Journal for Nature Conservation 19 (2011) 202–208

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.de/jnc

Dogs as a tool to improve bird-strike mortality estimates at wind farms

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ARTICLE INFO

Article history:
Received 9 June 2010
Received in revised form
28 November 2010
Accepted 13 January 2011

Keywords:
Avian conservation
Bird carcass searches
Conservation dogs
Detection dogs
Environmental monitoring
Field surveys

ABSTRACT

Management of avian populations near anthropogenic infrastructures, specifically wind farms, has been hampered due to biased bird fatalities estimates. Currently, these estimations are based on field surveys performed by humans, which is a method with low efficiency and accuracy. Detection dogs have been used for decades to assist humans, and their use for wildlife surveys is of increasing interest to scientists and wildlife managers. We evaluate the accuracy rates of human and dog-handler teams in real field conditions to address if dogs could be used instead of humans for bird carcass searches. Furthermore, to verify the efficiency of detection dogs (determined by the time spent to detect each bird carcass) searching for bird carcasses, we investigate the influence of several factors that affect the performance of dogs (carcass decomposition condition, distance to the target and weather conditions). Results indicate that dogs are more accurate than humans, independently of vegetation density. Furthermore, carcass decomposition condition, distances to the carcass and weather conditions significantly affect the efficiency of working dogs. The influence of these factors on detection time was minor. Results demonstrate the usefulness of dogs in field surveys to improve bird-strike mortality estimates at wind farms and other anthropogenic structures that cause bird fatalities worldwide.

Introduction

Bird fatalities caused by human-made infrastructures (e.g. high tension lines, communication towers, wind turbines) are high around the world (Erickson et al. 2005; Manville 2009). Particularly, infrastructures like wind turbines, among others, cause habitat loss and fragmentation, displacement due to disturbance, and death due to collision (Drewitt & Langston 2008). Considering that the number of wind turbines has more than doubled since 2005, and is expected to continue to increase in future years (WWEA 2009), wildlife conservation, specifically of birds and bats, is already, and will continue to be, a serious problem. Bird fatalities associated with wind turbines are more significant when endangered or protected species are involved, due to their small, fragmented and isolated populations. To understand and evaluate the real impact of these structures on the affected communities, both industry and government require and implement post-construction monitoring plans. The design of monitoring plans is usually case specific and varies between countries. The most common method to estimate bird mortality consists of carcass searches by humans, usually performed in time intervals of 7–14 days (Drewitt & Langston 2008; Lucas et al. 2004; Osborn et al. 2000). This method is time-consuming, impractical and biased, as it relies on human visual observations, which greatly depend on the skills of the observer, size of the carcass, vegetation structure and topography (Drewitt & Langston 2008; Erickson et al. 2005; Morrison 2002; Smallwood 2007). To improve mortality estimates and consequently improve conservation methods, it is necessary to develop a precise and accurate search method. Furthermore, it should be less time consuming when compared to the current methods being used.

Detection dogs (*Canis lupus familiaris* Linnaeus) have been used for decades to assist humans in a wide range of areas, from police service to hunting, and most recently have been used in wildlife surveys, specifically in conservation programs of many endangered species (Smith et al. 2001). The use of dogs has proved to be very efficient to detect species, or their traces, that are difficult to detect by humans in a wide range of environments, such as deserts (*Gopherus agassizii*), oceans (*Eubalaena glacialis*), grasslands (*Vulpes macrotis mutica*) and forests (*Ursus arctos*, *Ursus americanus*, *Martes pennanti* and *Lynx rufus*) (Cablk & Heaton 2006; Long et al. 2007a; Rolland et al. 2006; Smith et al. 2003; Wasser et al. 2004; Nussear et al. 2008), and also to identify individual siberian tigers (*Panthera tigris altaica*), evaluated in indoor trials (Kerley & Salkina 2007). Given the high accuracy of dogs, either to detect single species (Cablk & Heaton 2006; Smith et al. 2003) and individuals (Wasser et al. 2009) or to distinguish target from non target species (Long

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1617-1381/$ – see front matter
doi:10.1016/j.jnc.2011.01.002

et al. 2007a), detection dogs are now considered an important tool for ecological studies.

