Conservation detection dogs: A critical review of efficacy and methodology

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Abstract

1. Conservation detection dogs (CDD) use their exceptional olfactory abilities to assist a range of conservation projects. CDD are generally quicker, can cover wider areas, and find more samples than humans and other analytical tools. However, their efficacy varies between studies; methodological standardisation in the field is lacking. Considering the cost of deploying a CDD team and the limited financial resources within conservation, it is vital that their performance is quantified and reliable. This review aims to summarise what is currently known about the use of detection dogs in conservation and elucidate which factors affect efficacy. 2. We describe the efficacy of CDD across species and situational contexts like training and field work. Reported sensitivities (i.e., proportion of target samples found out of total available) ranged from 23.8% to 100% and precision rates (i.e., proportion of alerts that are true positives) from 28% to 100%. CDD are consistently shown to be better than other techniques, but performance varies substantially across the literature. There is no consistent difference in efficacy between training, testing, and field work, hence we need to understand the factors affecting this. 3. We highlight the key variables that alter CDD performance. External effects include target odour, training methods, sample management, search methodology and environment, and the CDD handler. Internal effects include dog breed, personality, diet, age, and health. Unfortunately, much of the research fails to provide adequate information on the dogs, handlers, training, experience, and samples. This results in an inability to determine precisely why an individual study has high or low efficacy. 4. It is clear that CDD can be applied to possibly limitless scenarios but moving forward researchers must provide more consistent and detailed methodologies so that comparisons can be conducted, results are more easily replicated, and progress can be made in standardising CDD work.

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Abstract

1. Conservation detection dogs (CDD) use their exceptional olfactory abilities to assist a wide range of conservation projects through the detection of a target specimens or species. CDD are generally quicker, can

cover wider areas, and find more samples than humans and other analytical tools. However, their efficacy varies between studies; methodological and procedural standardisation in the field is lacking. Considering the cost of deploying a CDD team and the limited financial resources within conservation, it is vital that their performance is quantified and reliable. This review aims to summarise what is currently known about the use of scent detection dogs in conservation and elucidate which factors affect efficacy.

2. We describe the efficacy of CDD across species and situational contexts like training and field work. Reported sensitivities (i.e., proportion of target samples found out of total available) ranged from 23.8% to 100% and precision rates (i.e., proportion of alerts that are true positives) from 28% to 100%. CDD are consistently shown to be better than other techniques, but performance varies substantially across the literature. There is no consistent difference in efficacy between training, testing, and field work, hence we need to understand the factors affecting this.

3. We highlight the key variables that can alter CDD performance. External effects include target odour, training methods, sample management, search methodology and environment, and the CDD handler. Internal effects include dog breed, personality, diet, age, and health. Unfortunately, much of the research fails to provide adequate information on the dogs, handlers, training, experience, and samples. This results in an inability to determine precisely why an individual study has high or low efficacy.

4. It is clear that CDD can be effective and applied to possibly limitless conservation scenarios but moving forward researchers must provide more consistent and detailed methodologies so that comparisons can be conducted, results are more easily replicated, and progress can be made in standardising CDD work.

Keywords : Search Dog; Sniffing Dog; Ecology Dog; Efficacy; Methodology; Standardisation; Conservation

Introduction

Domestic dogs (*Canis lupus familiaris*) have worked alongside humans for thousands of years, primarily used for hunting, guarding, and even forensic work by the ancient Greeks . Even now, dogs support humans by assisting those with disabilities, herding livestock in agriculture, providing protection in law enforcement and military, and utilising their sense of smell to find a vast range of substances . Dogs have searched for numerous targets including accelerants, hazardous chemicals, explosives, illegal drugs, disease in humans like cancers, diabetes and epilepsy, live humans, cadavers, and more . Within canine scent work, one of the most up and coming areas is that of conservation.

Dogs began working in conservation in the 1890's in New Zealand when they supported efforts to translocate kiwis and kakapos away from areas inhabited by invasive predators . Since then, there has been an almost unlimited scope to their application. Conservation detection dogs (CDD) can perform a variety of tasks like searching for live or dead specimens, nests or burrows, and residual scent from hair or urine . Additionally, scat surveys have been used for indicating animal presence particularly by using DNA analytical techniques like barcoding (i.e., species identification) and profiling (i.e., identification of an individual organism) located scats, especially when the scat of different animals is visually indistinguishable . CDD use has been documented in 62 countries across over 480 biological species including terrestrial, avian, and aquatic mammals, birds, reptiles, amphibians, insects, molluscs, fungi, bacteria, and invasive plants . Seemingly, scent detection dogs have "limitless potential" and their application is restricted only by the "human imagination" . They are invaluable, especially during a time when biodiversity is deeply threatened and the risk of extinction faces many species .

