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An assessment of the effects of habitat structure on the scat finding performance of a wildlife detection dog

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Summary

1. As threatened species decline in number, they become more difficult to detect and assess, decreasing our ability to make informed conservation management decisions. Wildlife scat detection dogs are a promising non-invasive survey method for increasing detection rates of these species. However, a complexity of variables can reduce the certainty of this method, which may contribute to low uptake rates by land managers. One of the variables discussed in dog training literature is the potential for habitats with more complex vegetation to inhibit dispersion of target odours, reducing the dog's ability to detect scats.

2. We undertook the first experimental study to test the effects of habitat structure on scat detection dog performance. We used a domestic dog trained to detect scats from endangered spotted-tailed quolls to undertake 120 searches across 3 habitats in both winter and summer conditions in NSW, Australia. Scat searches were located in open grassland, woodland and dense heath, and we recorded temperature, relative humidity and wind speed. Performance was measured by recording the distance at which the scat was first detected, the total search duration and the success rate of detection in each habitat.

3. Scat detection rates were 83% or higher in all habitats, and there was no significant difference in first detection distances between habitat structures. However, within habitats there was a significant, positive relationship between first detection distance and total search duration in the most complex habitat ($P = 0{\cdot}0002$, $R^2 = 0{\cdot}23$, d.f. $= 1$, SE $= 0{\cdot}53$).

4. The results support other findings showing that detection dogs can work effectively across a diversity of habitats, but specifically demonstrate that searches in complex vegetation should allow for increased search effort compared to relatively open vegetation. Otherwise, the risks of a type II error, of failing to detect a species when it is present, are likely to be higher in these habitats and this has significant implications for conservation management. The high detection rates in our results are discussed in the context of the odour thresholds used to train wildlife scat detection dogs, and we recommend future documentation of training methods to allow comparison of surveys across species and sites.

Key-words: conservation detection dog, conservation dogs, detection dog evaluation, scat detection, spotted-tailed quoll

Introduction

The total number of declining extant mammal species across the globe is expected to increase, with approximately 25% of mammal species so far assessed by the IUCN already listed as threatened (IUCN 2014). Low-density species are often difficult to detect and survey; therefore, as species are reduced in number, it becomes increasingly challenging to make informed conservation management decisions. This is particularly so for species which already naturally occur at low densities or are cryptic.

Wildlife detection or conservation dogs, trained to locate scats, have been demonstrated to be a highly effective non-invasive method of surveying carnivores and other wide-ranging and low-density species across a range of habitats, compared to hair snares, scent stations, camera traps and audio surveys (Wasser *et al.* 2004; Smith *et al.* 2005; Long *et al.* 2007a,b; Vynne *et al.* 2011; Wasser *et al.* 2012). Scat detection rates of up to 87% have been reported using dogs compared to up to 33% for detection of target species using alternative methods (Long *et al.* 2007b). Potential for this method has further increased since the advancement of genetic and endocrine techniques that can extract large amounts of information from scats (Ruibal *et al.* 2009; Vynne *et al.* 2012). Despite success in its application, the use of this survey method remains rare compared to more traditional methods such as trapping and human visual surveys which are well documented in survey guidelines provided by government land management agencies (Murray, Bell & Hoye 2002; Fraser, Thompson & Moro 2003; Bureau of Land Management 2011; DSEWPC 2011).

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The robustness of the scat detection dog survey method is dependent on many different variables. For example, Reed *et al.* (2011) showed that distance from the target odour, or scat, is a key factor in determining detection rates in scat surveys. One variable that has been discussed in dog training literature suggests that vegetation structure is similarly important for scent detection since scent particles are heavier than air and physically dense vegetation can cause scent to pool or hang (Syrotuck 1972; Snovak 2004). Scent dispersion from the target odour is also affected by topography, wind speed and direction; scent tends to pool in depressions and in contrast will be at lower density or absent in higher elevations and more exposed areas (Wasser *et al.* 2004). Therefore, habitats with thicker and more complex vegetation are expected to reduce the distance that scent travels from the target odour and potentially reduce the dog's ability to detect scats in these habitats. Studies from *in situ* surveys have attempted to model and account for the effects of many other important environmental variables on detection rates (Smith *et al.* 2003, 2005; Long *et al.* 2007b; Reed *et al.* 2011; Vynne *et al.* 2011; Tom 2012); however, there have been no studies undertaken to specifically test the impact of vegetation structure on detection dog performance. Consideration of all potentially confounding variables is important in order to maximize the likelihood of scat detection in any environment and will also help to improve certainty around the method and thereby encourage uptake by land managers.

