly, depending on the circumstances of the survey (Harrison 2006, Long et al. 2007). In a standardized cost comparison, the cost per site of using detection dogs (including costs of dog and handler training) was 16% to 32% higher than that of remote cameras (Long et al. 2007). In many cases, therefore, the increased effectiveness observed with detection dogs should offset a marginally higher cost per site.

The area enclosed by our transects (approx. 22 ha) represented only a fraction of the typical fisher, black bear, or bobcat home range. Because scats have been shown to persist for weeks or even months (Sanchez et al. 2004), it is theoretically feasible to detect individuals that are not currently using the surveyed portion of their home range. In studies such as ours, where the species likely ranges beyond the survey site, the system cannot be considered closed. Assuming changes in true occupancy of the site over time are random, the occupancy estimates are still unbiased (MacKenzie et al. 2005) but should be interpreted in terms of sites used by the target species (i.e., sites where the species was present sometime during or before the survey period) as opposed to sites occupied at the time of the survey. A synonymous interpretation would view the results in terms of the probability of a scat being detected at a given site if it was indeed present. Thus, as long as 1) the target species deposits scats and 2) repeat visits are spaced such that scats are unlikely to degrade completely between subsequent visits, it is not necessary for the species to be present at the site during a given survey for a detection to occur.

It is important to note that the ability of a detection dog to reliably locate and indicate on scat from a target species is dependent upon the dog's consistently receiving a reward when it detects scat from that species—and receiving no reward if it shows interest in a nontarget scat. If a handler misreads a dog's behavior at a nontarget scat and erroneously provides a reward for that scat, the dog may indicate on scat from the nontarget species in the future. Although this issue can be addressed through proper training, it illustrates a challenge for studies in which target scats can be easily confused with morphologically similar scats from nontarget species. Due to the potential for misidentification in the field, we recommend that species identity be confirmed by DNA analysis for at least a subset of scats collected. Further, pilot studies can be invaluable for working through protocols with dogs and handlers before embarking on a full-fledged survey.

As DNA confirmation of species identification from scat can sometimes fail, such failure rates should be considered when planning scat-based studies. For example, we were able to calculate probability estimates for 1) detecting fisher scat during a single site visit (0.95) and 2) successfully extracting and amplifying DNA material from a high confidence, putative fisher scat (0.58). By multiplying these probabilities, we estimated the comprehensive probability of confirming fisher presence with a single, high confidence scat collected via one visit by a detection dog team to be $0.95 \times 0.58 = 0.55$. Of course, researchers often collect more than a single scat from a given species, thus increasing this comprehensive probability. Nonetheless, it is clear that studies relying on DNA analysis of scat for species confirmation must take into account both the probability of detecting scat in the field and the probability that species identification can be confirmed via DNA analysis.

Detection dogs were highly effective at locating scats from target species in our study. There are, however, circumstances under which this survey method may not be the most efficient or appropriate choice. For example, if an alternative highly effective method for meeting survey objectives has already been identified, the costs and logistics associated with detection dogs may outweigh their benefits. This is especially true if (collected) scats are not necessary for additional survey-related analyses. Indeed, the logistical considerations for using scat detection dogs—including training, transporting, and maintaining leased dogs and providing a lifetime of care for purchased dogs—should not be underemphasized (although these considerations can be minimized by hiring professional handler-dog teams). The availability of professional trainers, experienced detection dogs, and mature personnel to serve as handlers—or of professional handler-dog teams—may also be a limiting factor. Extreme climates or treacherous terrain may prohibit the effective use of dogs. Lastly, detection dogs may not be the best survey method to use in situations where dogs are at high risk of injury from wildlife, or in urban parks or other high-use areas where distraction is a potential concern.

MANAGEMENT IMPLICATIONS

Scat is a source of valuable biological information that can provide answers to questions about genetics, diet, habitat use, dispersal and movement, stress, and reproduction. Detection dogs can effectively locate large numbers of scats from carnivores, and serve as a relatively efficient survey tool for species that occur at low densities. We suggest that researchers planning surveys for carnivores or similar species consider the use of detection dogs, especially if 1) target species are at relatively low-density, 2) the project will benefit from locating scats, or 3) avoiding biases associated with trail-based surveys or the use of attractants are high priorities. Finally, our method for quantifying confidence in declaring a site occupied by a target species could potentially be used in other situations where species confirmation via genetic analysis is possible or practical for only a subset of samples.

