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Wind Energy and Wildlife Conservation

Effectiveness of Search Dogs Compared With Human Observers in Locating Bat Carcasses at Wind-Turbine Sites: A Blinded Randomized Trial

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ABSTRACT With the expansion of wind-energy generation, there is a growing need to develop accurate and efficient methods to detect bat casualties resulting from turbine collision and barotrauma. We conducted a formal blinded trial comparing the abilities of search dogs and human observers to locate bat carcasses. Dogs located 73% (46/63) of bats, whereas humans found 20% (12/60). We therefore recommend search dogs as an effective means of monitoring bat fatalities, particularly when a high degree of search accuracy is important. This includes surveys for rare species, or cases where searches are limited in extent or duration, because the application of correction factors is problematic where very few or no casualties are found. The dogs averaged 40 min to complete a survey, which was <25% of the time taken by humans. At large sites, the high initial set-up costs for search dogs can therefore be offset by the increased number of surveys that can be conducted within a given time. However, care must be taken with the selection and training of the dogs and handlers to produce consistent results. To allow fatality rates to be estimated from the number of casualties located, it is essential that assessments of the accuracy of the dog–handler team are made at each site. © 2013 The Wildlife Society.

KEY WORDS bat, carcass, casualty, conservation, scent, search dog, turbine, wind energy.

Wind-energy generation is undergoing a rapid global expansion and currently is the fastest growing sector of the renewable energy market. Unfortunately wind turbines, whilst being a relatively "clean" method of energy production, can present a threat to wildlife. Collisions by birds, particularly raptors, have been widely reported (Lucas et al. 2004, Drewitt and Langstone 2008). More recently, the risk to bats, both from direct impact and from barotrauma has been highlighted (Kunz et al. 2007, Rydell et al. 2010). However, evidence currently available for bats is limited. Most data are derived from anecdotal reports, usually obtained incidentally during walking transect surveys for bird fatalities. Studies are beginning to be conducted at wind-energy installations, particularly in the United States, which do search systematically for bat casualties, attempt to identify risk factors for collisions (Barclay et al. 2007, Smallwood and Karas 2010), and test potential mitigation techniques (Baerwald et al. 2009, Arnett et al. 2011). However, most work remains unpublished, and in many countries outside the United States, few, if any, bat surveys are conducted. Given the tremendous diversity in bat species composition and abundance, even at relatively small spatial scales, there is an urgent, international need for further research to establish local risks and develop appropriate mitigation.

A major barrier to such studies is the difficulty of conducting effective surveys for bat carcasses. Most species recorded as frequent casualties at wind-energy installations are extremely small. In Europe, for example, the common pipistrelle (*Pipistrellus pipistrellus*) weighs 3.5–8 g and has a head–body length of 36–51 mm; and in North America, the little brown bat (*Myotis lucifugus*) weighs 3.1–14.4 g and has a head–body length of 79–93 mm (Schober and Grimmberger 1997). This, coupled with their cryptic coloration, makes them difficult to spot. Yet estimates of true impacts on local populations depend on accurate quantification of casualty rates. Making these estimates within reasonable confidence limits becomes increasingly problematic the closer the underlying casualty rate is to zero. Even where kill rates for bats

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are thought likely to be important, only small numbers of casualties are expected per turbine per search. Thus, if surveys of 10 turbines locate only one bat, there will be considerable uncertainty about the true casualty rate if the survey method is known to locate only 20% of carcasses: finding just one additional bat would double the estimate of mean fatality rates. If no carcasses at all are found, interpretation is problematic: even if observer efficiency is known to be poor, or only a low proportion of the site could be surveyed, a zero count cannot be multiplied by an appropriate correction factor. The estimate therefore remains at zero with potentially important consequences for the future management of the site.

Prompted by the need to conduct large numbers of surveys in the tall and dense vegetative cover frequently found at British wind-energy installations, we initiated a project to assess formally the abilities of human observers and trained search dogs to find bat carcasses, and to compare their relative efficiency. Search dogs have been used effectively in wildlife research, particularly in difficult landscape conditions, to find both bird carcasses (Homan et al. 2001, Paula et al. 2011) and feces (Wasser et al. 2004, Long et al. 2007, Vynne et al. 2010). To our knowledge, only one published study has previously reported the use of search dogs to find dead bats: Arnett (2006) reported promising results from a preliminary study using two Labrador retrievers. Our study was conducted in very different terrain, and was designed to allow assessment of the variability between dog–handler teams. We predicted that the dog–handler teams would retrieve a greater proportion of bats than would human observers, and that the accuracy of dogs would increase relative to that of humans as the height and visibility class of the vegetation increased.

