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Research Article

Detection Distance and Environmental Factors in Conservation Detection Dog Surveys

SARAH E. REED,[1,2] *Department of Environmental Science, Policy and Management, University of California, Berkeley, 137 Mulford Hall #3110, Berkeley, CA 94720, USA*

ALLISON L. BIDLACK, *Department of Environmental Science, Policy and Management, University of California, Berkeley, 137 Mulford Hall #3110, Berkeley, CA 94720, USA*

AIMEE HURT, *Working Dogs for Conservation, 52 Eustis, Three Forks, MT 59752, USA*

WAYNE M. GETZ, *Department of Environmental Science, Policy and Management, University of California, Berkeley, 137 Mulford Hall #3110, Berkeley, CA 94720, USA*

ABSTRACT Surveys using conservation detection dogs have grown increasingly popular as an efficient means to gather monitoring data, particularly for elusive and low-density species such as carnivores. Working with dogs can greatly increase the area surveyed for wildlife and the detection rate of survey targets. Due to the confounding effects of scent dispersion and dog movement, however, it can be difficult to estimate the area searched in a survey. Additionally, although detection dogs have been used in studies under a wide range of air temperature, humidity, and wind conditions, little research has examined how environmental factors affect detection dogs' effectiveness for wildlife surveys. Between 2003 and 2005, we trained 2 dogs to assist us with surveys for mammalian carnivore scats in northern California. We conducted controlled search trials to assess how the dogs' scat detection rates were affected by the distance of scats from the transect search line, as well as variation in six environmental factors. Both dogs detected >75% of scats located within 10 m, and the dogs' detection rates decreased with increasing distance of scats from the transect line. Among environmental factors, precipitation was the most important variable explaining variation in scat detection rates for both dogs. Precipitation likely degrades or removes scats from the landscape over time, and detection rates increase as scat begins to accumulate following the last substantial (>5 mm) rain event of the year. If scat accumulation is not controlled for in ecosystems with a strong seasonal pattern of rainfall, it could lead to considerable bias in study results. We recommend that researchers report the conditions under which conservation detection dog surveys took place and analyze how detection rates vary as a function of distance, temperature, precipitation, humidity, wind, and other locally important environmental factors. © 2011 The Wildlife Society.

KEY WORDS carnivore, detection distance, detection dog, environmental conditions, monitoring, non-invasive, scat survey.

Conservation and management of rare and wide-ranging species require monitoring data that can be collected inexpensively and repeatedly. Ideally, wildlife monitoring techniques should maximize the geographic area and number of animals surveyed, while minimizing cost and risk of disturbance or injury to individual animals. Non-invasive survey methods, which do not require direct observation or capture of wildlife, have increased in popularity as efficient techniques for gathering monitoring data, particularly for low-density and elusive species such as carnivores (Long et al. 2008).

One method for increasing the sample size and improving the accuracy of non-invasive surveys is the use of conservation detection dogs. "Conservation detection dog" is an umbrella term for detection dogs trained to locate or discriminate biological targets in a natural setting for research or management applications, distinguished from dogs that are trained to find wildlife contraband in a law enforcement context (Hurt and Smith 2009). Although dogs have been assisting biologists with wildlife surveys for more than a century (Zwickel 1980, Hill and Hill 1987, Gutzwiller 1990), recent applications have expanded both the scope and sophistication of their contributions, particularly through scent detection and discrimination work (Browne et al. 2006). Dogs have been trained to recover carcasses (Homan et al. 2001, Arnett 2006), locate invasive or endangered species (Engeman et al. 2002, Cablk and Heaton 2006), detect species' scent trails (Akenson et al. 2004), and identify occupied burrows (Reindl-Thompson et al. 2006). Dogs have also been trained to detect the scats of kit foxes (Smith et al. 2003), black bears (Wasser et al. 2004, Long et al. 2007), grizzly bears (Wasser et al. 2004), bobcats (Harrison 2006, Long et al. 2007), and fishers (Long et al. 2007) in terrestrial surveys and right whales in marine surveys (Rolland et al. 2006). Scats collected in detection dog surveys can be combined with recent advancements in laboratory techniques to generate a wealth of information about wildlife populations, including species- and individual-level identification, diet, disease, reproductive status, and physiological condition (Kohn and Wayne 1997).

Working with dogs can greatly increase the area surveyed for wildlife, as well as the detection rate of survey targets. For example, dogs searched up to 5 times as much distance as humans in 70% of the time (Nussear et al. 2008), and dogs' detection rates were 2–4 times greater than those of humans searching visually (Smith et al. 2001, Homan et al. 2001). Due to the confounding effects of scent dispersion and dog movement, however, it can be difficult to estimate the

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[1] *E-mail: sarah.reed@colostate.edu*

[2] *Present Address: Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, CO 80523-1474.*

distance at which the target is likely to be detected, and subsequently, to quantify the total area searched in a survey. Few studies have reported detection distances from conservation detection dog surveys, and measurements differed widely, ranging from mean detection distances of 4.8 m (Ralls and Smith 2004), 13.9 m (Cablk et al. 2008), and 29.3 m (Shivik 2002) in terrestrial surveys, to detection distances up to 1.9 km in marine surveys (Rolland et al. 2006).