ACKNOWLEDGMENTS

We thank B. Davenport, D. MacKenzie, D. Paetkau, A. Royle, S. Wasser, S. Weigley, J. Weldon, our field personnel, and our scat detection dogs for their contributions to this project. The Vermont Cooperative Fish and Wildlife Research Unit is jointly sponsored by the United States Geological Survey, the Vermont Fish and Wildlife Department, the University of Vermont, and the Wildlife Management Institute. Funding for this project was provided by the Vermont Department of Fish and Wildlife, the Northeastern States' Research Cooperative, the Jon C. and Katherine L. Harvey Charitable Foundation, the Southern Lake Champlain Valley Office of the Nature Conservancy, Sweet Water Trust, the United States Department of Agriculture Forest Service, and the United States Geological Survey. Finally, we thank W. Pitt and 2 anonymous reviewers for their valuable comments on this manuscript. Mention of services used in this research does not confer endorsement by the United States federal government.

LITERATURE CITED

Arthur, S. M., W. B. Krohn, and J. R. Gilbert. 1989. Home range characteristics of adult fishers. Journal of Wildlife Management 53:674–679.

Buckland, S. T., K. P. Burnham, and N. H. Augustin. 1997. Model selection: an integral part of inference. Biometrics 53:603–618.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Davison, A., J. D. S. Birks, R. C. Brookes, T. C. Braithwaite, and J. E. Messenger. 2002. On the origin of faeces: morphological *versus* molecular methods for surveying rare carnivores from their scats. London Journal of Zoology 257:141–143.

Farrell, L. E., J. Romant, and M. E. Sunquist. 2000. Dietary separation of sympatric carnivores identified by molecular analysis of scats. Molecular Ecology 9:1583–1590.

Foran, D. R., K. R. Crooks, and S. C. Minta. 1997. Species identification from scat: an unambiguous genetic method. Wildlife Society Bulletin 25: 835–839.

Ginsberg, J. R. 2001. Setting priorities for carnivore conservation: what makes carnivores different? Pages 498–523 *in* J. L. Gittleman, S. M. Funk, D. Macdonald, and R. K. Wayne, editors. Carnivore Conservation. Cambridge University Press, United Kingdom.

Halfpenny, J. 1986. A field guide to mammal tracking in western America. Johnson Books, Boulder, Colorado, USA.

Harrison, R. L. 2006. A comparison of survey methods for detecting bobcats. Wildlife Society Bulletin 34:548–552.

Johnson, W. E., and S. J. O'Brien. 1997. Phylogenetic reconstruction of the Felidae using 16S rRNA and NADH-5 mitochondrial genes. Journal of Molecular Evolution 44:S98–S116.

Kohn, M. H., E. C. York, D. A. Kamradt, G. Haught, R. M. Sauvajot, and R. K. Wayne. 1999. Estimating population size by genotyping faeces. Proceedings of the Royal Society of London 266:657–663.

Long, R. A. 2006. Developing predictive occurrence models for carnivores in Vermont using data collected with multiple noninvasive methods. Dissertation, University of Vermont, Burlington, USA.

Long, R. A., T. M. Donovan, P. MacKay, J. S. Buzas, and W. J. Zielinski. 2007. Comparing detection dogs, cameras, and hair snares for surveying carnivores. Journal of Wildlife Management 71:2018–2025.

MacKenzie, D. I., and L. L. Bailey. 2004. Assessing the fit of site-occupancy models. Journal of Agricultural, Biological, and Environmental Statistics 9:300–318.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248–2255.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2005. Occupancy estimation and modeling. Academic Press, Burlington, Massachusetts, USA.

MacKenzie, D. I., and J. A. Royle. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42: 1105–1114.

Moore, J. E., and R. K. Swihart. 2005. Modeling patch occupancy by forest rodents: incorporating detectability and spatial autocorrelation with hierarchically structured data. Journal of Wildlife Management 69:933–949.