The use of detection dogs in conservation studies and biological surveys has increased in recent years, mainly because of their high accuracy when compared to non-invasive traditional methods (Long et al. 2007b; Smith et al. 2001; Vynne et al. 2010). However, to our knowledge, only one published study to date has evaluated the use of detection dogs to recover bat fatalities associated with wind farms (Arnett 2006). However, this preliminary evaluation did not consider the impact of different habitats and the influence of weather conditions on the efficiency of dogs.

Compared to humans, dog detection rates in conservation studies are 4–12 times higher, depending on vegetation density (Long et al. 2007a; Smith et al. 2001). Even for small carcasses, like passerines (Homan et al. 2001) and bats (Arnett 2006). This is likely explained by the dog's use of olfaction (MacKay et al. 2008; Nussear et al. 2008), whereas humans depend entirely on visual cues to detect a target. Olfaction allows canids to detect a target at large distances, since they are able to detect scent molecules at very low concentrations (Garner et al. 2001). This physiological advantage allows for the design of new field methodologies that incorporate larger sample sizes and greater coverages (Rolland et al. 2006; Silveira et al. 2009; Vynne et al. 2010). As a result, several scientists have already suggested the use of detection dogs to locate bird carcasses (Drewitt & Langston 2008; Homan et al. 2001; Manville 2009 and references therein). In order to assure the best detection rates, some studies adjusted for factors that affect the fitness and efficiency of dogs: weather conditions (e.g. wind speed, temperature, humidity); habitat characteristics (e.g. topography, vegetation density, terrain irregularities) and target scent properties (e.g. odour composition and intensity) (Arnett 2006; Cablk et al. 2008; Wasser et al. 2004).

Although weather conditions can vary considerably, they do not influence the ability of the dog to find a target (accuracy). However, weather conditions do affect the work time (efficiency) and the fitness of the dog, which prevents the achievement of consistent results (Cablk et al. 2008; Homan et al. 2001). For instance, in extreme weather conditions, dogs may fail their tasks due to, among other factors, physical failure and nasal tissue dryness (MacKay et al. 2008). Additionally, weather conditions can affect the molecular composition of the odour (Cablk et al. 2008) and its production by the target (Gutzwiller 1990). In the specific case of detection of bird carcasses, weather conditions can also affect carcass decomposition and its odour properties. It is still unknown if the changes in carcass odour properties that might occur throughout the decomposition process affect the accuracy and efficiency of detection dogs, and if the odour that the dog matches to the target (bird carcass) remains unchanged throughout carcass decomposition, which usually takes several days (Osborn et al. 2000).

An additional challenge faced in surveys of wildlife mortality is the removal of carcasses. Carcass removal rates by predators and scavengers vary among sites, habitats, seasons and bird size (Erickson et al. 2005; Homan et al. 2001). For instance, Prosser et al. (2008) obtained removal rates up to 32% (winter) and 91% (summer) four days after placement, while Kostecke et al. (2001) found that the rates of scavenging significantly increased during colder temperatures, possibly due to a lack of alternative food sources. Kostecke et al. (2001) obtained removal rates up to 40% and Osborn et al. (2000) of 37% five and seven days after placement, respectively. Despite rates being highly variable, carcass removal by predators or scavengers is extremely likely to occur in the first seven to 14 days (the monitoring frequency often used in carcass searching surveys) (Drewitt & Langston 2008; Erickson et al. 2005). Therefore, before removal or scavenging takes place, a quick recovery of carcasses is important to obtain accurate mortality estimates and thus improve wildlife conservation methods. By using detection dogs, the probability that a carcass remains undetected during a field survey and therefore might be removed before the subsequent survey is strongly reduced.

The main objective of our study was to assess the use of dogs for bird carcass searches in real field surveys. The following hypotheses were addressed: (1) dogs are more accurate than humans to detect bird carcasses under different vegetation conditions; and (2) carcass decomposition, weather conditions (temperature and wind speed) and distance to the target affects the search accuracy and efficiency of the working dog.