Given that most animals have olfactory capabilities for navigation and communication , why are dogs used most frequently for conservation detection work rather than other species? A key factor is the sheer capacity of canine olfaction. Dogs have up to 250 million olfactory receptors, depending on breed, in comparison to five million in humans and can detect odours at concentrations as low as one part per trillion whereas analytical instruments are restricted to parts per billion . This is due to the unique anatomy of canine nasal organs and brain . However, rats, insects, and pigs can also be trained to perform scent discrimination like CDD , so why are these species used less frequently?

For conservation work, trainability and capability in the field are required in addition to olfactory acuity . Canine domestication means that the species has been selected for sociability, motivation, and flexibility of learning ; psychological traits necessary for conducting complex scent work alongside humans. Furthermore, most conservation work takes place outdoors for several hours in varied weather, topographical, and vegetation conditions, meaning CDD must be able to traverse great distances, over extended periods of time, whilst manoeuvring through obstacles. As such, specific physical features are sought when selecting a dog: stamina, agility, and resilience to temperature to name a few . These are characteristics seen in many dogs that are rarely found in smaller or less domesticated species.

CDD have been highly beneficial to conservation outcomes. Their use is non-invasive which protects environmental and wildlife welfare and is preferable to capture-recapture methods . Across many circumstances, CDD are faster, can find more samples, and cover greater distances during a survey than other methods . For example, found that when comparing humans and CDD during searches for bat carcasses at wind turbine sites, CDD took on average 40 minutes to conduct a search versus humans taking 2 hours and 46 minutes and CDD found 75% of targets versus humans finding 20%. Furthermore, using CDD can reduce sampling bias as they do not rely on visual information to find targets the way methods like human surveys and camera-trapping does. Therefore, CDD are more capable of finding obscured samples and those in visually less obvious places . Additionally, CDD can play the role of ambassador for conservation work through people's affinity towards dogs .

However, like any detection tool, disadvantages must also be considered. CDD teams are expensive both in terms of time and money. It takes months, if not years, to train a CDD and its handler along with the monetary cost of training and maintaining the dog through transport, housing, food, etc. . Acquiring samples for training can be difficult both practically and legally depending on whether the target species is elusive, endangered, or invasive . Moreover, despite generally high efficacy rates, substantial variation occurs which brings CDD reliability into question. Indeed, modern guidelines for conservation methods, such as 'What Works in Conservation 2021' by along with governmental protocols for target species searches , do not include CDD despite their widespread use, which may be indicative of the concerns around their efficacy. Given that conservation suffers from underfunding , the tool used for a project must be worth the cost.

Hence this review aims to answer the questions how, why, and to what extent does efficacy vary, as these must be understood to achieve the best results possible when using CDD. To do this, all available CDD studies were searched for (n=67) and analysed in light of these questions. A major difficulty facing CDD work is a lack of standardisation across the field . Although efforts to standardise procedures for the use of scent detection dogs in general have been made , they have not included the specifics of CDD work. At present in CDD literature, terminology for analytical measures is inconsistent , sample sizes are small leading to low statistical power , up to 70% of CDD studies report no training details, and almost 25% are considered poor quality . All these factors together greatly harm the field's reliability and replicability, which is key to verifying results and improving future research. By assessing efficacy and methodology, issues in the literature can be highlighted, thereby increasing understanding of best practice. In this review, the efficacy of CDD will be investigated across training, testing, and operational searches and when searching for different target species. Once efficacy rates have been established, the factors affecting efficacy will be discussed along with how methodological problems may be contributing.

Efficacy Rates Across Contexts

When assessing the efficacy of CDD, one must be consistent in which measures are considered. However, it can be unclear what a study is measuring and terms like 'detection rates' may be used without stating what they quantify regarding the search and dog performance . recommend sensitivity (i.e., proportion of target samples found out of total available), also known as 'accuracy', and precision (i.e., proportion of alerts that are true positives), also known as 'reliability' or 'predictive positive value', as measures to be used for evaluating CDD performance. Sensitivity can investigate performance during training and testing which can then help predict the probability of detection during operational searches, as sensitivity in the field is difficult to ascertain without estimating the total number of targets in an area often using techniques with high margins of error like playback . Precision aids in determining the ability of the CDD to distinguish and discriminate the target scent from other odours. propose measuring sensitivity and 'specificity' (i.e., proportion of non-alerts that are true negatives) in tandem as key to scent detection work. However, they also acknowledge that specificity is often challenging to accurately measure due to the limitless number of distractor scents that may be available during field trials or operational searches, as well as the difficulty of ascertaining that the target scent is completely absent in a natural environment. As such for this review, sensitivity and precision will be the measures of focus (see Table 1).