To our knowledge, no researcher using conservation detection dogs has attempted to model the probability of detection to estimate the actual density or abundance of survey targets (Thomas et al. 2010). Yet as is true for many other wildlife survey methods, knowledge of the detection function is critical for designing research studies, selecting transect locations, and estimating species' densities.

Variability in habitat or weather conditions and the physiological condition of dogs can affect detection rates and potentially bias the results of wildlife surveys (Gutzwiller 1990). Air temperature, vapor pressure, and the direction and variability of wind currents all affect how scent disperses through the air (Syrotuck 1972, Snovak 2004). Environmental factors are also believed to affect the production of scent through the decomposition of its source, but there is currently little scientific evidence to support these theories (Stockham et al. 2004). Air temperature and relative humidity may influence the evaporation rate of the scent source (Pearsall and Verbruggen 1982) or the bacterial activity that releases scent vapors (Syrotuck 1972). In general, higher temperatures correspond to higher rates of evaporation and bacterial activity (Wasser et al. 2004), but this intensity may be short-lived, and temperatures that are too high can kill bacteria and halt scent production. On the other hand, air moisture slows evaporation rates and is essential to maintain bacterial activity, but prolonged precipitation may dampen or wash away scent vapors near the ground (Syrotuck 1972). Over time, wildlife researchers have noted that precipitation and other weather factors contribute to degradation or disappearance of survey targets such as scats (Smith et al. 2005, Harrison 2006).

Environmental conditions also influence the physiological state of detection dogs. Observations indicate that higher temperatures can lead to excessive panting (Smith et al. 2003) and more rapid fatigue (Homan et al. 2001, Nussear et al. 2008). Panting is a dog's primary means of cooling its body, and because a dog cannot sniff and pant simultaneously, increased panting causes a decrease in sniffing rate and scent detection (Gazit and Terkel 2003). Dry conditions can cause dehydration or a dry nose, which also limit a dog's ability to detect scent (Snovak 2004).

Detection dogs have been used under a wide range of air temperature, humidity, and wind conditions (Table 1). However, as Shivik (2002) and Cablk and Heaton (2006) note, little research has examined how these environmental factors affect conservation detection dogs' abilities or their effectiveness for wildlife surveys. Although most papers published on detection dog methods discussed potential effects of environmental factors, few reported the environmental conditions in which surveys took place (Homan et al. 2001, Smith et al. 2003, Harrison 2006) or analyzed the relationship between environmental variables and dogs' detection rates (Shivik 2002, Cablk and Heaton 2006, Long et al. 2007, Cablk et al. 2008, Nussear et al. 2008).

Table 1. Ranges of air temperature, humidity, and wind conditions reported for prior conservation detection dog surveys conducted in the United States, 1997–2005.

Temp (C)	Relative humidity (%)	Wind speed (m/s)	References
3–11	23–70		Homan et al. (2001)
19–31	25–91		Homan et al. (2001)
8–22			Smith et al. (2003)
14–32			Smith et al. (2003)
11–23			Harrison (2006)
12.2–26.7	15.8–87.9	0–8.7	Cablk and Heaton (2006); Cablk et al. (2008)
9.4–29.9	9.8–85.8	0–3.2	Nussear et al. (2008)

Here, we present the results of controlled search trials investigating the influence of distance and environmental conditions on the scat detection rates of two conservation detection dogs in northern California. We empirically assessed how dogs' detection of mammalian carnivore scats was affected by the distance of scats from the transect search line, as well as variation in several environmental factors. We also examined the influence of environmental conditions on scat detection rates in uncontrolled field searches in 30 research sites located throughout the San Francisco Bay Area. Our objectives were to 1) estimate the dogs' probability of detecting a target species' scat by distance from the transect search line, and 2) assess how temperature, precipitation, humidity, vapor pressure, and wind affect dogs' scat detection rates.

STUDY AREA

We conducted our research in California oak woodlands, located to the north and east of San Francisco Bay (37°51′N, 122°26′W). This region experienced rapid conversion of undeveloped land to residential and agricultural uses, and remaining oak woodlands primarily occurred along hillslopes ranging from 50 m to 1,000 m in elevation. Woodlands in our study area were dominated by several oak species: coast live oak (*Quercus agrifolia*), Oregon oak (*Q. garryana*), valley oak (*Q. lobata*), black oak (*Q. kelloggii*), and blue oak (*Q. douglasii*), with small patches of bay laurel (*Laurus nobilis*) and Douglas fir (*Pseudotsuga menziesii*), and chaparral at higher elevations.

We conducted dog training and experimental trials at the Hopland Research & Extension Center (HREC), a 2,139-ha field station managed by the University of California, Davis in southern Mendocino County (Fig. 1). The 30 field sites we surveyed were located in Alameda, Contra Costa, Marin, and Sonoma counties and were owned and managed by several public agencies and conservation organizations.