Materials and methods

Dog training

From April to July 2008, the Special Operations Group of the Portuguese Public Security Police (PSP) trained a handler and a detection dog (a two year-old female German shepherd) to form a dog-handler team. The techniques used were quite similar to those used to train narcotic, explosive, search and rescue, and also conservation dogs (Cablk & Heaton 2006; Smith et al. 2003; Wasser et al. 2004). The dog was selected according to specific attributes (object orientation, high drive, appropriate temperament, etc.) and was initially trained to associate the scent of a bird or bat carcass to a reward (dog toy). The handler's training consisted in dog driving, body language interpretation and assisting the dog to work with the odour source. To ensure the dog was trained to detect several avian carcass scents, rather than just a single species, the training used a variable number of 17 different bird and bat species, collected in field surveys (*Alauda arvensis* Linnaeus, *Apus apus* Linnaeus, *Buteo buteo* Linnaeus, *Columba palumbus* Linnaeus, *Coturnix coturnix* Linnaeus, *Emberiza calandra* Linnaeus, *Falco tinnunculus* Linnaeus, *Hirundo daurica* Linnaeus, *Luscinia megarhyncos* Brehm, *Motacilla alba* Linnaeus, *Passer domesticus* Linnaeus, *Phylloscopus* sp., *Pipistrellus* sp., *Saxicola torquatus* Linnaeus, *Sylvia atricapilla* Linnaeus, *Turdus merula* Linnaeus and *Tyto alba* Scopoli). Subsequent steps in the training process used a "scent line" (line of several pots) with a carcass placed in one of the pots. The dog learned the required association by the reward (toy) that was given when it located the pot with the target and performed the trained alert (stay, point and bark). The dog-handler team performed numerous field trials in a wind farm located in Serra de Candeeiros (Portugal), with carcasses of several wild species and unknown decomposition days, in order to simulate real field survey conditions. During these trials, carcasses were placed in different habitats (e.g. shrub, bush, grass, no vegetation, rocks and humanised environments) and difficulty levels (e.g. different topography, meteorological conditions, exposed/hidden carcass).

In order to improve accuracy, precision and interpretation of results, the recommendations referred by Gutzwiller (1990) were followed, together with other procedures such as periodic dog training to reinforce scent detection. Accuracy is defined as the ability of a dog to find bird carcasses and is calculated as the number of detected carcasses divided by the number of carcasses available. Accuracy thus measures the usefulness of dogs as a survey tool and can be compared with the ability of humans to find bird carcasses (Cablk & Heaton 2006). Efficiency is defined as a measure of competence of a dog to accomplish the required work, which is determined by the time spent to detect each bird carcass. Another important component to consider is reliability, which is defined by Cablk and Heaton (2006) as the number of times the dog finds the target and performs its trained alert. Consequently, reliability is a measure of the behaviour of a dog as a search tool. In this view, a false alert was considered when the dog performed the trained alert to mark non-existent target.

Search-accuracy

Search-accuracy trials of dog-handler (hereafter referred to as "dog") and human teams were tested on 12 September, 2008 in the Serra de Candeeiros wind turbine facility (Portugal). To reproduce conditions of real field surveys, we used circular plots (50 m radius; area of 0.785 ha) near 10 wind turbines. A total of 30 carcasses of *Coturnix coturnix*, with a decomposition state of three days, were randomly distributed in the defined plots. A maximum of four carcasses per plot were used with the location of each carcasses referenced by GPS (Garmin GPS 60, Olathe, KS, USA). The carcasses were distributed among three different habitats, according to vegetation structure and density, as defined by the monitoring plans in place at this facility (J. Bernardino, unpublished data). These different habitats were associated with visibility classes for humans that were performing the field survey. These visibility classes were classified from one to three, where one corresponded to a low vegetation density and regularly spaced shrubs (coverage <30%), hence providing good visibility for humans, and three corresponded to a high vegetation density dominated by shrubs (coverage >60%), and thus poor visibility. It should be noted that carcass placement, dog trials and human trials were performed independently, i.e., different tasks were always carried out by different humans at different times. While only one dog was used, the human team (hereafter referred to as "human") consisted of five technicians with experience in field surveys. The circular plots were first searched by the dog and afterwards by the human. For both dog and human, the search time for each plot was 20 min. During the dog searches, in addition to registering the number of detected carcasses, the time spent (i.e., efficiency) to detect each carcass was recorded. The dog was unleashed and was allowed to move freely during searches. Nonetheless the handler determined the search strategy based on wind direction and topography. When a bird carcass was found, the dog communicated the information to its handler via trained alert or body language. The handler then walked to the dog to verify the presence of the carcass and rewarded it upon verification. At the end of all trials, every placed carcass was verified using a GPS (Garmin GPS 60, Olathe, KS, USA) to assure that none had been removed.