Detection probability is also likely to be affected by the type of methods employed to train the dogs. Similarly to survey design considerations, there are a range of variables that can affect the success of scat detection dog training. Many papers refer back to the training methods described by Smith *et al.* (2003) and Wasser *et al.* (2004) which mention the importance of the number of scats used, collection from a number of individuals and a range of diets. However, an evaluation of the available literature cited in this study revealed an absence of documentation on the odour thresholds used for training wildlife detection dogs. MacKay *et al.* (2008) provide a thorough review of dog training considerations and do mention the age of scats as important, yet we found no subsequent published studies that documented this type of data. All training methods use positive association, whereby the dog associates finding the target odour with a reward in the form of a toy or food. Due to the nature of *in situ* wildlife scat surveys, the range of concentrations and variations in the target odour is likely to be high due to degradation in the environment, particularly due to precipitation and increasing bacterial loads (Wasser *et al.* 2004; Reed *et al.* 2011; Vynne *et al.* 2012). Therefore, if a dog is trained only using intact and fresh scats, it is reasonable to hypothesize that it may not associate the expected reward with an old degraded scat and may not indicate on very low concentrations of odour.

In this study, we aimed to: (i) experimentally test the effects of vegetation structure on the performance of a scat detection dog under a broad range of environmental conditions; (ii) assess the effects of climatic conditions on detection dog performance, specifically temperature, wind and humidity in both summer and winter conditions, and (iii) document the odour thresholds used in training and discuss implications for scat detection probability.

We used a dog trained to locate scats of the spotted-tailed quoll (*Dasyurus maculatus*), a wide-ranging marsupial carnivore species listed as threatened in south-eastern Australia under the federal Environment Protection and Biodiversity Conservation Act (1999). The species has suffered dramatic population declines which, combined with its arboreal and nocturnal behavioural patterns, has made it increasingly difficult to detect using traditional camera trap survey methods (Belcher 2003; Ruibal *et al.* 2009). Spotted-tailed quolls frequently use forested habitats with high rainfall, which increases the difficulty of visual scat location. Spotted-tailed quolls deposit their scats on prominent landscape features such as fallen logs, rocks and trails. They often form latrine sites, which are thought to be a form of semiochemical communication (Jones, Rose & Burnett 2001; Long & Nelson 2008) and can also include scent from urine and cloacal dragging (Ruibal *et al.* 2009). Since latrine scat collections can persist in the landscape longer this makes them particularly suitable for scat surveys, which are also used for many other wide-ranging carnivores (Ralls & Smith 2004; Long *et al.* 2007a,b; Tom 2012).

Studies aimed at assessing detection dog performance under various environmental variables such as temperature, humidity and wind conditions have all been undertaken outside of Australia under different conditions (review in MacKay *et al.* 2008; Reed *et al.* 2011). Therefore, this site provided an opportunity to further evaluate the impact of environmental variables on detection dog performance.

Scat detection dogs are expensive to train, ranging from US $20 000 to $30 000 per dog to train and deploy (M. Dominick pers. comm.; Long *et al.* 2007a); therefore, many studies have been limited to a small number of dogs, generally between one and four dogs (Smith *et al.* 2003; Wasser *et al.* 2004, 2012; Long *et al.* 2007b; Reed *et al.* 2011; Vynne *et al.* 2011; Oliveira *et al.* 2012). This study was limited to use of a single dog therefore results should be considered in this context. However, our general findings are supported by other published studies that demonstrated the utility of scat detection dogs compared to other survey methods and were carried out across a wide diversity of habitats.

Methods

DOG TRAINING AND ODOUR DETECTION RATES

A 4-year-old male Australian Shepherd was selected for this study. Australian Shepherds are a high-energy working dog breed that have been previously used for wildlife scat detection (Smith *et al.* 2003). The dog was first assessed by a professional detection dog trainer from K9-Centre Australia (M. Dominick) for suitable attributes including temperament, intelligence and play drive. The dog was then trained to detect the scat of a single species, *Dasyurus maculatus*, to maximize sampling effort in controlled trials (Vynne *et al.* 2011). Food reward was used for the early stages of training then the dog's play drive was increased via training techniques for longer distance work, including tug of war games and ball fetching which both use a toy reward. Second stage training involved a volunteer wearing gloves and planting the scats so that the handler was not aware of their location and could not accidently or subconsciously communicate with the dog and affect the success of the search (Lit, Schweitzer & Oberbauer 2011). Extensive false trails of human scent were laid to teach the dog to use air scenting rather than following trails of human footprints to the target odour. Based on data from training, scats were placed out 24 h prior to each search, although Wasser *et al.* (2004) considered several hours sufficient for human scent to dissipate. The dog was trained not to chase wildlife. Training included testing the dog on handled scats and *in situ* quoll scats to ensure the dog would indicate on both. For the research surveys, all scats had been handled the same way so any effect on scent dispersion would be consistent.