STUDY AREA

Our study was conducted in two geographical areas, representing typical sites for wind-energy installations in the United Kingdom. The first was an area of upland heath with variable topography in Devon (Southwest England; 50°40′N, 3°22′W). The vegetation in this area was generally tall and dense, dominated by gorse (*Ulex* spp.) and heather (*Erica tetralix* and *Calluna vulgaris*), with some areas of sedge (*Carex* spp.) and rough grassland. No wind turbines were present at this site, but the landscape characteristics and vegetative cover were similar to that found at wind-energy installations nearby. The second site was a lowland arable farm in Lincolnshire (Eastern England 53°25′N, 0°4′W), which was used for arable production. This site has 20 turbines, of which nine were randomly chosen for inclusion in the trial.

METHODS

We conducted 123 searches across 17 plots using 46 bats. All plots were searched both by a human observer and a search dog, with the order of searching (dog or human) being determined randomly. Additional searches by the second dog and/or a second human observer were conducted on some plots, again with randomization of order, to achieve the required sample size, with the statistical analysis taking account of the repeated surveys on the same plots. The searches were made in December 2010 and February 2011 within grids measuring 5,027 m^2 (equivalently, a circle of radius 40 m). We chose this distance because most previous research indicates that the majority of fatalities are found within 40 m of the turbine (Arnett et al. 2005, Brinkmann 2005). Daytime temperatures ranged from 4° C to 8° C, there was light overnight frost, and no rain during the searches.

We used two 18-month-old Labrador retrievers specifically selected for the study on the basis of their high drive to search and to play (with a ball) as a reward. They were trained for 8–12 weeks by one of us (MS), with >20 years of experience as a dog trainer and handler with the English Police force. The dog trainer then taught two novice handlers, who were familiar with pet (but not search) dogs, how to work with the dogs during 4 days of intensive training. The searches using dog–handler teams are subsequently referred to as “dogs.”

Bat carcasses were held under license from Natural England (no. 20103751). A field worker not involved in subsequent searching distributed dead bats across the grid, enabling all searches to be conducted “blind” to the location of the bats. Between 1 and 5 bats were placed on each grid, with the density determined randomly for each plot. We did not use >5 bats/plot on the grounds that such a high level of “seeding” would be unrealistic given field research elsewhere (e.g., Arnett et al. 2005, Brinkmann 2005, Rydell et al. 2010). Ten of the 17 species of bats resident in the United Kingdom were used. The species (no.) of bats were as follows: *Plecotus auritus* (7); *Pipistrellus pipistrellus* (12); *P. pygmaeus* (7); *Myotis daubentonii* (1); *M. nattereri* (3); *M. mystacenus/brandtii* (7); *Nyctalus noctula* (3); *Rhinolophus ferrumequinum* (2); *R. hipposideros* (3); *Barbastella barbastellus* (1). About two-thirds of the bats had been frozen for up to 6 months before they were used; the rest were in varying states of decay.

The dead bats were dropped from about waist height at grid points selected randomly. Care was taken to handle the specimens using disposable gloves or forceps, ensuring that human scent was not transferred to them. To allow human scent from footprints to dissipate, we left an interval of ≥1 hr, and usually overnight, between placing the bats and conducting a dog search. To minimize the impact of predator-removals, we did not leave the bats in position for >24 hr before conducting the search. Nevertheless, two of the bats searched for by dogs appeared to have been removed before the search was conducted (established by subsequent hand-searching of the site by the assistant to retrieve the bat). These searches are included in the analyses we report here to allow for the possibility that the bat was still present and the lack of retrieval was due to observation failure by the assistant. None of the results were materially different if these searches were excluded from the analyses. We scored the vegetation at each plot using methods used previously with bat surveys at wind turbines: indices of visibility were then made for the entire plot and also for the spot where the bat was placed following Arnett et al. (2005, 2011).