In controlled training and testing trials in CDD literature, the ability to find present targets accurately appears to vary greatly. For insects like beetles, bumble bees, and stonefly, reported sensitivity has ranged from 55% to 100% with the use of targets like nest material, infested wood, or larvae . For plant species, rates were high with 81% to 100% sensitivity and 85% to 100% precision . Work with reptiles and amphibians reported rates of between 62% to 100% for sensitivity and 50% to 100% for precision . CDD detecting carcasses of birds and bats on windfarms were reported to show sensitivities between 71% and 100% . Searching for bird species through scat, carcasses, or eggs has resulted in sensitivity rates between 66.7% and 100% with precision reported between 50% to 100% . However, the study by , where dogs searched for rock ptarmigan (*Lagopus muta*) scat in lab conditions, had three dogs out of four perform no better than chance and none of the dogs or handlers had any previous experience of training for CDD work.

Mammals are by far the most common animals searched for in CDD work. For small mammals, sensitivity in training and testing contexts ranges from as low as 29% to as high as 100% with 44% to 100% precision . Regarding the 29% sensitivity in , this was during a search for both natural bat roosts and suspended bags of guano where guano was the original trained target. This could have caused the CDD to have a preference for the guano samples (i.e., ono which they had been imprinted and trained) over the bat roosts which were novel. Indeed, sensitivity was 79% on guano bags alone, and 77% when only searching for bat roosts. The concepts of using different samples in training versus testing, generalisation of CDD to non-trained targets, and the effects of odour concentration in search performance are elaborated on further in the Training section.

For larger mammals, sensitivity rates during training and testing of between 23.8% for sheep remains and 93.3% for cheetah scat occurred with demonstrating 100% precision on cheetah scat. Although 23.8% sensitivity for CDD seems low, this was compared to 2.5% sensitivity of human searchers looking for the same carcasses . Improvements in detection of even small proportions can be hugely beneficial as conservation projects often rely on methods with overall low detection rates . These examples demonstrate how there appears to be little pattern regarding the target species when it comes to success during training and testing except for greater variation with mammal targets which could be due to a few things: an inherent issue with the target odours, the quality of the study, or the simply greater number of papers in that area (i.e., out of 67 studies reviewed: 44 on mammals, eight on reptiles, seven on birds with three of these overlapping with mammal studies, seven on invertebrates, three on plants, one on amphibian (see Table 1)).

CDD efficacy should be evaluated during training and testing rather than waiting until operational searches to assess performance, however, many published studies simply investigate whether CDD can discriminate the target odour in a simple controlled trial and do not progress to testing the CDD in a field environment under operational conditions. Indeed, of the 67 studies examined in this review, 42% focus only on training and testing, 42% assess solely field performance, and 16% look at both. Of those studies that measure training and testing performance, 31% conduct their experiments in purely lab-based or controlled field conditions. Moreover, seemingly obvious statistics are sometimes stated such as strong positive correlations between CDD alerts and true positives which simply means that the dog is doing what it has been trained to do; an unsurprising result given the decades of effective scent detection work performed by canines. Is there a question at present as to whether dogs can distinguish scents? Or should the literature have accepted this as a fact by now given the longstanding history of scent detection dogs and instead be moving towards assessing field work capabilities and cementing methodological practices?

Sensitivity and precision rates within field work vary similarly to those of training and testing. Although most operational windfarm mortality searches did not report precision, achieved rates of 100% meaning all indications were true positives. Of studies assessing performance in the field, scat surveys of mammals are the most prevalent with precision rates of between 28% to 100% . Low rates of precision may occur as it can be difficult for the handler to accurately identify scats visually which can lead to them accidentally rewarding indications on non-target scats (i.e., false positives) hence reinforcing and leading to a subsequent increase in their frequency. Additionally, CDD may be correctly alerting, and DNA barcoding and profiling of the scat can be wrong due to contamination from non-target species resulting from coprophagy, urination, and contact with saliva . Furthermore, both and used CDDs which had also been trained to indicate on other targets as part of previous work. Training CDD to detect multiple species with overlapping habitats can lead to indications on all targets. As such, most of the false positives in these studies were for the previously trained targets which although classified as a false positive in the context of the study, is not a false positive in the context of the dog's training.