The dog was taught to sit, stay and bark after locating the target scat; the barking allowed the handler to locate the dog if the dog was out of visual contact when indicating. The dog was then taught the command 'show me', to put its nose next to the scat so the handler could see and collect the scat.

Target odours used in training included 20 scats of varying quantities and age with subsamples of each exposed to a range of environmental conditions (outlined in Table 1), and all scats listed were subsequently successfully detected in training field trials. Scats were collected from a range of unrelated animals of both sexes including captive and free-ranging quoll populations in NSW and Victoria. Free-ranging quolls were monitored using camera traps to confirm the scat was collected from the target species. Training methods generally followed those described in Wasser *et al.* (2004), with the exception that all training took place outside in the natural environment at a diversity of sites to expose the dog to an increased range of non-target odours that are likely to be encountered during survey work. The focus of the training was for the dog to locate visible quantities of scats (that could provide DNA samples), therefore, if the dog indicated in an area where a scat had been completely removed 24 h or more beforehand, it was not rewarded. Due to limited available area of some habitat types, some initial training trials were undertaken in the same area on different days, where the dog occasionally indicated where a scat had been placed but then removed up to 3 days earlier. Prior to field surveys, two independent scientists observed the dog undertake 15 searches each and verified the dog's ability to successfully detect quoll scats.

Controlled trials were used to test the dog's single species focus, by placing a 3 × 3 grid of one spotted-tailed quoll scat and 8 non-target species scats collected in grassland and forest, spaced 10 m apart (see Fig. 1). Non-target species were the domestic cat *Felis catus,* introduced red fox *Vulpes vulpes*, dingo *Canis lupus dingo*, brush-tailed possum *Trichosurus vulpecula*, swamp wallaby *Wallabia bicolor*, rabbit *Oryctolagus cuniculus*, emu *Dromaius novaehollandiae* and chicken *Gallus gallus domesticus*. A search was conducted three times, one hour apart, with the position of scats changed each time and the dog was directed towards each scat. The sites where the quoll scat was placed were not reused to avoid false-positive results.

Table 1. Parameters describing the range of the condition of scats used for training of the detection dog

Variable	Minimum	Maximum
Age	<24 h old	324 days old
Weight and structure	0·51 g of dried scat, in the form of crumbs.	7·9 g fresh scat, typical intact deposit.
Environmental Exposure		
Temperature	3°C	22°C
Time *in situ* in bushland	0 days	84 days (36 with rain)
Total precipitation	0 mm	200 mm

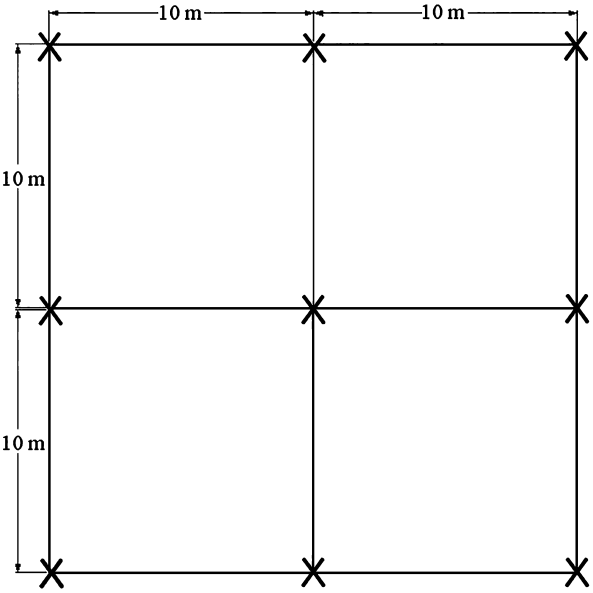

Fig. 1. Survey design for the target/non-target trial. *X* in the figure shows the positions of the 9 scats in each trial, which were rotated between each of 3 trials.