The human observers (ecologists) conducted their searches by walking transect lines across the plot. They searched an area about 1 m wide on each side of the transect line, meaning that the survey plot was covered by means of 2-m strips. This distance was substantially less than described elsewhere for human searches for bat carcasses, (e.g., 10-m strips by Arnett et al. [2005, 2011]; 6 m by Brinkmann [2005]), but our preliminary trials showed that the height of the vegetation on most plots prevented human observers from detecting a bat at a greater distance. We conducted the searches using dogs by allowing the dogs to "quarter" the search area, with the handler directing the dog as necessary to ensure the whole search area was covered (Fig. 1). The dogs were worked both on and off a long-line; the choice of method depended on the behavior of the dog, type of vegetation, and handler preference during a particular search. For example, line-working can be useful where a dog indicates a bat is present in an area but is having difficulty in 'homing in' on the precise location. For all dog searches, the handler took account of wind conditions to both determine the direction of the search and to estimate the likely distance over which the dog would be able to detect the carcass scent. When the dogs found the scent of the bat carcass, they would track into the scent and adopt a recognizable posture (an "indication") to show the handler the location of the bat. Dogs were able to search each grid during a single session, whereas human observers required a rest period half way through the search in order to maintain concentration.

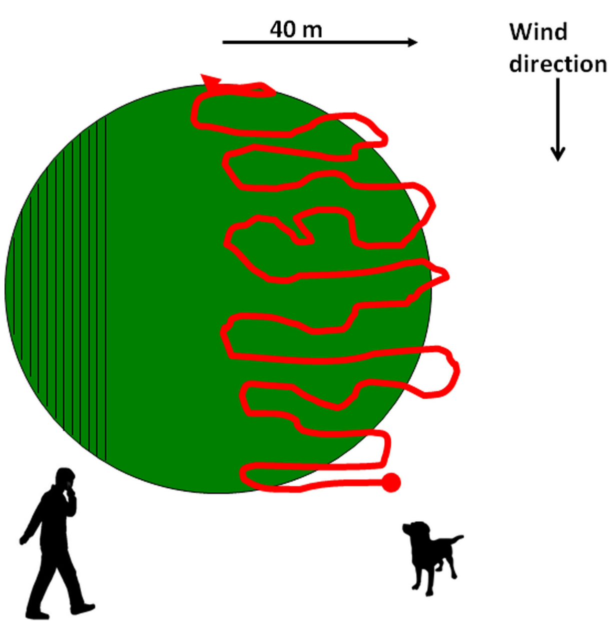

Figure 1. An example of search protocol used in Devon and Lincolnshire, England, United Kingdom, during December 2010 and February, 2011. Each human observer and dog–handler team searched the entirety of each plot (half shown here for clarity). Bat carcasses were located randomly on the plot. Transects strip for humans were 2 m wide. The exact route taken by the dog was dependent on wind strength and direction, but was directed by the handler. Dogs were permitted to "home in" when they indicated that a scent had been located.

After each search was completed, the searcher or dog handler conferred with the assistant, and each bat was scored as having been found ("located") or not. We did not move the bats until all the searches for a particular plot had been completed. For ease of comparison with others (Cablk and Heaton 2006, Paula et al. 2011), we define search accuracy as the location rate for bat carcasses (*n* found/*n* actually present), whereas search efficiency describes the time taken by dogs or humans to complete the search of each plot.

Statistical Methods

We analyzed the data using Program R (version 2.10.1; R Development Core Team 2009). To allow for the potential autocorrelations in the data resulting from repeated searches for the same bats, we built models of the probability of each search being successful (i.e., the bat was found) using a generalized mixed-modeling approach with a binomial error structure in the package LMER (Bates et al. 2011). Bat identity number (BatID) was specified as a random effect, and models were allowed to have random intercepts. We then built more complex random-intercept models, which allowed for possible non-independence, specifying plot as a random factor with BatID nested within it. We examined several fixed effects that could have affected the probability of successful retrieval: vegetation height, visibility class, time since start of project (to allow for improvement over time), and bat species. The slopes for each covariate were allowed to vary randomly given BatID (and where appropriate, BatID within plot), as was the intercept for each model. Because we were particularly interested in whether any of the variability in search outcome was due to bat species, rather than in quantifying the absolute differences between species, we also re-ran the analyses specifying species as a random factor. Interactions between searcher type and the covariates were tested, to assess whether differences between the probability of retrieval by dogs and humans depended on the covariates. We judged the importance of each variable and the alternative model structures by comparing Akaike's Information Criterion (AIC) for each model fitted, and examining the significance of changes to sequentially fitted models (estimated using likelihood-ratio tests as described by Pinheiro and Bates (2000): the estimated *P*-values will be conservative). Finally, we examined whether there was a difference between the 2 dog–handler teams using the subset of data from the dog searches. Because the data sets differed, we made no attempt to compare these models with those described previously.