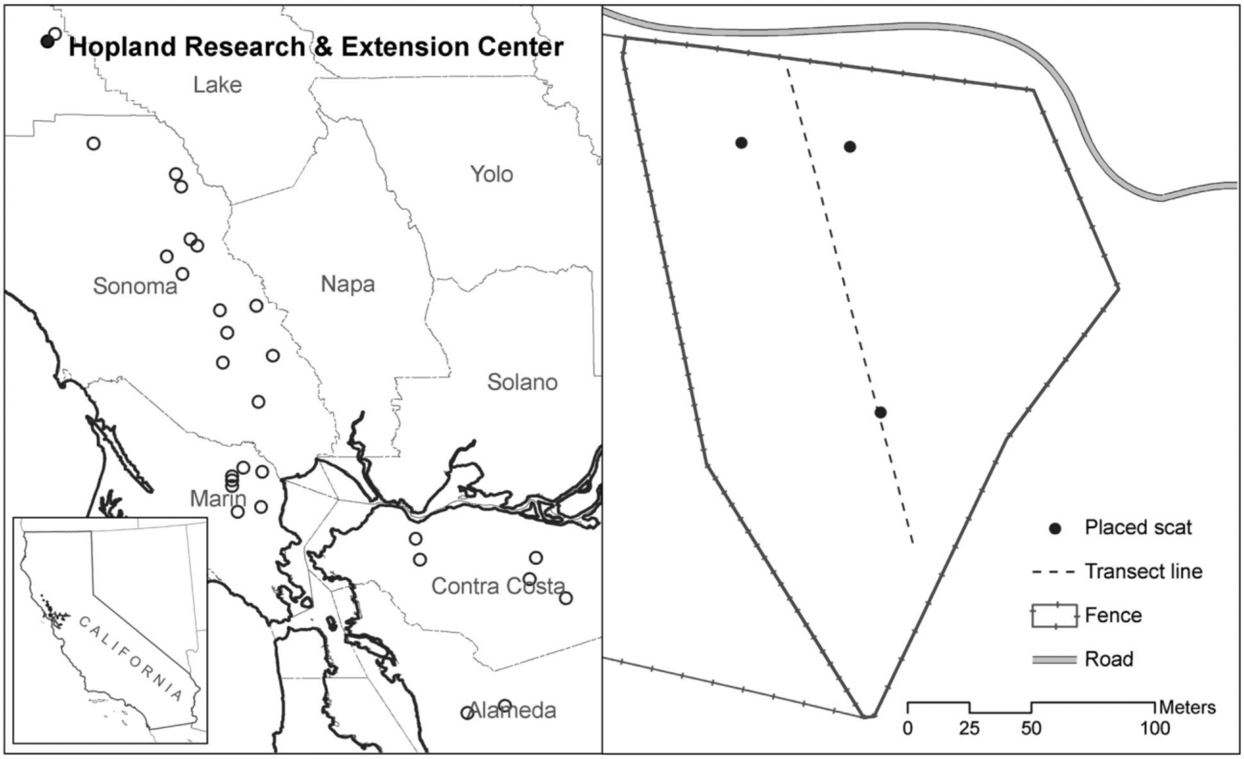

Figure 1. Location of the Hopland Research & Extension Center (HREC) and additional research sites in northern California where we used conservation detection dogs to survey for mountain lion, bobcat, domestic cat, red fox, gray fox, and coyote scats. Randomly selected placement locations for 3 scats in one controlled search trial are shown in a diagram of the fenced pasture at HREC where experimental trials occurred from 2003 to 2005.

METHODS

Dog and Handler Training

The non-profit organization Working Dogs for Conservation (WDC) led dog and handler training seminars in August 2003 and January 2004. Handler training included dog selection and testing, positive reinforcement techniques, scent discrimination training, and field handling skills.

We searched for candidate detection dogs in shelters and rescue organizations throughout northern California. We tested candidates for their level of object obsession (i.e., toy drive) and agility, using methods modified from the Brownell–Marsolais motivation and drive test (Brownell et al. 2000), standard search-and-rescue (SAR) techniques (Snovak 2004), and the early stages of scent discrimination training. Each handler tested >300 dogs before selecting the final training candidates from Bay Area shelters. Dog 1 was a 1.5-year-old female Labrador retriever mix adopted in fall 2003, and dog 2 was a 2-year-old male pit bull terrier mix adopted in spring 2004 (University of California Berkeley Animal Care and Use Committee Protocol no. R245-0503).

We trained the 2 dogs to detect the scats of different suites of species. We trained dog 1 to detect mountain lion (*Puma concolor*), bobcat (*Lynx rufus*), and domestic cat scats, whereas we trained dog 2 to detect red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), and kit fox (*Vulpes macrotis*) scats. We collected training scats from zoos and animal rehabilitation centers throughout California, and for each target species, we collected scats from several captive individuals fed a variety of diets.

Dog training followed methods previously described by Smith et al. (2003). We taught the dogs to associate the scent of the target species scats with a reward (i.e., a play session with a tennis ball) and to ignore the scent of non-target species scats. Training progressed through increasingly complicated search conditions until, at the end of the training period, each handler was able to walk along a transect line up to several kilometers in length, with the dog air-scenting and signaling detection of target species scats in the surrounding landscape. Total time required to train each dog was approximately 12 weeks.

Detection Distance Trials

When the dogs had successfully passed through all stages of scat detection training and were capable of long-distance field searches, we designed an experiment to test how distance from the transect search line affected dogs' ability to detect scats. We conducted search trials in a small pasture at HREC that was fenced to exclude livestock and wildlife for many years (Fig. 1). Because most of our target species occur at HREC, we thoroughly searched the pasture with each dog to ensure the pasture was cleared of target species scats before beginning the test. We conducted detection distance trials with dog 1 from December 2003 to January 2004 and trials with dog 2 from January to February 2005.