Dog detection efficiency

To test the influence of carcass decomposition on the accuracy and efficiency of the dog, the following carcass decomposition conditions were used: zero; three; seven; 10; and 14 days after death. This choice was based on the periodicity of real monitoring plans (seven to 14 days) and carcass removal rates obtained from the study area, which is about 60% after seven days (J. Bernardino, unpublished data). In this view, fresh carcasses (zero days) of wild raised *Coturnix coturnix* were kept in wire cages in the field, to simulate a real decomposition process and avoid being removed by scavengers.

The field experiment to test the accuracy and efficiency of the dog was performed in five separate days, between October 26th and November 9th, 2009, in the Serra de Candeeiros wind farm (Portugal). The trials were performed in defined rectangular plots (75 m × 150 m; area of 1125 ha; hereafter referred to as search plots—SP). The SPs were defined in contiguous areas with similar topography and vegetation structure and density (scrub habitat; <30% vegetation coverage).

Using six SPs instead of one larger search area presents two advantages: it avoids potential distractions, associated with the residual scent of carcasses remaining after detection; it permits the definition of a maximum search time per area (10 min), followed by a rest period (20 min), and it allows the dog to rest and recover. These conditions provide a mean to equalise level of performance during each trial.

For each day, a total of 30 carcasses with different decomposition conditions (six carcasses of each decomposition condition) were randomly distributed along six SP (2–7 carcasses per SP). To reduce the number of sacrificed animals, the same carcasses were replaced in the cages each day to continue the decomposition process. Therefore, the field experiment used a total of 54 carcasses, given that each carcass was reused in the following days but with a different decomposition condition.

For each detected carcass the time spent (s) and the distance from the starting point to the detected carcass (m) were measured (using a Garmin GPS 60, Olathe, KS, USA). The weather conditions were assessed at the beginning and at the end of each SP through air temperature (in °C) and wind speed (in m/s), using a hand held wind meter (Skywatch Xplorer 3, Sudbury, Suffolk, UK). The procedure taken by the handler during the search was the same as described for the searcher-accuracy experiment.

Data analysis

The results were analysed using several methods. To compare search-accuracy between dog and human, we used a chi-square test. The differences in detection time for carcasses placed in different habitats were tested using a Kruskal–Wallis variance test.

The accuracy variation of the dog with different carcass decomposition conditions was analysed with a Fisher exact test. Temperature and wind speed differences between trial days were analysed with a Kruskal–Wallis variance test. To analyse the efficiency of the dog, we used generalised linear models (GLM) to fit a model with detection time as the response variable.

The significance of the four predictors analysed (carcass decomposition status, distance from starting point for each carcass search to the place of detected target, temperature, wind speed) was tested first by fitting univariate models. As we stated above, SPs were placed in a contiguous and homogeneous area regarding both topography and vegetation structure and density. Therefore no correlation structure was considered between carcasses regarding SPs, consequently all observations were assumed to be independent. The final model only included predictors with a Wald's test P value for the univariate model below 0.2 (Hosmer & Lemeshow 2000), and predictors that were not correlated with each other, as evaluated by Spearman's ρ. Model selection was carried out using AIC criterion running a backward stepwise procedure. Besides AIC criterion, goodness-of-fit evaluation also relies on the assumption that the difference between the null deviance and residual deviance approximately follows a chi-square distribution, with the same number of degrees of freedom (df) as the difference between the df of the two deviances (Faraway 2006). Accordingly, the goodness-of-fit is evaluated by the size of the residual deviance compared to its df. The determination coefficient was also calculated (r^2). As residual analysis for model diagnostics, we investigated the relationship between the linear predictor and jackknife deviance residuals, as well as the shape of a QQ plot with standardised deviance residuals. Finally, we plot Cook statistics against the standardised leverages to identify cases with high influence and/or high leverage. All statistical analysis were performed using R (R Development Core Team 2009).