RESULTS

Visibility at the upland plots was poor (Fig. 2a,b). Where bats were found, median vegetation height = 50 cm (SD = 26; classified as tall) and median ground cover = 100% (SD = 13; classified as high cover). On the farmland site, visibility was more variable (Fig. 2a,b). Where bats were found, median vegetation height = 15 cm (SD = 9), and median cover = 83% (SD = 39). Deep furrows made bare ground difficult to survey across the

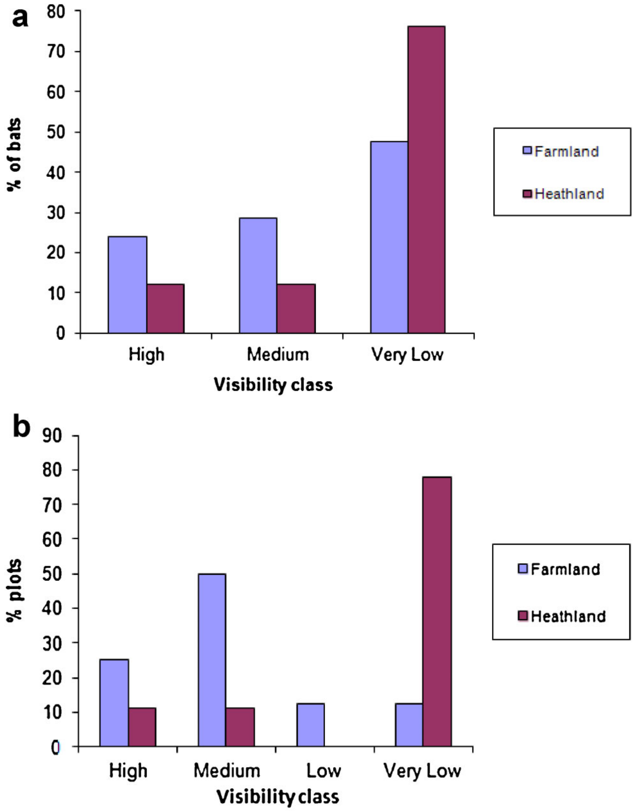

Figure 2. The percentage of bat locations falling into different visibility (a) and the proportions of search plots classified overall as belonging to different visibility classes (b) for searches conducted in Devon (heathland) and Lincolnshire (farmland), England, United Kingdom in December 2010 and February 2011.

farmland plots. All turbines had an access track and apron, and visibility in these areas was high.

Accuracy of Dogs Versus Humans

Dogs found 73% (46/63) of all trial carcasses, whereas humans found 20% (12/60). Excluding searches for bats later found to be missing, the efficiency of dogs was 75% (46/61). Differences in the probability of detection between dogs and humans remained evident after accounting for the autocorrelation between searches on the same bat (AIC for model = 134.0, effect of search type $P < 0.001$; Table 1). Adjusting for the potential grouping effect of plot, in addition to BatID, did not improve the model fit (AIC for model = 135.37, effect of plot $P = 0.439$). Inclusion of plot also did not materially affect the results of any other models, and so for simplicity, the final models adjusted for BatID only.

Dog searches were considerably more efficient than those of humans. Searches with dogs took an average of 40 min (SD = 18), whereas those conducted by ecologists took 2 hr 46 min (SD = 23). The minimum time taken for the ecologists' surveys was 2 hr 20 min at sites with low vegetation and ranged up to 3 hr 30 min in areas with high vegetation.

Factors Influencing Likelihood of Carcasses Being Found

We found no evidence of a systematic improvement overall in the likelihood of bats being found in the second trial

Table 1. Summary of generalized linear models with binomial error structures, which explored contribution of fixed effects to the probability of bats being found during searches in Devon and Lincolnshire, England, United Kingdom in December 2010 and February 2011. All models also included BatID as a random factor.