We established a fixed 200-m line transect running north northwest–south southeast through the center of the pasture and marked it using visual landmarks and flagging. For each dog, we used scats collected from one captive animal, to minimize any potential variation in detectability due to species or individual scent. We used a random number generator (Microsoft Excel, Microsoft Corporation, Redmond, WA) to select placement locations for each of 3 scats per search trial. We randomly stratified scat locations by distance along the transect line (in 10-m intervals), direction from the transect line (east or west), and distance from the transect line (in 5-m intervals).

We began by placing the 3 scats and recording their Global Positioning System (GPS) locations. We stored the scats frozen but allowed them to thaw for $\geq$0.5 hr before placing them. We did not walk directly to placement locations, but instead walked all around the pasture to disperse the human scent trail. After placing scats, we waited an average of 1.0 hr (range: 0.3–4.8 hr) before searching to allow the scent to disperse in the air.

We returned with the dog for a search trial, walking slowly in one direction down the transect line. The dog worked off-lead, moving freely around the handler. When the dog signaled a detection, we marked the position where we stopped walking on the transect line and approached the dog. If the dog successfully located a scat, we rewarded him or her with a play session, collected the scat, and recorded its GPS point location. We then returned to the position where we stopped on the transect line and continued searching. We took a short break at the end of the line and then searched the transect in the opposite direction. At the end of each search trial, we left all uncollected scats in the pasture.

We completed 14 search trials with dog 1 ($n = 41$ scats) and 15 search trials ($n = 45$ scats) with dog 2. We used a Geographic Information System (GIS) database in ArcView 3.2 to match scat locations and calculate the delay time between placement and collection of each scat. We used JMP (SAS Institute, Inc., Cary, NC) to perform all statistical analyses, and we analyzed data sets for each dog separately. We considered only those scats found during the first search trial after placement, to minimize any effect of scat decomposition on detection distance. We assigned a value of 1 to scats detected during the first search trial following placement and a value of 0 to those that were not.

Wind direction and strength could affect the dogs' detection of scats placed on either side of the search transect. We collected data on wind direction and wind speed during search trials using an automated weather station located at HREC and managed by the California Irrigation Management Information System (CIMIS). We calculated wind direction relative to the direction of scat placement from the transect line; in other words, values ranged from 0 (wind blowing from the scat toward the transect) to 180 (wind blowing away from the transect toward the scat). We used logistic regression to estimate the dogs' detection functions as a function of scat placement distance, wind direction, wind speed, and the interaction between wind direction and speed (WINDDIR × WINDSP; Buckland et al. 2006), and we used a model selection approach to compare the resulting models (Burnham and Anderson 2002). We compared a balanced set of 11 models for combinations of $\leq$2 explanatory variables using the Akaike Information Criterion with a small sample-size adjustment (AIC_c). We present results for the model with the greatest support (min. AIC_c) and for competing models ($\Delta AIC_c < 3$).

Environmental Conditions

Controlled trials.—We also used the results of the controlled search trials to test for effects of variable environmental conditions on the dogs' scat detection rates. We examined the dogs' detection rates in search trials conducted in the experimental pasture described above. For the environmental conditions analysis, we included all scats left in the field from previous search trials to account for possible effects of scat decomposition over time. Thus, we knew the total number of target scats available for detection during each search trial, allowing us to calculate the dogs' actual detection rates.

We recorded several environmental variables for each search trial from HREC's automated weather station: air temperature, vapor pressure, wind speed, wind variability (SD of wind direction), and relative humidity. We averaged values for all variables for the nearest hour to the search trial. We also recorded cumulative precipitation for each search trial, beginning with the start date of the experiment (Table 2).

We used a model selection approach to examine the relationships between environmental conditions and scat detection rates. We calculated the proportion of available scats (scats that were placed or were remaining in the pasture) detected during each search trial. We compared a balanced set of 22 models for combinations of $\leq$2 environmental factors using AIC_c. We present results for the model with the greatest support (min. AIC_c) and for competing models ($\Delta AIC_c < 3$).

Uncontrolled trials.— To better understand how environmental factors affect actual field surveys, we repeated our

Table 2. Mean values and ranges of environmental variables in controlled and uncontrolled field searches using conservation detection dogs in northern California, 2003–2005.

		Controlled trials		Uncontrolled trials	
Variable	Code	$\bar{x}$	Range	$\bar{x}$	Range
Temp (C)	TEMP	11.1	4.4–21.8	17.1	9.3–28.7
Vapor pressure (kPa)	VP	0.9	0.6–1.3	1.3	0.9–1.8
Wind speed (m/s)	WINDSP	1.6	0.7–3.4	1.6	0.8–3.3
Variability of wind direction (°)	WINDVAR	34.5	18.5–58.9	40.7	13.4–68.5
Relative humidity (%)	RH	68	22–100	71	45–95
Cumulative precipitation (mm)	PRECIP1	138	1–310		
Days since precipitation (>5 mm)	PRECIP2			41	5–115

analysis of the relationships between environmental conditions and dogs' scat detection rates using data from uncontrolled field searches conducted in 30 additional research sites. All sites were located in similar oak woodland habitats, and because the 2 dogs were trained to locate the scats of different target species, we analyzed variation in detection rates among surveys for each dog separately.