Results

Search-accuracy

Of the 30 placed carcasses, four were removed before or during the study period. Therefore the study only considers 26 carcasses. While the dog detected 96% of the carcasses, the human only

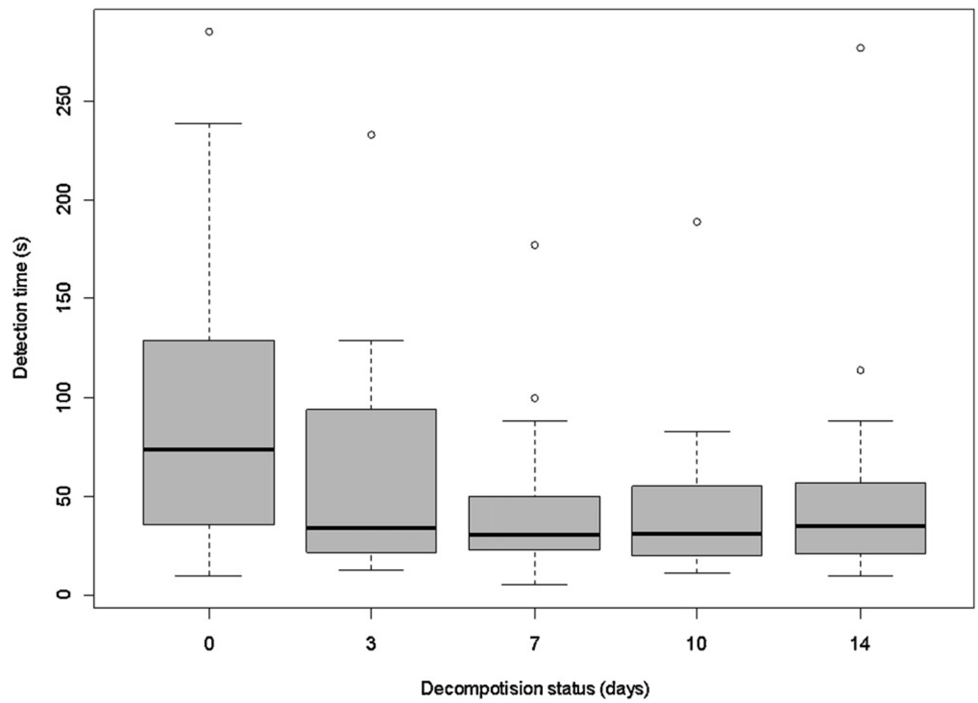

Fig. 1. Dog's detection time (s) by carcass decomposition status (days). Box plots illustrate median, interquartile range, minimum, maximum and outliers.

detected 9% of them ($\chi^2_1 = 90.49$, $P = 0.000$). The reliability of the dog was 100%, since no false alerts were performed.

The accuracy of the dog was 100% for the habitats 1 and 2, whereas for the habitat 3 was 92%, since one of the carcasses was not detected. On the other hand, human's accuracy was 20%, 7% and 10% for habitats 1, 2 and 3, respectively. The detection time of the dog (mean time ± SD) for habitats 1, 2 and 3, were 172.33 ± 254.17, 132.09 ± 100.92 and 235.91 ± 62.41 s, respectively. Despite the relatively higher detection times observed for habitat 3, the observed differences were not significant ($H = 1.32$, $P = 0.52$).

Dog detection efficiency

The accuracy of the dog during this experiment was 99% and no significant difference was observed between carcass decomposition state (Fischer exact test, df = 4, $P = 1$). Furthermore, the reliability was 100%, since no false alerts were registered.

Detection efficiency is assessed by the time spent to detect each carcass. Generally, detection time, as well as its variability, decreased with increasing carcass decomposition condition (Fig. 1). Detection times of fresh carcasses (0 days) were generally less than 150 s, while for non-fresh carcasses most of the observed results were less than 100 s.

The relationship between detection time and the other measured variables, apart from wind speed, is presented in Fig. 2. Detection time was less than 150 s for the carcasses placed apart 25–125 m from the starting point of the dog, while lower detection times were observed for shorter distances (Fig. 2A). Concerning temperature variation, the observed results could be distinguished in two groups: cold and warm (Fig. 2B). In the first group the temperature ranged from 11.6 to 16.7 °C and in the latter one ranged from 20.35 to 25.80 °C. These groups were significantly different and were associated to the day of experiment (Kruskal–Wallis: $H = 118.96$, $P = 0.000$), since warmer temperatures were registered in the first two experimental days while colder temperatures were registered in the last three days. Nevertheless, detection times observed were similar between each temperature group. With regards to wind speed, results were on average 6.16 m/s and ranged between 0.85 and 12.75 m/s. Most of the low detection times (<50 s) were associated to medium wind speeds, from 4 to 8 m/s, but, unlike temperature, no differences could be observed between groups (data not shown).

To analyse the efficiency of the dog in a comprehensive approach, considering all analysed factors that could potentially influence detection time, we developed a gamma GLM (Table 1).