After training, we evaluated the dog's ability to detect 10 different spotted-tailed quoll scats that varied in condition and quantity. The trials were carried out *in situ* in grassland habitat with the scats placed on pieces of tree bark substrate from a single species of eucalyptus. Scat condition ranged from an intact 2-day-old scat weighing 8 g (dark brown and moist), to 324-day-old dried crumbs of scat weighing 0·51 g (pale cream in colour). An additional sample was included where dried scat had been placed on bark substrate for 48 h then removed 24 h before the trial. Scats had been stored in plastic ziplock bags with silica gel desiccant sachets. Each quoll scat was randomly placed amongst 8 other odour targets spaced 5 m apart, including non-target scats and empty pieces of bark (as controls containing handling odours), and the dog was instructed to search past all 8 targets.

STUDY SITE

Detection dog performance was assessed across three habitats of varying vegetation structure (Fig. 2) on private properties and crown land in Lithgow, Hassans Walls Recreational Reserve and the Wolgan Valley in NSW. (i) Open grasslands consisted of level sites with groundcover of native and pasture grasses less than 15 cm high, with 0% understorey cover and canopy cover of < 15%. (ii) Woodland consisted of Blue Mountains Sydney peppermint-silvertop ash shrubby woodland (DEC 2006), characterized by a dense shrubby understorey with 40-60% cover and approximately 50% canopy cover. (iii) A Sydney Montane Heath community (DEC 2006), characterized by a single diverse and complex understory layer of 75–90% cover, up to 2 m tall averaging 1–1·5 m in height, with localized ground cover. Topographical features can affect scent dispersion and could confound our ability to detect the impact of vegetation on detection dog performance, therefore, gullies and steep landscape features were avoided. There were no recent (<10 years) records of quolls at the sites chosen for study.

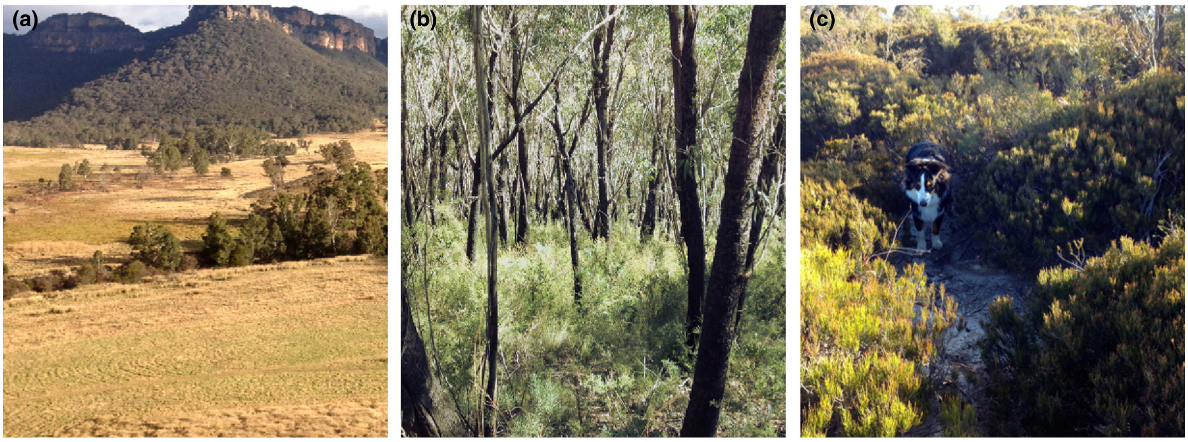

Fig. 2. Photographs of representative vegetation structure in each habitat: a) Grassland, b) Woodland, c) Heath.

FIELD SURVEYS COMPARING HABITATS

A total of 120 searches were undertaken in 2012 and 2013: twenty searches were carried out in each habitat type during winter conditions and twenty during summer conditions, giving a total of 40 searches per habitat over a range of temperatures (6–33°C for grasslands, 7–25·3°C for woodland and 6–25·3°C for heath). Comparable studies in the USA had a maximum temperature range of 20°C (summarized in Reed *et al.* 2011). A single dog and handler were used for all searches which although limiting in some regards, reduced potential bias resulting from variation in individual performance (Wasser *et al.* 2004; Lit, Schweitzer & Oberbauer 2011). Searches were rotated between habitats within each season to cover a maximum range of environmental conditions in each and to avoid any bias in dog performance over time.