Each dog-handler team completed 15 uncontrolled field searches. We surveyed sites between April and June 2004 with dog 1 and between July and September 2005 with dog 2. We used a handheld GPS device to record our transect search line and the point location of each scat collected. We downloaded and differentially corrected the GPS data and exported it to ArcGIS 9.0, and we corrected transect lines using the Smooth Line tool in ArcToolbox (PAEK algorithm with a smoothing tolerance of 50 m).

We determined the nearest CIMIS weather station to each field site and averaged the values of environmental variables for the hours searched in each site. We collected the same set of environmental variables as for controlled field trials (Table 2), but we calculated the effect of precipitation differently. We conducted controlled searches repeatedly in one site during the rainy season of California's Mediterranean climate, which allowed us to examine the effect of daily variation in precipitation on scat detection. We conducted the uncontrolled searches in 30 dispersed field sites, and we surveyed each site only once during the dry season. There is considerable variation in rainfall across the study region, and cumulative precipitation values are not likely to be comparable among sites. Because we assume that the primary effect of precipitation is likely to be removal or decomposition of scats, for uncontrolled searches we calculated the number of days that passed since a substantial precipitation event occurred in each field site. Exploratory analysis of weather data indicated that >5 mm of rainfall in 1 day was an appropriate threshold for a substantial precipitation event in our study area.

We searched an average of 4.1 km (range: 1.5–10.2 km) of transects in each site, and we used a model selection approach to examine effects of environmental conditions on scat detection. We counted the number of scats collected in each site, and we calculated the scat detection rate as the number of scats found per distance searched. We compared a balanced set of 22 models for combinations of ≤ 2 environmental factors using AIC_c and we present results for the model with the greatest support (min. AIC_c) and for competing models ($\Delta\text{AIC}_\text{c} < 3$).

RESULTS

Dog 1 detected 68% of scats and dog 2 detected 77% of scats during the first search following placement, and the dogs' detection rates decreased with increasing distance of scats from the transect line (Fig. 2). Scat placement distance was the most important variable identified in the full model sets for dog 1 ($w_+(\text{DIST}) = 1.00$) and dog 2 ($w_+(\text{DIST}) = 0.90$) and appeared in all of the top-ranked models selected for both dogs (Table 3). Confidence intervals for all coefficients of the wind conditions variables overlapped zero.

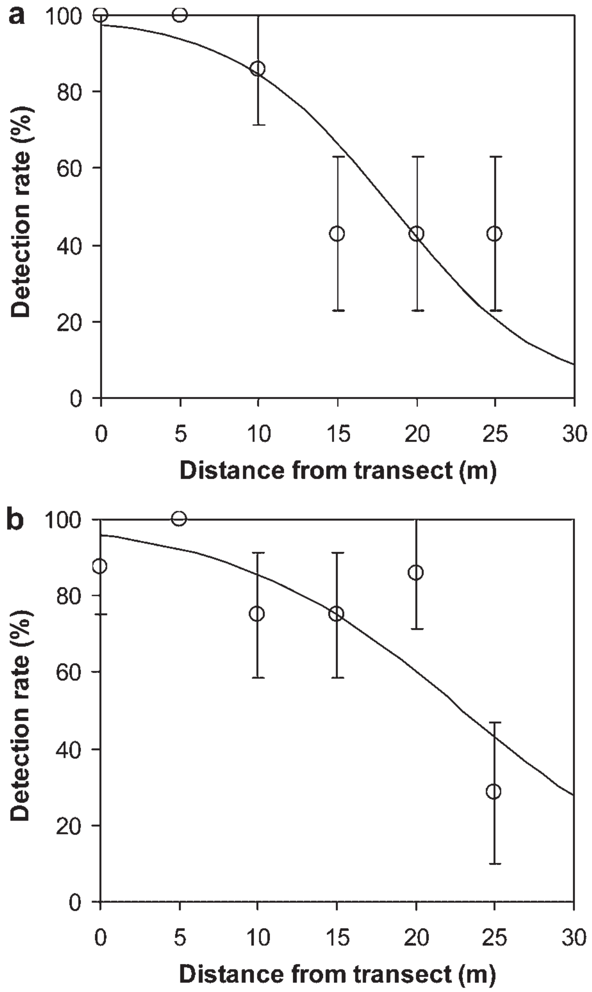

Figure 2. Results of detection distance trials conducted at the Hopland Research & Extension Center (HREC) using (a) dog 1 in 2003–2004 and (b) dog 2 in 2004–2005. Both dog 1 and dog 2 detected placed scats less frequently as the distance from the transect line increased. Model-averaged estimates of scat detection functions are shown for each dog, given mean wind conditions during the search trials. In addition, mean detection rates (±SE) are given for scat placement distances to the nearest 5 m. Dog 1 searched for a mean of 6.8 scats and dog 2 searched for a mean of 7.5 scats at each distance.

In controlled search trials at HREC, top-ranked models ($\Delta\text{AIC}_\text{c} < 3$) for detection rates of dog 1 and dog 2 included both air temperature and cumulative precipitation (Table 4). Cumulative precipitation was the most important variable identified in the full, balanced model sets for dog 1 ($w_+(\text{PRECIP1}) = 0.96$) and dog 2 ($w_+(\text{PRECIP1}) = 1.00$), and it was negatively related to scat detection rate for both dogs. Air temperature ($w_+(\text{TEMP}) = 0.47$) had a weak positive relationship to detection rate for dog 1, whereas for dog 2, air temperature ($w_+(\text{TEMP}) = 0.20$) was negatively related to detection rate. However, confidence intervals for the coefficient of air temperature for dog 2 and the coefficients of relative humidity for both dogs overlapped zero.