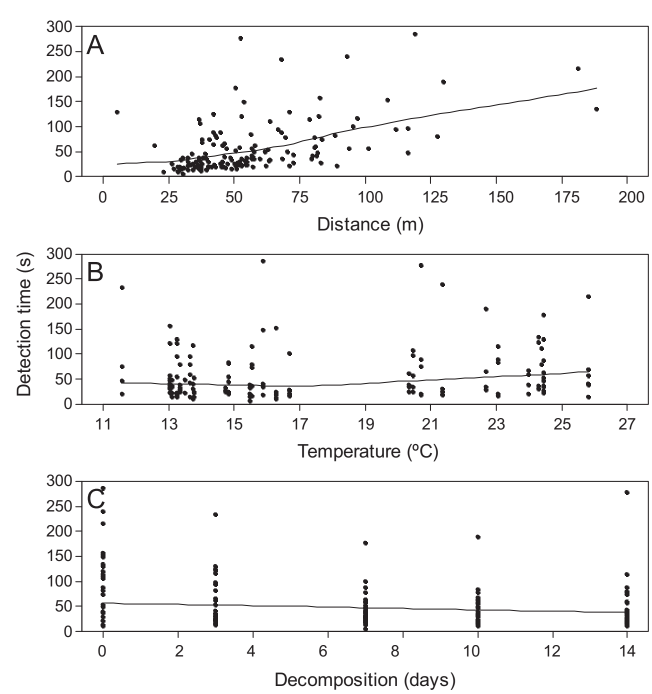

Fig. 2. Relation between dog's detection time (s) and (A) distance to detected carcass (m), (B) temperature (°C) and (C) carcass decomposition condition (days), and the predicted detection time by the final model (line) in relation to respective variable.

Table 1
Gamma General Linear Model fitted on carcass detection time and statistic test statistic value and corresponding *P* value. Positive estimate values indicate that the variable affects detection time positively while negative values indicate an inverse effect.

Variable	Estimate	Standard error	*t* value	*P*
Constant	1.826	0.622	2.937	0.004
Decomposition	−0.010	0.041	−2.426	0.017
Distance	0.038	0.009	4.388	0.000
Temperature	0.073	0.032	2.237	0.027
Decomposition × temperature	0.004	0.002	1.618	0.108
Distance × temperature	−0.001	0.000	−2.730	0.007

All tested predictors, namely decomposition time, distance to the carcass, temperature and wind speed, were important to predict detection time, since Wald's tests for univariate models were all significant ($P < 0.05$). To avoid the inclusion of predictors highly correlated, Spearman's ρ coefficients between variables were calculated. Significant correlations were only observed between temperature and wind speed ($\rho = -0.426$, $P = 0.000$), therefore, due to this strong and significant correlation, only temperature was included in the final model. This decision was also based on the empirical knowledge of how these predictors influence detection time (see "Discussion" section). Table 1 presents the main effects associated to the predictors that significantly influence detection time, which are considered in the final model. In the same table, we also present the interaction effects between decomposition and temperature, and between distance and temperature. The model developed has a considerable r^2 (59%), with no lack of fit as evidenced by the residual deviance comparison to its df ($P = 1$). Even with the achieved goodness-of-fit and the significance of each variable, the coefficient estimates of the considered variables were low (Table 1). The model fits the field results (Fig. 2), and predicts that detection time increases with increasing distance to the carcass and temperature, and decreases with increasing decomposition days of the carcass. The model outputs predict the best detection times are obtained at temperatures near 17 °C, with slight decreases on detection efficiency at lower and higher temperatures. According to the trend line produced by the model, greater distances to the detected carcass increase detection time. On the other hand, decomposition status has no major influence.