Detection dog performance in each habitat was recorded by measuring the distance at which the target odour was first detected (first detection distance), and whether the scat was successfully located. Additionally, total search duration was recorded to establish the search effort for each survey. First detection distance was visually estimated by the handler based on 'on-scent' behaviours exhibited by the dog; a sudden change in direction with accompanying consistent air-scenting behaviour (nose lifted higher), suddenly slower speed and behaviour indicating the decision phase (Thesen, Steen & Døving 1993) followed by a change in behaviour from a general zigzagging search across the belt transect to a directional search indicating the dog was working a narrower scent cone from the target odour, including sniffing of depressions and vegetation where scent naturally pools. The first detection location was marked using a handheld Garmin GPSMAP 62s and later the distance between the first detection location and the target scat was measured in ArcGIS ArcMap software (V9.3.1, Environmental Systems Resource Institute (ESRI), Redlands, CA, USA).

Habitat patches were mapped using ArcMap, and scats were placed within each habitat based on random allocation to cells in a grid design ensuring they were at least 70 m apart. Due to the limited size of habitat patches, some search plots were used more than once within a season; however, scats were removed after each search and the plot was reused a minimum of 4 weeks later with the scat placed a minimum of 50 m from previous scat locations. Scats were planted 24 h before each search to allow the scent to disperse. For validity of comparison across sites, searches were not undertaken during periods of rain. The scats used in the field trials were 6 months old, since standard field surveys are likely to encounter aged scats, and consisted of a single scat deposit weighing approximately 3 g. The consistent age also ensured that the target odour for each search was consistent. Each search was initiated from a minimum distance of 50 m downwind, based on maximum detection distances of 30 m in open habitats in other terrestrial studies (Reed *et al.* 2011). The dog was verbally guided by the handler so it remained within a 100 m wide belt transect. The top of the belt transect passed within 5 m of the scat location; if the dog did not locate the scat beforehand, it was guided along the top of the belt transect and within 5 m of the scat, to test if the dog was working. The dog worked off leash to increase area coverage and to allow it to adapt its search pattern to changes in wind speed and direction (Syrotuck 1972).

At the start of each search wind speed, temperature and relative humidity were recorded according to the nearest Australian Bureau of Meteorology weather station.

This study was carried out in strict accordance with the animal welfare legislation and guidelines provided by the Department of Primary Industries NSW, Lithgow City Council and with the consent of private property owners.

STATISTICAL ANALYSIS

Field survey data were tested for normal distribution by visual inspection of histograms and using D'Agostino's K-squared test (D'Agostino 1970) for skewness and kurtosis. Both of the dependent variables (i) first detection distance and (ii) total search time were found to have a positively skewed distribution ($P < 0{\cdot}05$). Data were log-transformed to stabilize variance that then gave a normal distribution for both dependent variables. Predictor variables of temperature, humidity and wind speed were not transformed.

Detection dog performance between habitats was then compared using one-way ANOVA to test for differences in first detection distance and total search time and to test for any differences between environmental variables in each habitat. Multiple linear regression using Wesser (2013) was used to investigate the relationship between the environmental predictor variables and detection dog performance within and between habitats. The relationship between the two dependent variables in each habitat was calculated using the Pearson correlation coefficient and a two-tailed *t*-test.

Results

The three non-target/target odour discrimination trials confirmed that the dog successfully indicated only after locating the target odour, 100% of the time (1 target odour amongst 8 non-target odours). In trials evaluating odour thresholds, the dog detected all target scats to the minimum weight of 0·51 g of scat and a maximum age of 324 days. The dog did not indicate on the substrate where the scat had been placed but removed 24 h prior.

In the experimental testing of detection dog performance in different habitat structures, the dog successfully located the target scat in every search in each vegetation type ($n = 120$), confirming the dog was consistently working to a high level. If the dog had not located the scat by the end of the belt transect, it was verbally guided across the top of the transect to within 5 m of the scat, to test if it was working. Therefore, scats detected from a distance of 5 m or less were removed from the data, which then showed 83% of scats were detected in both grassland and heath, and 87% in woodland. A single scat in heathland was not located, although the dog narrowed the search to a 2 m^2 area around a dense clump of vegetation. After an extensive search, the handler and volunteers were not able to locate the scat, which may have been removed overnight by other species; therefore, this search result was removed from the analysis and replaced by another search.