In the uncontrolled field trials for dog 1, we identified 7 competing models ($\Delta\text{AIC}_\text{c} < 3$) to explain the relationship between scat detection rate and environmental conditions

Table 3. Top-ranked models from an Akaike Information Criterion (AIC)-based model selection of scat detection rates in detection distance trials at Hopland Research & Extension Center for dog 1 (2003–2004) and dog 2 (2005). For each model we included parameter estimates (b_1, b_2) and 95% confidence intervals (CI) for 1 or 2 variables, log-likelihood (Log(L)), number of parameters (K), AIC$_c$ (small-sample correction to AIC), and Akaike weight (w_i). Scat placement distance was the most important explanatory variable in the full model sets for dog 1 ($w_+(\text{DIST}) = 1.00$) and dog 2 ($w_+(\text{DIST}) = 0.90$).

Model, by dog	b_1	CI (b_1)	b_2	CI (b_2)	Log(L)	K	AIC$_c$	w_i
Dog 1								
DIST^{a} + WINDDIR × WINDSP^{b}	−0.221	0.148	0.010	0.012	−838.35	3	41.69	0.410
DIST^{a} + WINDDIR^{c}	−0.208	0.139	0.012	0.017	−860.80	3	42.79	0.237
DIST^{a}	−0.171	0.119			−871.03	2	42.90	0.224
DIST^{a} + WINDSP^{d}	−0.183	0.128	1.09	2.14	−886.95	3	44.06	0.125
Dog 2								
DIST^{a} + WINDSP^{d}	−0.153	0.125	−1.08	1.28	−1041.46	3	47.01	0.412
DIST^{a}	−0.116	0.101			−1066.89	2	47.79	0.278
DIST^{a} + WINDDIR × WINDSP^{b}	−0.115	0.104	−0.002	0.007	−1102.90	3	49.74	0.105
DIST^{a} + WINDDIR^{c}	−0.123	0.103	0.004	0.013	−1103.48	3	49.76	0.104

[a] Distance of scat from the search transect.

[b] Interaction between wind direction and wind speed during the search trial.

[c] Wind direction relative to the direction of scat placement from the search transect.

[d] Wind speed during the search trial.

(Table 4). The null model was the top-ranked model, and the environmental variables with the greatest relative importance in the 6 models were days since precipitation ($w_+(\text{PRECIP2}) = 0.32$) and wind variability ($w_+(\text{WINDVAR}) = 0.24$). However, confidence intervals for the coefficients of both variables overlapped zero. Only one model had strong support ($\Delta\text{AIC}_c < 3$) to explain the relationship between detection rate and environmental conditions for dog 2 (Table 4). Days since precipitation ($w_+(\text{PRECIP2}) = 1.00$) and relative humidity ($w_+(\text{RH}) = 0.90$) were both positively related to detection rate.

DISCUSSION

We were unsurprised to find that the dogs' scat detection rates declined by distance from the transect search line. However, estimates of the dogs' detection functions are useful for calculating the area searched around the survey transect and the overall density or abundance of survey targets (Thomas et al. 2010). We defined detection distance as the distance between the scat's placement location and the transect search line. We recognize that although the handler

Table 4. Top-ranked models from an Akaike Information Criterion (AIC)-based model selection of scat detection rates in controlled search trials at Hopland Research & Extension Center (2003–2005) and uncontrolled searches of 30 research sites in northern California (2004–2005). For each model we included parameter estimates (b_1, b_2), and 95% confidence intervals (CI) for 1 or 2 environmental variables, log-likelihood (Log(L)), number of parameters (K), AIC$_c$ (small-sample correction to AIC), and Akaike weight (w_i). In the controlled trials, cumulative precipitation was the most important explanatory variable in the full model sets for both dog 1 ($w_+(\text{PRECIP1}) = 0.96$) and dog 2 ($w_+(\text{PRECIP1}) = 1.00$). In the uncontrolled trials, the most important explanatory variables in models selected for dog 1 were days since precipitation ($w_+(\text{PRECIP2}) = 0.32$) and wind variability ($w_+(\text{WINDVAR}) = 0.24$). For dog 2, they were days since precipitation ($w_+(\text{PRECIP2}) = 1.00$) and relative humidity ($w_+(\text{RH}) = 0.90$).