Unfortunately, even while assessing the ability of CDD using these set measures, not every study reports results clearly enough to make inferences. Sometimes, the number of targets found is the only measure reported due to budget constraints, being unable to verify true positives in the field (e.g., small mammals hiding or denning in inaccessible places), or simply a lack of information given within the study itself . Although these results are still valuable for comparisons with other methods and establishing species presence, without any information on error rates it cannot be determined whether the CDD is performing efficiently or if the authors are merely reporting successes and ignoring mistakes.

Despite this, it is clear that across training, testing, and operational tasks, CDD perform generally well and much better than other methods with CDD outperforming humans in 96% of the 24 studies analysed where comparisons were made as well as other analytical tools (see Table 1, Columns 3 and 4), excluding select cases: bumble bee nest detection where performance was equivalent to humans and rhinoceros scat searches where the size of the scat means CDD do not provide a distinct advantage over the standard method . However, this review has established that sensitivity and precision rates still vary by a large margin across the literature regardless of target species and search context. So, the question remains, what drives the variation in CDD efficacy?

Factors Affecting Efficacy and Methodological Issues

Training

Training is the foundation of CDD performance with several stages including imprinting, indication, search tasks, and discrimination trials. Each has the potential to affect efficacy. In the context of scent detection dogs, imprinting is the process of familiarising the CDD with the target odour and is therefore the basis for conducting CDD work . Given the sensitivity of the canine nose, sample handling during training must be conducted with care . Subtle aspects of sample preparation can lead to the dog learning that another odour is paired with the reward rather than the target itself . Papers often provide only limited information on sample storage and handling so no inference can be made on whether this affected efficacy. Indeed, issues identified regarding sample use include sample contamination with human scent or other non-target scents , poor decontamination procedures like running under hot water rather than sterilisation, dog saliva touching sample containers , and urination and/or defecation by dog during searches which poses a threat to samples and ecosystems . Furthermore, a review of bias in scent detection dog work suggests that over

20% of studies may have used the same samples across training and testing which means the dog may have learnt the specific samples rather than the target odour profile .

Given that CDD are biological systems, their olfactory function is subject to many influences. Factors linked to reductions in olfaction capability include older age, use of certain pharmaceuticals, diseases, dehydration, diet and nutrition, activity levels, temperature, and humidity and precipitation . There is simply no way to know if any internal variables have played a role in CDD efficacy, if details are missing about the dogs used and their care. Furthermore, the target odour which a CDD has been trained to find, can also affect operational search efficacy. It is unclear whether CDD search for complete odour signatures or simply components of the target odour that are present across samples and conditions . Indeed, CDD are very capable of generalising from low scent profiles during training to full specimens in the field and vice versa . However, depending on the samples used to train the dog, different errors may be made in the field. For example, if trained on extremely low concentrations of odour then CDD may alert where no visual sample can be found due to residual scent from past specimen presence. Alternatively, smaller samples may be missed if training involved only high odour concentration samples or failed to simulate any aspect of search environments through field tests and discrimination training, meaning the sample can be masked by non-target scents from wildlife or the environment.

Indication or alerting is how a CDD informs a handler that they have found a target through a distinct and consistent change in behaviour. Indications can be passive (i.e., no interaction with target) or active (i.e., body contact with target) depending on the needs of a project. Passive indication is recommended for CDD work to protect sample integrity and the safety of both the dog and wildlife . However, details and definitions of CDD indications are regularly omitted in the literature. Furthermore, some authors report changes of behaviour (COB) (i.e., notable shifts in CDD behaviour that suggest the dog has found or is tracking a scent) or partial indications as a suitable criteria for a true positive which is far more subjective and open to interpretation and unable to be standardised, thus altering efficacy rates .

Several types of search tasks can be used when training and testing CDD efficacy. Multiple-choice tasks are where the CDD has the option to investigate multiple containers and is rewarded if they alert on the correct one. These can simulate exposure to different scents available in the field and also facilitate discrimination training which is key to ensuring CDD are exposed to commonly encountered scents that should be ignored in favour of the target odour . However, they also provide more sensory interference for the dog and can cause preferences for specific container positions which makes assessing true odour discrimination and indication performance more difficult . Alternatively, yes/no or go/no-go tasks involve presenting the dog with a singular sample and rewarding if they make the correct choice in alerting or ignoring. These allow for a clear examination of where the dog may be making mistakes and whether they are making choices more liberally (i.e., more false positives) or conservatively (i.e., more false negatives . However, requiring the dog to have greater response inhibition during these tasks can make them needlessly challenging . Yes/no tasks have been recommended for CDD , but multiple-choice tasks are commonly seen in the literature. Although this method has benefits, it lacks details on dog performance which can help estimate and explain field efficacy rates.