Table 2 shows the range of environmental conditions under which searches were undertaken and the mean first detection distance and search time in each habitat. Contrary to expectations in the literature, which suggest that first detection distance is likely to decrease in denser vegetation due to physical obstruction of scent dispersion (Syrotuck 1972; Snovak 2004), here was no significant difference in first detection distances or search duration between habitats, as shown by the ANOVA of log-transformed data (see Table 2). Despite the dense and complex vegetation coverage in heath, the largest first detection distance in this habitat was 35 m, comparable to that in both grassland and woodland (detection distance range of 2–48 m for grassland, 2–35 m for woodland and 4–35 m in heath).

While there were no significant differences in detection dog performance between sites, multiple linear regression within sites showed a significant relationship between the first detection distance and total search duration in heath, the most complex vegetation structure ($P = 0{\cdot}0002$, $R^2 = 0{\cdot}23$, d.f. = 1, SE = 0·53). Subsequent Pearson's correlation of the two dependent variables showed a significant positive relationship ($P = 0{\cdot}0018$; R = 0·47, and see Fig. 3).

There were no significant differences between data from different habitat types therefore data were pooled and multiple linear regression was used to test for relationships between independent environmental variables (temperature, humidity, wind speed) and detection dog performance across sites. No significant relationships were found between indicators of performance and any environmental parameters ($P > 0{\cdot}05$).

Discussion

Contrary to expectations outlined in wildlife detection dog training literature, we found no significant effects of vegetation structure on the distance at which scats were first detected. Our results concur with more generalized *in situ* studies on detection dog performance that have been carried out in a diversity of countries and conditions, and when combined suggest detection dogs are capable of reliably detecting scats in a broad range of habitat types (Smith *et al.* 2003; Wasser *et al.* 2004; 2012; Long *et al.* 2007a,b; Vynne *et al.* 2011; Lit, Schweitzer & Oberbauer 2011; Tom 2012; Woollett (Smith), Hurt & Richards (2014). Specifically, our results indicate that detection dog performance is robust to changes in vegetation density, if allowances are made for increased search time in denser habitats.

Other terrestrial surveys of a range of mammal species for scats and other target odours have reported mean detection distances of 4·8–29·3 m for *in situ* studies (Shivik 2002; Ralls & Smith 2004) and 9·6–10·4 m in controlled trials (Reed *et al.* 2011); therefore, based on available data, the results from our study (Table 2) fell within the range of detection distances in habitats evaluated outside of Australia. Similarly, the rates of successful scat detection in this study (83–87% after adjustment) were within the higher limits of *in situ* studies in other countries, which varied between dog and handler teams but included detection probabilities from 29% to 97% for scats from a range of species (Long *et al.* 2007a, b; MacKay *et al.* 2008; Reed *et al.* 2011; Vynne *et al.* 2011; Wasser *et al.* 2012). It is important to note that this experiment was carried out with one dog and handler over relatively short distances and level ground and intentionally removed potential limitations such as dog and handler fatigue (MacKay *et al.* 2008) and access problems. Level of exposure and steepness of terrain may still impact scent dispersion, and further experimental studies using more dog and handler teams are recommended.

The expectation that vegetation structure should reduce detection probability in surveys was based on the theory that scent may be found at lower concentrations further from its source in thick vegetation and will be more dispersed in exposed terrain and under wind conditions (Syrotuck 1972; Snovak 2004). Our results did not support this theory. There may be finer scale temporal patterns in scent dispersion that our study failed to detect. For instance, scent dispersion in thicker habitats with more physical barriers may be slower which could be more relevant for detection dogs tracking live animals rather than stationary scats. For scat searches, the results of this study suggest that 24 h or more is sufficient for odour to disperse equally large distances in any of the habitats tested.

Despite the large range of seasonal conditions tested in this study (temperature range of 27°C), we found no significant relationship between environmental variables (temperature, humidity, wind speed) and performance of the detection dog. While there are likely to be limits to dog performance caused by more extreme temperatures, for example heat causing excessive panting and reducing detection ability, our result is consistent with recent *in situ* field surveys (Reindl-Thompson *et al.* 2006; Long *et al.* 2007b; Reed *et al.* 2011) and confirms that detection dogs can perform effectively across a range of conditions.