Discussion

Detection accuracy

Several studies have pointed out human difficulties to locate bird carcasses and its high detection variability due to several factors, such as topography, vegetation and carcass size (Drewitt & Langston 2008; Erickson et al. 2005; Morrison 2002). Despite these difficulties, the field surveys to evaluate bird mortality associated with wind farms, and other anthropogenic infrastructures, are still based on field surveys performed by humans. The major findings of this study demonstrate that dogs can locate bird carcasses in real field conditions with higher accuracy than humans, as observed by Homan et al. (2001) and by Arnett (2006) to recover passerine and bat carcasses, respectively. Furthermore, it is verified that habitat, which greatly affects human accuracy during field surveys (Morrison 2002; Smallwood 2007), does not significantly affect the accuracy of dog. However, in habitats with dense vegetation, mainly formed by *Quercus coccifera* Linnaeus (a dense thorny leaf shrub), accuracy of the dog is relatively lower when compared with the other two habitats. For humans this vegetation could mask or hide the carcass and consequently impair carcass detection, while for dogs the dense vegetation only complicate its movements without significantly compromising detection accuracy. Furthermore, dense vegetation can prevent the odour plume dispersion (MacKay et al. 2008), which could explain the slight differences observed between different habitats. Beyond vegetation density, another factor that may compromise detection accuracy is cold temperatures (Gutzwiller 1990). Cold temperatures inhibit odour production and as a result affect detection accuracy. Although freezing conditions are not usually observed in Portugal near wind farms, it is a factor that must be considered in other countries. For the range of temperatures, wind speed and carcass decomposition conditions analysed in this study, we observed no significant differences in the accuracy of the dog. However, since it is known that fresh carcasses have lower odour intensity, it remains to analyse if the combination of fresh carcasses with freezing conditions of precipitation significantly affects detection accuracy. If future studies, under extreme weather conditions, identify different results for accuracy rates, it will be necessary to develop a correction factor to apply to the results predicted by the model.

Overall, during both experiments, the trained dog proved to be very accurate and reliable. Only one carcass was left undetected and no other natural elements were marked (e.g. lizards, mammal scats, plants). In other words, no false alerts were observed. This study supports the tested hypothesis that properly trained dogs are more accurate than humans to detect bird carcasses under different vegetation conditions. Furthermore, it also shows that weather conditions, distance to target, and carcass decomposition conditions, do not affect the accuracy of the dog. Therefore, we reject the hypothesis that these variables affect the accuracy of the dog.

Detection efficiency

Since accuracy is proven to be very high (Cablk & Heaton 2006; Manville 2009; Smith et al. 2001, 2003; Vynne et al. 2010), the next issue to evaluate and improve in detection dogs should be detection efficiency, evaluated though detection time (Homan et al. 2001). To our knowledge, the efficiency of dogs in conservation studies has only been studied by Rolland et al. (2006) for North Atlantic right whales fecal sampling in the marine environment. For this study, the efficiency of the dog is evaluated together with most factors that could potentially affect it (carcass decomposition, distance to carcass and weather conditions). The observed detection times are generally lower than 60 s, and detection times are only higher for fresh carcasses, reaching sometimes 240 s. Time variation is mostly affected by distance to the carcass, air temperature and carcass decomposition condition, thus supporting the tested hypothesis that these variables affect the search efficiency of dogs. These results were statistically significant. However, the influence of these factors on detection time was reflected in a reduced time scale (s). This result probably means that detection time is somehow independent of the measured variables and the dog was always efficient. Apart from humidity, this study analyses all variables that are usually referred to influence the performance of dogs (Gutzwiller 1990; Homan et al. 2001; MacKay et al. 2008). Furthermore, the study considers humidity to be correlated to the measured atmospheric variables (such as temperature and wind speed), and consequently is excluded from the final model. The developed model confirms the influence of temperature on detection time, and the slightly greater influence of warmer than colder temperatures. Warmer temperatures affect the fitness of dogs (Homan et al. 2001; MacKay et al. 2008) and inhibit odour production (Cablk et al. 2008; Gutzwiller 1990), delaying carcass detection. The range of temperatures during the field tests was not extremely high. However, the influence of temperature in the efficiency of dogs is confirmed, even though affecting the results only in a reduced time scale (s). The study also considers wind speed, which affects odour plume dispersal, and as a result the detection efficiency of dogs (MacKay et al. 2008). However, when the model is considered, we chose temperature instead of wind speed because the latter mainly affects odour dispersal, while the former has a broader range of effects. Specifically, temperature affects the fitness of the dog and its odour detection capacity. Increasing temperatures promote weariness of the dog, which can reduce its efficiency, and nasal tissue dryness, which can potentially decrease its ability to smell (MacKay et al. 2008). Tissue dryness is an important factor to take into account when considering areas where climate is characterised by dry and hot summers (e.g. Mediterranean climate). Furthermore, temperature can also affect odour intensity of the carcass, since extreme temperatures can change bacterial action and thus alter scent production (Gutzwiller 1990). Concerning carcass decomposition, the difference in detection results between fresh and decomposed carcass is probably related to training of the dog and/or intensity of odour production by the carcass during decomposition process. During the training process, several carcasses were presented to the dog with unknown decomposition days, but none of them was fresh. As a result, the dog learned to match an odour regardless of the species and decomposition condition, but did not learn to detect the odour properties of a fresh carcass, which might have a different molecular composition from a more decomposed one. Otherwise, the carcasses could have the same odour properties but different intensity throughout decomposition process. Consequently, the odour of fresh carcasses may be not only less intense but also different in chemical composition, which could explain the reduction in the efficiency of the dog detecting fresh carcasses.