A vital factor for ensuring efficacy results are reliable is blinding. Single blinding is done to ensure the dog is using olfaction rather than memory to find the target. But double blinding is preferred where both the handler and tester also do not know where the target is . This avoids the 'Clever Hans effect' which is an example of a horse seemingly being able to count but instead was reading human behaviour to determine when the correct response was given to receive a reward . Domesticated animals like dogs are highly skilled at reading human behaviour so even in cases where the handler or tester knows the target location and believes that efficacy will be unbiased due to the dog ignoring them for the most part , they may still unconsciously and unintentionally signal the location of the target to the CDD. Indeed, found that within ecological, evolutionary, and behavioural research, only 13.3% of studies susceptible to observer bias, reported use of blinding. IN our own analysis we found that 43% of the studies described in Table 1 used blinding, with 90% of these being double-blinding and 10% single-blinding. In all other cases, it is either unreported or more worryingly not being conducted at all.

CDD Selection and the Handler

Although CDD are used as a tool for detection, unlike analytical devices each individual dog will differ which means the selection criteria of CDD for efficacy is vital. There is little doubt that all dogs with a functioning sense of smell can detect any target that emits odour . This has been demonstrated with pet dogs and their owners that have been trained to perform scent discrimination and search tasks for novel odours similar to CDD teams . However, the breed of CDD is often considered influential in achieving the biological and psychosocial traits necessary for field work. Breeds that have been historically selected for their scent abilities are frequently used under the belief that they will inherently perform well . However individual differences can affect efficacy . Across CDD literature 128 breeds of dogs have been used and minimal differences found in suitability . Furthermore, the assumption that brachycephalic breeds will perform worse is unverified with pugs outperforming German Shepherds in scent discrimination tests , although their ability to physically endure under field conditions is untested.

More important than breed specific differences is individual personality. No standardised measures for conducting personality testing exist and it is unknown when in the dog's life cycle their ability to work can be determined . Indeed, wastage (i.e., failing training) is a major problem in breeding for CDD as the dog may be unsuited to conservation work . The essential characteristics for CDD are high play and/or food drive, high hunt drive, and low prey drive . However, the lack of quantitative measures means that most assessments of these traits rely on the subjective view of whoever chooses the dog . Moreover, dogs are biological systems and there will always be an amount of variability in performance based on countless internal and external factors throughout their development .

CDD must work as a team alongside a human handler who oversees searches, verifies finds, and reinforces training. As such, the handler also plays a crucial role in CDD outcomes. Similar to dogs, specific skills and traits must be demonstrated to be a handler: ability to direct a search by assessing where the dog has yet to investigate, understanding of animal behaviour, learning, and scent theory, attention to detail, consistency, and endurance for working in field conditions . Handlers can both positively and negatively influence dog performance. The handler's beliefs about how a search will go or the dog itself , the handler's behaviour during a search regarding possible finds, the handler's level of experience , and the handler's personality can all result in changes to the dog's behaviour . Furthermore, the bond between a CDD and handler matters for search performance . Dogs working with an unfamiliar handler, display more stress-related behaviours and have reduced search efficacy, if they will even search at all .

Search Environment and Method

Various elements of a search including the area and methods used, also play a role in efficacy. The environment is cited as a part of efficacy variation , but the results for how it can alter CDD performance are mixed . In some cases, detection rates have been seen to have a positive relationship with wind speed and a negative relationship with vegetation density . Precipitation can be a concern as it can wash away or degrade samples . In other cases, no effects for temperature, wind, humidity, or vegetation were found across studies looking for a range of targets including mammalian carnivore scats, bat and bird carcasses at windfarms, scat from different species of quoll, Hermann tortoises, cheetah scat, and bird carcasses infected with avian botulism , and it can be difficult to determine why results differ considering the wide range of climates and locations that these studies took place in.