Model, by trial and dog	b_1	CI (b_1)	b_2	CI (b_2)	Log(L)	K	AIC$_c$	w_i
Controlled trials—dog 1								
PRECIP1^{a} + TEMP^{b}	−0.0028	0.0014	0.058	0.056	23.54	4	−34.08	0.460
PRECIP1^{a}	−0.0023	0.0016			20.80	3	−32.93	0.258
PRECIP1^{a} + RH^{c}	−0.0029	0.0017	−0.0064	0.0088	22.29	4	−31.58	0.131
Controlled trials—dog 2								
PRECIP1^{a}	−0.0039	0.0010			33.36	3	−58.55	0.436
PRECIP1^{a} + TEMP^{b}	−0.0033	0.0013	−0.012	0.018	34.51	4	−57.02	0.203
PRECIP1^{a} + RH^{c}	−0.0034	0.0014	0.0018	0.0039	34.01	4	−56.02	0.123
Uncontrolled trials—dog 1								
Null					−7.61	2	20.15	0.240
PRECIP2^{d}	0.045	0.070			−6.61	3	21.21	0.141
WINDVAR^{e}	−0.042	0.085			−7.00	3	21.99	0.095
PRECIP2^{d} + WINDVAR^{e}	0.054	0.069	−0.055	0.082	−5.40	4	22.44	0.076
WINDSP^{f}	0.71	3.23			−7.49	3	22.97	0.058
TEMP^{b}	0.054	0.357			−7.55	3	23.11	0.055
RH^{c}	−0.015	0.102			−7.56	3	23.11	0.054
Uncontrolled trials—dog 2								
PRECIP2^{d} + RH^{c}	0.162	0.055	0.201	0.105	−8.72	4	29.88	0.902

[a] Cumulative amt of precipitation since the beginning of the study.

[b] Temp during the search trial.

[c] Relative humidity during the search trial.

[d] Days since precipitation (>5 mm).

[e] Variability of wind direction during the search trial.

[f] Wind speed during the search trial.

walked along the transect search line, the dog had freedom of movement and may have been to the right or left of the line at any given time. Therefore, scent from a scat placed 10 m to the left of the line may have been detected by a dog when it was 5 m to the right of the line, for an actual detection distance of 15 m (Cablk et al. 2008). Because we did not directly assess the point at which the dog detected the scent, similar to distance sampling methods, our approach defined a nominal detection function around the transect search line, which should be kept in mind when interpreting the distances discussed below.

The average distance at which dog 1 detected a scat during the first search trial following placement was 9.6 m, whereas the average distance for dog 2 was 10.4 m, and at a placement distance of 10 m, both dogs detected scats >75% of the time (Fig. 2). Results for these 2 dogs are similar to one another and comparable to detection distances reported for other terrestrial surveys (Ralls and Smith 2004, Cablk et al. 2008). It would be helpful to repeat similar controlled trials with several more dogs to understand the degree to which the detection function varies by individual dog. In addition, controlled search trials should be repeated with scats placed at greater distances from the survey transect to get a better estimate of the distance at which the detection rate approaches zero.

We did not find evidence for the influence of wind conditions on the dogs' detection functions (Table 3). In all cases, coefficients for wind speed, direction, and the interaction of wind speed and direction substantially overlapped zero, which may be because wind speeds were mild during the search trials (Table 2) or because the dogs' movement around the transect line compensated for any effect of wind. In addition, we searched the transect in 2 directions during each trail, which likely enhanced the dogs' overall detection rates. Wind conditions could have a greater effect on surveys conducted with detection dogs on-lead, when a dog has less freedom to search for scents from multiple directions.

Although results of our search trials indicate there is a clear relationship with scat placement distance, the top-ranked models explained only part of the variation in the detection rates of dog 1 ($R^2 = 0.32$) and dog 2 ($R^2 = 0.19$). Many other factors could affect the probability of detection around a transect line. For example, topography and vegetation can influence the distribution of scent in space. Search dog professionals report that scent pools in drainages or depressions, along walls or fences, or in areas of dense vegetation (Syrotuck 1972, Snovak 2004). We selected the pasture where we worked because it was a flat and open grassy area, but the dogs' detection functions might change in areas with variable terrain and vegetation structure.

Scent contamination is another potential confounding factor for conservation detection dog surveys (Snovak 2004). Although we used the same pasture for all of our controlled trials, we were unable to control for possible temporal sources of variability in the olfactory environment, such as the proximity of livestock, vehicle exhaust, and residual scent from prior searches. In addition, when dogs are trained to detect multiple survey targets (e.g., scats from multiple species), researchers must account for the possibility that dogs detect targets from different species or individuals at variable distances or rates, especially when independent verification of target detection is difficult or impossible (Reindl-Thompson et al. 2006). We were able to control for this factor in the trials at HREC by using scats from only one target individual per dog, but we could not account for it in uncontrolled field searches. Lastly, perhaps the most important unmeasured variable in all of our search trials was the rate of communication between dog and handler. We measured not only the ability of dogs to detect scats at different placement distances and under variable environmental conditions, but also the ability of the dog to successfully communicate its alert when it found a scat and the ability of the handler to correctly interpret and reinforce the alert. Some of these issues could be addressed by establishing consistent standards for obedience and search skills through a certification program for conservation detection dog-handler teams (Cablk and Heaton 2006, Long et al. 2008).

Researchers frequently discuss the potential for environmental conditions to influence the results of conservation detection dog surveys (e.g., in 100% of the studies we reviewed), but most of the available information is anecdotal or drawn from the popular literature (Pearsall and Verbruggen 1982), and relationships between environmental factors and detection rate are rarely examined empirically. Cablk and Heaton (2006) and Nussear et al. (2008) did not observe significant variation in detections of desert tortoises (*Gopherus agassizii*) by wind, temperature, or humidity, and Long et al. (2007) found that the same factors did not influence detection of forest carnivore presence in scat surveys. Shivik (2002) observed a positive relationship between wind variability and time to detection, suggesting that highly variable wind may disperse scent and make it more difficult for a dog to follow it to its source. However, many of these previous studies were not explicitly designed to examine the influence of environmental factors, and any effect of environmental conditions may have been overwhelmed by other sources of variation in the study systems (Smith et al. 2005) or obscured by model analyses that focused on species presence rather than detection rate (Long et al. 2007).