The variable with the strongest influence in the detection time is distance to the carcass. Longer distances are associated to higher detection times. This knowledge, when combined with search areas with adapted size, could improve detection efficiency of working dogs during real field surveys. Since weather condition's variation can hardly differentiate from distance to the carcass, the management of search areas is the only factor that can be controlled to improve efficiency.

Application of dogs in bird collision assessments

Results here presented support the application of dogs in field surveys for carcass searches, since its accuracy is far greater than the accuracy of humans. Although the use of dogs in field surveys does not prevent the removal of carcasses by predators, a common problem in bird collision assessments, as previously noted in this study, it still improves the actual methods to estimate bird and bat mortality. Even though with the use of dogs more accurate results are obtained, one could argue the higher costs of dogs *versus* human surveys (Long et al. 2007b). This study used five technicians for the human team during the search-accuracy trials; however, in normal collision assessments, only one technician is needed to perform the task. Therefore, collision assessments made by dogs need one dog and one technician, which has higher costs. Nevertheless, as the time spent during searches can be reduced if performed by dogs, overall costs may be lower, as dogs can be perform searches in larger areas without requiring more time (Silveira et al. 2009; Vynne et al. 2010). Arnett (2006) and Homan et al. (2001) used dogs with low training costs and achieved nearly the same accuracy. However, it is our belief that a rigorous training methodology guarantees accurate results, regardless the environmental factors that may affect poorly trained dogs' work. Furthermore, as discussed by Long et al. (2007b), the accuracy and effectiveness of each method is significantly different and should be considered when comparing costs.

Conclusions

Increasingly, conservationists must be ready to employ more effective methods to be successful on wildlife conservation. To this end, accurate data is essential to support ecologists and managers in the management of wildlife populations. The results of the present study support the use of detection dogs to provide a search mechanism unparalleled in its accuracy and efficiency. Although this study has been conducted in a wind farm, the use of detection dogs for carcass search can also be applied in other areas where the mortality of birds and bats also occur (e.g. power lines, fences, roads, etc.), and where a more accurate and efficient search method is also needed (Drewitt & Langston 2008; Erickson et al. 2005).

Future research should focus on the following areas: training methodologies concerning different species and carcass decomposition conditions, to ensure that dogs will efficiently detect any bird or bat species independently of its decomposition condition; selection criteria of dog breeds, to understand which breeds are more suitable for this kind of search; and, development of a certification process to progress from experimental trials to standard recognition of dogs as a sampling tool, as referred by Arnett (2006) and Cablk and Heaton (2006). The certification process should be ongoing, possibly having regular panels assessing the scope (e.g. carcass detection, wildlife surveys) and the breadth of search skills (e.g. terrain topography, vegetation cover, and meteorological conditions). The panels should consider the characteristics of the sites of concern where the working dog will be used. The certification process for dogs searching for bird corpses associated with vertical collision hazards should consider several key species, based on available data in each country concerning bird fatalities in the industrial sites. Likewise, the certification trials should consider different species and carcass decomposition conditions. Since it is difficult to obtain fresh corpses from wild species, the use of wild raised native bird species is encouraged.

Acknowledgements

We thank the staff from Estação Zootécnica Nacional (Paulo Dias and Luis Inácio) for dog upkeep. We also thank the Grupo Operacional Cinotécnico – Unidade Especial (PSP) for initial dog training, namely Fernando Pacheco, Amilcar Santos and Artur Lemos, and also to IBERWIND for making space available at the wind farm. We offer special recognition to Joana Bernardino, Gil Penha-Lopes and Sergio Loureiro for comments and English revisions on the manuscript, to several anonymous reviewers for their suggestions and comments, and to all Bio3 team for help and support during the study period.

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