Fixed effects included in model	AIC_c	P[a]
Search type		
Search type (dog or human)	134.0	<0.001
Visibility		
Search type, visibility class for plot	129.4	0.015
Search type, visibility class, visibility class × search type	135.3	0.432
Bat species		
Search type, bat species	144.4	0.694
Search type, bat species, search type × bat species	148.7	0.164

[a] P-values for last term in model (from comparison of sequential models).

session compared with the first (AIC for model = 135.7, $P = 0.592$). Nor was there any evidence for change between the 2 sessions in the differential abilities of dogs compared with humans (AIC for model including interaction time × search type = 136.6, $P = 0.357$).

We found no difference in the probability of bats being found according to species (Table 1). Similarly, no improvement to the basic model was obtained by including bat species as a random factor in the analysis (AIC for full model = 135.97). Due to the low sample size for large bats, we made no attempt to determine whether large bats were more detectable than small ones; nor did we conduct *post hoc* species-specific comparisons. We found no evidence for an interaction between species and search type (Table 1), which indicated that, even for dogs, species of bat appeared insignificant to detection rates.

We also assessed the effect of vegetation cover on the accuracy of humans and dog searches. As the visibility class of the plot overall declined, so did the probability of locating the carcasses (Table 1; Fig. 3). We found that we obtained very similar results when we replaced the overall visibility of the plot with visibility at the precise location of the bat.

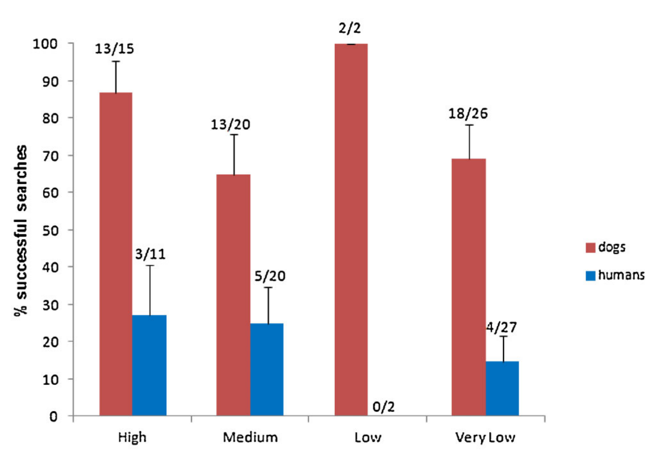

Figure 3. The percentage of successful (+SE) dog- and human-searches for bat carcasses conducted in Devon (heathland) and Lincolnshire (farmland), England, United Kingdom in December 2010 and February 2011 by the visibility class of the landscape.

Likewise, we found that using alternative classifications of visibility (Arnett et al. 2009), or simply the minimum vegetation height, made little difference to the results. The relative performance of dogs and humans did not change according to visibility category or vegetation height (Table 1).

Analysis of the subset of data from the dog searches showed that the 2 dogs had similar search abilities, and there was no evidence for differences between the handlers (dog identity $P = 0.130$; handler identity $P = 0.527$).

DISCUSSION

Search dogs are relatively expensive to buy and professionally train. Based on the dogs used for this project, and those we have trained subsequently, we estimate an inclusive cost of about US$8,000/animal, though the costs will obviously vary between countries. Search dogs also bring additional constraints to the surveillance programs, because unlike human observers, they are not readily replaceable. When used for extended periods, it is also helpful to have a specialist vehicle to help ensure the welfare of the dog (cost approx. US$3,250). Given all these costs, it is appropriate to evaluate carefully the potential benefits. In our study, dogs found 3.5 times as many bats as humans and took less than a quarter of the time to do so. If we assume an hourly labor rate for a human observer of US$25 (base rate per hour at Altamont Pass since 2006) and the average survey times observed in this project, then the saving accrued per turbine search by using a search dog is on the order of US$50 (excluding set-up costs). Equivalently, approximately twice as many turbines can be searched with dogs as with humans, given the same time and/or budget availability. In Northwest Europe, the base rate for human observers is somewhat higher (approx. US$50/hr), and the savings associated with using dogs would consequently be greater. The economic arguments for using search dogs will be particularly strong for long-term studies or those at large wind-energy installations; whereas, the incentive may be less clear if the time spent searching is small relative to other costs, such as travel time to the site.