Regarding search methods, elements that differ include searching on or off leash, operational time, and effective search distance. In terms of how dogs search alongside handlers, it is recommended that CDD perform off-leash searches to avoid handler bias and allow the dog to move freely and make independent decisions regarding following scent trails . This would mean that those who opt for line search where the dog is leashed may be inadvertently altering efficacy. However, line search must be conducted in some circumstances due to safety concerns for the dog regarding the environment or predators, dense vegetation, or safety for wildlife . Traditionally, operational searches occur in 30-minute intervals , but evidence suggests dogs may be able to work continuously for up to two hours if so trained . As such, if the dog has been conditioned poorly for operational searches, they may become demotivated or fatigued too soon into a search which could cause their efficacy to drop. Lastly, CDD have an effective operational search distance from the handler or transect lines. Despite maximum recorded search distances of up to 62.8m , handlers should have continuous visuals of the dog for safety and noticing alerts promptly. In addition, efficacy does appear to be negatively related to search distance . Therefore, the recommendation is usually less than 10m - 15m for the most efficient and productive search , although even this can vary if wind directions and speed are more optimal for the dog which can increase olfaction abilities .

Future Progress

Although there are clearly issues that need to be addressed regarding CDD use, research, and efficacy, the benefits CDD can offer to conservation in this time of worldwide ecological crisis demonstrates the necessity to improve their utilisation for the future. Conservation in general requires more funding to achieve its goals and slow down species decline . If CDD teams had more financial resources, then the budget constraints which prevent some studies from conducting efficacy assessments or deploying CDD on larger scales would be less of a problem. Furthermore, greater communication between CDD practitioners and researchers across institutions could lead to the development of empirical standards of practice with the subsequent following of standards by authors, researchers, and CDD teams globally.

Conclusion

In conclusion, there can be little doubt based on efficacy rates and comparison with other techniques, that using CDD is an effective and beneficial method for conducting a wide range of conservation work. However, the variation in CDD efficacy reported across studies signifies that substantial longstanding issues with standardisation and methodology within the field that are interfering with the understanding of and use of dogs in conservation. CDD are biological systems, meaning their performance is affected by factors including traits of the dog, training methods, experience of both the dog and handler, variables altering olfactory capabilities, and the techniques used during a search as well as the search environment itself. This review has critiqued and described ongoing difficulties facing CDD methodology, namely a lack of detail on dogs, handlers, training, experience, and study results, and contamination of samples during training and searches. The performance of CDD may vary for numerous reasons and as such a cause cannot be determined in any one case without the relevant information. The question is no longer can CDD work in conservation, but rather what can be done to achieve the highest quality performance, whilst mitigating error and bias. Highlighting these outstanding problems within the literature can enhance future efforts to standardise and improve the CDD research quality, as until then these issues will overshadow the outstanding abilities of CDD.

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Credit author statement

Beth McKeague: Conceptualisation, Methodology, Formal analysis, Investigation, Writing – Original Draft, Writing – Review & Editing, Visualisation; **Caroline Finlay:** Resources, Writing – Review & Editing, Supervision, Project administration; **Nicola Rooney:**Writing – Review & Editing, Supervision, Project administration

Conflict of Interest Statement

There was no conflict of interests for the authors in this study.

Data Archiving Statement

Given that this is a review article, no data were required to be archived.

References

Table 1. Summary of literature reviewed that investigates CDD efficacy rates.