Table 2. Summary table showing mean and standard error of all measured search variables within each habitat (n = 40 per habitat), and one-way ANOVA results for log-transformed data from three habitats (grassland, woodland and heath)

	Grassland		Woodland		Heath		ANOVA				
Variable	Mean	SE	Mean	SE	Mean	SE	Sum of Squares	d.f.	Mean square	f	*P*
1st Detection Distance (m)	15·4	1·6	12·9	1·3	12·9	1·2	0·35	2	0·18	0·355	0·7
Search Duration (min)	4·3	0·6	4·7	0·5	5·3	0·6	1·32	2	0·66	1·61	0·2
Temperature (°C)	18	1·1	15·3	0·7	15·9	0·8					
Relative Humidity (%)	60·9	2·8	59·3	3·2	66·2	3·1					
Wind Speed (km h^{-1})	9·2	0·9	9·3	1·5	7·6	1·5					

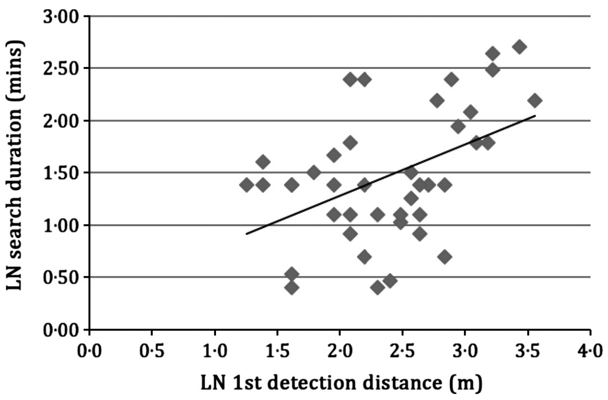

Fig. 3. Relationship between Search Duration and First Detection Distance in Heath habitat (n = 40).

Another possible explanation of why we did not detect any reduction in first detection distance across habitat structures is related to training of the detection dog. If, as was the case in this study, the dog is successfully trained to detect very low odour concentrations, in varying states of degradation, the expected effect of lower odour concentrations with increasing distance from the source in thicker habitats may be greatly mitigated. The dog would detect and indicate on low concentration odours. If, on the other hand, dogs are trained only on relatively fresh intact scats, it is reasonable to assume that performance may be reduced by variations in scent concentration and composition if the dog does not associate those variations with reward.

A previous study indicated that detection rates start to decline after the last 5 mm rain event (Reed *et al.* 2011). In our study, scats used in training included those exposed to high levels of precipitation (Table 1), and during field trials the dog successfully indicated on scats that had been exposed to up to 200 mm of precipitation. Similarly, the dog detected scats with obvious fungal and bacterial loads, up to 324 days in age and down to 0·5 g in weight. The dog in this study was trained to find scats that were visually detectable by humans and if, during training, the dog indicated on areas where scats had been removed days or weeks beforehand it was not rewarded. Subsequently, in later odour threshold trials the dog did not indicate on an area where scat had been placed for 2 days and then removed 24 h before the trial. Based on information from professional industry trainers, this result is likely to be due to successfully setting odour concentration thresholds in training, rather than a limit of the dog's ability to detect odour (M. Dominick unpublished data). Methods used by industry professionals to train narcotics and explosives detection dogs have shown that dogs can detect odours from source loads down to 500 parts per trillion (Kafka 1997; MacKay *et al.* 2008) and support the concept that training dogs on a maximum number and combination of odours increases the dog's overall ability.

Since many variables can affect detection dog performance, this is an area that requires further investigation and is likely to be most relevant for target species where scats of lower concentrations and various states of degradation are likely to be encountered by the dog, as is the case with quolls and other wide-ranging carnivores. Importantly, statistical comparisons with other studies cannot be made since there is an absence of information in the wildlife detection dog literature as to the odour concentrations used to train wildlife scat detection dogs. Many studies mention using scats from several individuals and diets (Smith *et al.* 2003; Wasser *et al.* 2004; Long *et al.* 2007b; Vynne *et al.* 2011; Oliveira *et al.* 2012), some studies subjectively describe odour or moisture content (Vynne *et al.* 2011, 2012); however, none of the studies reviewed here objectively quantify scat weight, age, condition or odour concentration.

We recommend, where possible, the future documentation of odour thresholds used in wildlife scat detection dog training, to enable more replication and detailed comparison of survey detection rates between studies and to further knowledge on how ensure the most robust survey results. Our results reinforce recommendations in the general dog training literature that suggest that the age and condition of target scats used should be carefully considered during project design and in the evaluation stages of dog training (MacKay *et al.* 2008).