Murphy, M. A., L. Waits, and K. C. Kendall. 2001. Quantitative evaluation of fecal drying methods for brown bear DNA analysis. Wildlife Society Bulletin 28:951–957.

National Climatic Data Center. 2003. Cooperative summary of the day. <http://ols.nndc.noaa.gov/plolstore/plsql/olstore.prodspecific?prodnum=C00447-CDR-S0001>. Accessed 1 October 2003.

Nudds, T. D. 1977. Quantifying the vegetation structure of wildlife cover. Wildlife Society Bulletin 5:113–117.

Riley, S. J., S. D. DeGloria, and R. Elliot. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. Intermountain Journal of Sciences 5:23–27.

Sanchez, D. M., P. R. Krausman, T. R. Livingston, and P. S. Gipson. 2004. Persistence of carnivore scat in the Sonoran Desert. Wildlife Society Bulletin 32:366–372.

Smith, D. A., K. Ralls, B. L. Cypher, and J. E. Maldonado. 2005. Assessment of scat-detection dog surveys to determine kit fox distribution. Wildlife Society Bulletin 33:897–904.

Smith, D. A., K. Ralls, B. Davenport, B. Adams, and J. E. Maldonado. 2001. Canine assistants for conservationists. Science 291:435.

Smith, D. A., K. Ralls, A. Hurt, B. Adams, M. Parker, B. Davenport, M. C. Smith, and J. E. Maldonado. 2003. Detection and accuracy rates of dogs trained to find scats of San Joaquin kit foxes (*Vulpes macrotis mutica*). Animal Conservation 6:339–346.

Syrotuck, W. G. 2000. Scent and the scenting dog. Barkleigh Productions, Inc., Mechanicsburg, Pennsylvania, USA.

Thompson, E. H., and E. R. Sorenson. 2000. Wetland, woodland, wildland: a guide to the natural communities of Vermont. The Nature Conservancy and the Vermont Department of Fish and Wildlife, Hanover, New Hampshire, USA.

Tyre, A. J., B. Tenhumberg, S. A. Field, D. Niejalke, K. Parris, and H. P. Possingham. 2003. Improving precision and reducing bias in biological surveys: estimating false-negative error rates. Ecological Applications 13: 1790–1801.

von der Ohe, C., and C. Servheen. 2003. Measuring stress in mammals using fecal glucocorticoids: opportunities and challenges. Wildlife Society Bulletin 30:1215–1225.

Waits, L., G. Luikart, and P. Taberlet. 2001. Estimating the probability of identity among genotypes in natural populations: cautions and guidelines. Molecular Ecology 10:249–256.

Wasser, S. K., B. Davenport, E. R. Ramage, K. Hunt, M. Parker, C. Clarke, and G. Stenhouse. 2004. Scat detection dogs in wildlife research and management: application to grizzly and black bears in the Yellowhead Ecosystem, Alberta, Canada. Canadian Journal of Zoology 82:475–492.

Weaver, J. L., P. C. Paquet, and L. F. Ruggiero. 1996. Resilience and conservation of large carnivores in the Rocky Mountains. Conservation Biology 10:964–976.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:120–138.

Wintle, B. A. 2003. Dealing with uncertainty in wildlife habitat models. Dissertation, University of Melbourne, Melbourne, Australia.

Wintle, B. A., R. P. Kavanagh, M. A. McCarthy, and M. A. Burgman. 2005. Estimating and dealing with detectability in occupancy surveys for forest owls and arboreal marsupials. Journal of Wildlife Management 69: 905–917.

Woodroffe, R. 2001. Strategies for carnivore conservation: lessons from contemporary extinctions. Pages 61–92 *in* J. L. Gittleman, S. M. Funk, D. Macdonald, and R. K. Wayne, editors. Carnivore conservation. Cambridge University Press, Cambridge, United Kingdom.

Woodroffe, R., and J. R. Ginsberg. 1998. Edge effects and the extinction of populations inside protected areas. Science 280:2126–2128.

Zielinski, W. J., N. P. Duncan, E. C. Farmer, R. L. Truex, A. P. Clevenger, and R. H. Barrett. 1999. Diet of fishers (*Martes pennanti*) at the southernmost extent of their range. Journal of Mammalogy 80:961–971.

Associate Editor: Pitt.