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
	Cross River gorilla (*Gorilla gorilla diehli*) (scat)	N/A	NS	F	N/A	Human	3	NS
Asian longhorn beetle (*Anoplophora glabripennis*), Citrus longhorn beetle (*Anoplophora chinensis*)	80.4% (lab), 87.8% (controlled field), 95.3% (field)	NS	TT	Double	N/A	2	2-3 years	
Rock ptarmigan (*Lagopus muta*) (scat)	66.7% (lab)	NS	TT	Double	N/A	4 (5)	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Bat species	71%-81% (TT: field)	NS	Both	NS	Human	2	NS	
West European hedgehog (*Erinaceus europaeus*)	N/A	100%	F	N/A	Infra-red thermal camera, Spot-light survey	1	NS	
Cheetah (*Acinonyx jubatus*) (scat)	N/A	NS	F	N/A	Human	2	9 years (collective)	
Black bear (*Ursus americanus*), Grizzly bear (*Ursus arctos horribilis*), Cougar (*Puma concolor*), Grey wolf (*Canis lupus*) (scat)	N/A	98.6%	F	N/A	N/A	4	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Storm petrel (*Hydrobates pelagicus*), Manx shearwater (*Puffinus puffinus*)	86.5% (field 1), 62.6% (field 2)	67%-100% (lab 1), 50%-100% (lab 2), 97.5% (field 1)	TT	Double	N/A	2	NS	
Javan rhinoceros (*Rhinoceros sondaicus*) (scat)	N/A	NS	F	N/A	N/A	2	NS	
Tuatara (*Sphenodon punctatus*), Marlborough green gecko (*Naultinus manukanus*), Forest gecko (*Mokopirirakau granulatus*)	NS	76.9% (lab, gecko), 88.9% (lab, tuatara)	TT	Double (tester present)	N/A	13 (20)	3 days-8 years	
Desert tortoise (*Gopherus agassizii*)	91% (surface), 86% (burrow 1), 100% (burrow 2)	50% (surface), 68% (burrow 1), 69% (burrow 2)	TT	Double	Human	2	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Bat species (roosts, guano)	78.6% (controlled field, guano), 28.6% (controlled field, roost)	NS	TT	NS	Radio telemetry	2	NS	
Bobcat (*Lynx rufus*) (scat)	N/A	62.8%	F	N/A	Camera-trapping	NS	NS	
Wolf (scat)	N/A	84.38%	F	N/A	Camera-trapping, Audio recorders	3	NS	
Koala (*Phascolarctos cinereus*) (scat)	97% (field, leash) to 100% (field, off leash)	N/A	TT	Double	Human	1	NS	
Bush dog (*Speothos venaticus*)	N/A	NS	F	N/A	N/A	1	NS	
Jaguar (*Panthera onca*), Puma, Ocelot (*Leopardus pardalis*), Oncilla (*Leopardus tigrinus*) (scat)	N/A	92.4%	F	N/A	N/A	1	NS	
Bat and bird species	77.3% (field)	NS	TT	Single	Human	3	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Franklin's ground squirrel (*Poliocitellus franklinii*)	NS	44%-67% (F, indication only, 1 dog to both), 59%-83% (F, indication and behaviour change, 1 dog to both)	Both	Double	Live trapping	2	NS	
Brown tree snake (*Boiga irregularis*)	61.9% (field)	NS	TT	Double	N/A	NS	NS	
Indian mongoose (*Herpestes auropunctatus*) (scat)	92% (TT: field)	98% (TT: field), 92% (F)	Both	Double	N/A	2	>1 year	
Indian peafowl (*Pavo cristatus*) (eggs)	100% (TT: field)	NS	Both	NS	N/A	3	NS	
Jaguar (scat)	N/A	93%-100%	F	N/A	Capture, Camera-trapping	NS	NS	
Feral cat (*Felis catus*)	N/A	NS	F	N/A	Camera-trapping	2	5-7 years	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Spotted knapweed (*Centaurea stoebe*)	81% (field)	94% (field)	TT	Double	Human	3	1-6 years	
Eurasian otter (*Lutra lutra*), American mink *(Neogale vison*) (scat)	100% (lab)	85% (lab, mink) to 97% (lab, otter)	TT	Double	Human	4	NS	
Sheep (*Ovis aries*) (remains)	23.8% (TT: field)	NS	Both	NS	Human	16	NS	
Bobcat (scat)	N/A	89%-91%	F	N/A	Hair snare, Scent station, Camera-trapping	1	NS	
Golden jackal (*Canis aureus*) (scat)	N/A	73%	F	N/A	Bioacoustic stimulation	2	NS	
Cheetah (scat)	45%, 75%, 93.3% (field, dog only, human VS dog, 'effective transect area')	100% (field, human VS dog)	TT	Double (tester present)	Human	1	8 years	
	Eurasian lynx (*Lynx lynx*) (scat)	N/A	30.8%	F	N/A	Camera-trapping	2	NS