A key finding from this study was the significant positive relationship between first detection distance and search duration in the densest habitat structure type, heath (Fig. 3). This result was supported by visual observations whereby the dog appeared to traverse the scent cone more frequently and spent more time investigating depressions and clumps of vegetation, compared to open grassland where the dog followed a more direct line to the odour source. Although there was no statistically significant difference detected, there was also a trend of increasing mean search duration with increasing habitat complexity (Table 2). This result could be partly due to restricted access and the dog having to navigate and around thick clumps of vegetation and relocate the scent trail. It may also support the theory around pooling of scent in thick vegetation

(Syrotuck 1972; Snovak 2004), which as shown here may not prevent the dogs from locating the scent from a distance but could make tracing the scent cone to the source more difficult due to variations in scent concentration.

Based on our results, searches in complex vegetation should allow for greater search effort compared to relatively open vegetation. Without adjustment for the time and effort required in different vegetation types the risks of a false negative, of not detecting a scat which is present, is likely to be increased in more complex vegetation. False negatives have significant implications for conservation, if the presence of a threatened species at a site is missed when the species is present. This is particularly relevant for presence–absence data but can also dramatically affect abundance studies based on capture–recapture approaches from scat surveys combined with DNA analysis (Ruibal *et al.* 2009; Gormley *et al.* 2011; Jones 2011).

The handler must be able to identify the first signs of the dog being on-scent, and compensate for increased risk of false negatives in thicker habitats. There are many other factors that may reduce detection success in fieldwork including factors that vary per individual, such as the effects of fatigue and general work ethic where the dog may continue following verbal instructions but no longer be focused on the target odour, plus expectations and behaviour of the handler which can affect dog performance (Wasser *et al.* 2004; Lit, Schweitzer & Oberbauer 2011; Vynne *et al.* 2011). All of these factors can be difficult to detect and may be more likely in complex vegetation where our results suggest greater search effort is required. Our findings reaffirm that expert handlers with 'an exceptional constitution for field research' (MacKay *et al.* 2008) are critical for any scat detection dog surveys, since inexperienced handlers can reduce search efficiency and reduce the reliability of results (Vynne *et al.* 2011).

Aside from the effects of vegetation structure on detection dog performance, and handler expertise considerations, land managers should be aware that there are many other variables to consider to ensure robust survey results, both in dog training and survey design. In this case temperature, humidity and wind speed did not significantly affect results which concurs with findings by Long *et al.* (2007b), but other studies identified environmental variables as important particularly rainfall which is expected to increase rates of degradation and removal of scats (Reed *et al.* 2011). Other factors to consider include the biology and status of the target species to be surveyed, the suitability of the dog, availability of scent/scat for training, terrain of the study site, and handler behaviour (Gutzwiller 1990; Thesen, Steen & Døving 1993; Long *et al.* 2007b; MacKay *et al.* 2008; Lit, Schweitzer & Oberbauer 2011; Oliveira *et al.* 2012). Thus, all surveys must be adapted to site-specific and species-specific variables both temporally and spatially, and the suitability of detection dogs whether alone or in combination with other methods should be thoroughly assessed (Woollett (Smith), Hurt & Richards (2014).

The use of only one dog is an important consideration in interpreting results for this study. However, as documented here, the dog completed rigorous training and evaluation prior to the research and was proven to maintain its work ethic by successfully locating all scats in 120 searches. Considering the high level of replication in searches across habitats in both summer and winter conditions, we anticipate that our results give a sound indication of the effect of vegetation structure on detection dog performance. We recommend further studies on this subject and based on the literature to date would expect that the addition of more dogs and more sites would most likely create variation in overall scat detection success rates and first detection distances, based on individual dog behaviour, scat type and condition and environmental variables. However, we would not expect further trials to change the significance of the results of this study in terms of the relative impact of vegetation structure on dog performance.

For the purposes of improving wildlife conservation outcomes, our results suggest that with due diligence in training, and adjustment for longer search effort in more complex habitats, there are few limitations to the type of vegetation and conditions that wildlife scat detection dogs can effectively work in. Our findings add support to *in situ* field studies that have indicated the suitability of wildlife detection dogs for finding cryptic species that are otherwise difficult to survey by more traditional methods.

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Data accessibility

The data used in analysis and descriptors of condition and characteristics of scats used are available at Figshare http://dx.doi.org/10.6084/m9.figshare.1333621; http://dx.doi.org/10.6084/m9.figshare.1333625

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