Our controlled search trials allowed us to examine the relationship between the dog's actual detection rate of placed scats and a realistic range of environmental conditions for our study area. The same group of top-ranked models explained the variation in detection rates for the 2 dogs (Table 4), and the most important variable in all of the models was cumulative precipitation. We conducted controlled search trials during the rainy season of California's Mediterranean climate, and we suspect that regular rainfall during the study led to degradation or removal of placed scats over time.

Interestingly, air temperature appeared to affect the dogs differently. Higher temperatures correlated with higher detection rates for dog 1, whereas dog 2's detection rate declined with increasing temperature. Both variable relationships were weak, and the confidence interval for the coefficient of temperature for dog 2 substantially overlapped zero. These divergent results may be attributable to differences in the conditions in which we conducted the surveys, differences in the bacterial activity or scent volatility of the target scats, or most likely, differences in the heat tolerances of the individual dogs. Increased panting leads to decreased sniffing and scent detection (Gazit and Terkel 2003), and prior observations indicate that detection dogs can have highly variable panting rates in response to the same environmental conditions (Smith et al. 2003).

Selection of models for environmental conditions in the uncontrolled field searches further underscored the influence of precipitation on detection rates. Although there was substantial uncertainty in model selection for dog 1, the most important variable overall was days since precipitation, which was positively related to detection rate (Table 4). Dog 1's detection rate increased with days since precipitation, but the confidence interval for the coefficient of precipitation overlapped zero. The best model for dog 2 showed an even stronger positive relationship between days since precipitation and detection rate (Fig. 3). Dog 2's detection rate also increased with increasing levels of relative humidity (Table 4). Some search dog professionals have suggested that humidity may slow the evaporation rate or increase bacterial activity at the scent's source, thereby increasing the intensity of the scent (Syrotuck 1972, Pearsall and Verbruggen 1982).

Our results indicate that precipitation plays a strong role in degrading or removing scats from the landscape and that detection rates increase as scat begins to accumulate following the last substantial (>5 mm) rain event of the year. Although some researchers have suggested that precipitation plays a role in scat removal (Smith et al. 2005, Harrison 2006), we are not aware of any other studies specifically examining this relationship. We speculate that the stronger relationship for dog 2 was primarily attributable to surveys using that dog being conducted later in the dry season, allowing more time for scats to accumulate (Fig. 3). For ecosystems with a strong seasonal pattern of rainfall such as coastal California, scat accumulation could lead to significant bias in study results if researchers do not control or account for this factor. On the other hand, given the positive relationship with relative humidity shown for dog 2 (Table 4), the complex relationship between air moisture, precipitation, and detection rate warrants further investigation in ecosystems with more variable rainfall patterns.

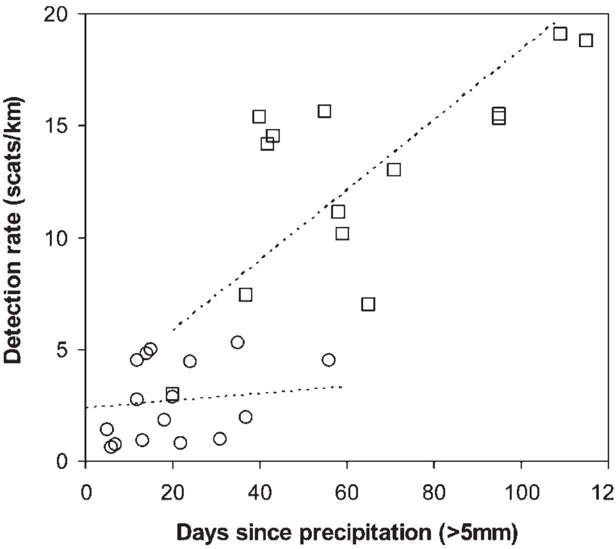

Figure 3. Scat accumulation over time in 30 field sites in northern California. Model-averaged estimates of the relationship between the number of days since precipitation (>5 mm) and scat detection rate are shown for uncontrolled field searches using dog 1 (○) during April–June 2004 and dog 2 (□) during July–September 2005, given mean values for other environmental factors.

MANAGEMENT IMPLICATIONS

As recent contributions to the literature suggest, surveys using conservation detection dogs will become increasingly common in wildlife research and management. Because the influence of environmental conditions is likely to vary substantially by study environment and individual dog, it is important for researchers to quantify the factors affecting detection rates and minimize potential biases. At a minimum, we recommend that researchers report the conditions under which wildlife detection surveys took place and analyze whether detection rates vary as a function of temperature, humidity, wind, precipitation, and other locally important environmental factors.

In addition, wildlife surveys should be designed to maximize the abilities of the detection dog. Ideally, controlled search trials should be conducted under a variety of conditions, similar to the experiments we described, to assess detection distances and environmental thresholds of individual dogs. Where applicable, trials should be repeated for multiple survey targets, to verify whether dogs' detection rates vary by target species or individual. This information would allow researchers to calibrate their survey design (i.e., the spatial arrangement of transects, time of day, and duration of searches) to individual dogs' abilities.

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