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Asian longhorn beetle	75%-88.1% (field), 85%-92.6% (lab)	NS	TT	Double	N/A	18	Several months-6 years	
Hermann tortoise (*Testudo hermanni*)	75% (field 1), 100% (field 2)	NS	TT	NS	Human	6	NS	
Eastern box turtle (*Terrapene carolina carolina*)	N/A	NS	F	N/A	Human	NS	NS	
Moose (*Alces alces*) (scat)	N/A	28%	F	N/A	N/A	2	NS	
Bumble bee species (nests)	NS	NS	TT	NS	N/A	3	NS	
Black bear, Fisher, Bobcat (scat)	N/A	NS	F	N/A	Camera-trapping, Hair snare	5	NS	
Black bear, Fisher, Bobcat (scat)	N/A	NS	F	N/A	N/A	5	NS	
Bat species	75% (field)	NS	TT	Double	Human	2	NS	
Giant bullfrog (*Pyxicephalus adspersus*)	87% (lab)	84% (lab)	TT	Double	N/A	1	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Feral cat	N/A	NS	F	N/A	Leg-hold trapping	2	NS	
Hermit beetle (*Osmoderma eremita*)	55%-84% (field)	NS	TT	Double	N/A	1	NS	
Tall Daisy (*Brachyscome diversifolia*)	100% (lab)	85%-100% (lab)	TT	Double (tester present)	N/A	8	NS	
Bumble bee species (nests)	79% (TT: controlled field)	75% (TT: controlled field)	Both	Double	Human	1	NS	
Red brocket (*Mazama americana*), Grey brocket (*Mazama gouazoubira*), Small red brocket (*Mazama Bororo*) (scat)	29% (field)	NS	TT	NS	Human	1	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Western black crested gibbon (*Nomascus concolor*), Indochinese grey langurs (*Trachypithecus crepusculus*), Stump-tailed macaques (*Macaca arctoides*) (scat)	N/A	81% (including unidentified), 92% (excluding unidentified)	F	N/A	Human	1	NS	
Bat and bird species	99% (field)	100% (field)	TT	NS	Human	1	NS	
Prey remains of Grey wolves, Black bear, Coyote (*Canis latrans*), Bobcat	N/A	NS	F	N/A	Human	3	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Mountain lion, Bobcat, Domestic cat, Red fox (*Vulpes vulpes*), Grey fox (*Urocyon cinereoargenteus*), Kit fox (*Vulpes macrotis*) (scat)	68% (field, dog 1), 77% (field, dog 2)	NS	TT	Single	N/A	2	NS	
Black-footed ferret (*Mustela nigripes*)	82.5% (field)	100% (field)	TT	Double	Spotlight survey	2	NS	
Koloa (*Anas wyvilliana*) (carcasses infected with avian botulism)	82% (field 1), 77% (field 2 timed)	NS	TT	Double	Human, All-terrain vehicle (ATV)	4	<1-4 years	
North Atlantic right whale (*Eubalaena glacialis*) (scat)	N/A	NS	F	N/A	Human	3	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Alpine stonefly (*Thaumatoperla alpina*)	100% (TT: lab)	87.5% (TT: lab)	Both	Double	N/A	4	NS	
Pyrenean brown bear (*Ursus arctos*) (scat)	N/A	100%	F	N/A	Human	1	NS	
Bat and bird species	96% (field, bats), 90% (field, birds)	NS	TT	Double	Human	NS	NS	
San Joaquin kit fox (*Vulpes macrotis mutica*) (scat)	NS	100% (F)	Both	Double	Human	4 (7)	<1-2 years	
Blunt-nosed leopard lizard (*Gambelia silus*) (scat)	N/A	82.4%	F	N/A	N/A	3	NS	
Eastern indigo snake (*Drymarchon couperi*)	91% (TT: field)	NS	Both	Double	N/A	1	NS	
Black-tailed antechinus (*Antechinus arktos*)	NS	100% (F, TT: field)	Both	N/A	Camera-trapping, live capture	1	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Bilby (*Macrotis lagotis*) (scat)	98.9% (field)	100% (field)	TT	Double	Human	1	NS	
Fisher (*Pekania pennanti*) (scat)	N/A	55.4%	F	N/A	N/A	NS	NS	
Kindcaid's Lupine (*Lupinus sulphureus* subsp. *kincaidii*)	98.8% (field)	97.5% (field)	TT	Single	N/A	3	2-8.5 years	
Maned wolf (*Chrysocyon brachyurus*), Puma, Jaguar, Giant anteater (*Myrmecophaga tridactyla*), Giant armadillo (*Priodontes maximus*) (scat)	N/A	71.1%	F	N/A	N/A	NS	NS	
Grizzly bear, Black bear (scat)	N/A	NS	F	N/A	N/A	5	NS	

Citation	Target Scent (Material)	Sensitivity (Trial Setting)	Precision (Trial Setting)	Study Type	Blinding	Compared To	No. of Dogs Used (Trained)	Operati Experie of CDD
Bumble bee species (nests)	100% (TT: controlled field)	100% (TT: controlled field)	Both	Double	N/A	1	NS	
Loggerhead sea turtle (*Caretta caretta*), Green sea turtle (*Chelonia mydas*) (eggs)	NS	100% (field 1), 98.8% (field 2)	TT	NS	N/A	1	NS	

Note. TT = Training/Testing, F = Field Work, NS = Not Stated, N/A = Not Applicable