The probability of finding each bat declined as the landscape characteristics and vegetative cover became more challenging. This was true for both dogs and humans, and, in contrast with the previous report by Arnett (2006), we did not find that the dog–human differential became any greater in more difficult conditions. This may reflect the fact that our search plots included a greater proportion of very-low visibility landscapes: searching tall, dense vegetation requires strenuous exercise and it is likely that panting, fatigue, and declining concentration influenced dogs' ability to find the targets, as has been demonstrated for search dogs in other contexts (Gazit and Terkel 2003). Handlers also had increasing difficulty in ensuring that the dogs covered the entirety of the search area in dense, tall vegetation: we suggest that future research could consider working dogs on a long leash where landscape is challenging. Finally, we noticed that where the bats fell down into pockets surrounded by tall, dense vegetation, dogs had difficulty in locating the carcass at close quarters, despite being able to detect the scent some distance away. We speculate that this resulted from the scent plume being funneled up by the vegetation and carried over the head of the dog.

Although our results show that search dogs can offer an accurate and efficient way of searching for bat carcasses, it is important to emphasize that dog searches still have their limitations (see also discussions in relation to search-dog location of scats (Wasser et al. 2004); game-birds (Gutzwiller 1990); and tortoises [*Gopherus agassizii*; Cablk and Heaton 2006]). Failure to account for these potential limitations when designing projects can result in poor success or potentially biased results. First, the ability of the dog to find a carcass depends on landscape characteristics and vegetative cover (as discussed above), weather, local topography, the concentration of the dog during that particular search, physical fitness of the dogs, and the presence of distractions within the search area (such as other dog walkers, game birds, etc.). A second important limitation is handler error. In our trials, this usually involved failure of the handler to ensure the dog covered the whole of search area or "calling off" the dog when it ran toward an area where one bat had already been found on the assumption it was returning to the first scent. It is also possible for inexperienced handlers to fail to "read" the signals given by a dog, particularly if they are searching for weak scents, and therefore remove dogs from a search area before the carcass has been located. During operational work with 4 search dogs following this trial, we found that handlers inadvertently can, over an extended period of time, encourage signaling on non-target scents. This happens where the dog has not found bats at a search site, but shows an interest in another scent (e.g., a dead shrew [Soricidae], feces). If these partial indications are rewarded, due to uncertainty from the handler about whether a bat has been found or not, then the behavior is reinforced. Bat carcasses will still be found when this happens, but the additional signaling on non-target scents means that time is wasted by the handler hand-searching for bats following the signal, thereby reducing efficiency.

Finally, the importance of careful selection of the search dog cannot be over-stated. The dogs used in our trial were specifically selected for the purpose, based on their extremely high drive for both searching and playing: many dogs were evaluated for aptitude before the dogs used in the project were selected. Similar careful searching for working dogs with the correct aptitude has been used by other ecologists who have used search dogs successfully (Reed et al. 2011; S. Wasser, University of Washington, personal communication), and follows well-established models for selecting search dogs for use in forensic investigations (Wilsson and Sundgren 1996, Rooney et al. 2004). In contrast, pet dogs that the owners have noted to be good at 'tracking' or 'retrieving' often make poor search dogs. Whilst all dogs have excellent olfactory senses and can be trained to find specific objects, most lack the drive to carry out many repetitions of the same activity (i.e., search and indicate) before obtaining a reward; indeed, the high drive of search dogs often means that they are unsuitable as family pets. It is also critical to the success of research projects that the dog not only identifies the target object, but also indicates the find reliably to its handler (Cablk and Heaton 2006) and does not touch or move the object.

We recommend that researchers conduct assessments of the accuracy of dog–handler teams in locating bat carcasses at every site they study. This will allow adjustment of fatality estimates for detection error, and site-specific evaluation of the association between vegetative cover and detectability. It is also important to consider the effect of weather conditions on search efficiency (Reed et al. 2011). During our trials, the effectiveness of the dogs was likely to be limited due to the low dissipation of scent in the prevailing cool weather temperatures. Our estimates of the difference between human observation and search dogs will therefore tend to be conservative, because the dogs rely on largely on olfactory cues, which will be negatively affected by cold; whereas, the visual cues used by humans would not have been affected. Conversely, in hot weather, rapid panting can interfere with their olfactory abilities. Wind speed and its variability may also affect detection distances.

We recommend, as have others working with search dogs in other contexts (Long et al. 2007, Reed et al. 2011), that internationally accepted operational standards are implemented to reduce the amount of variability between study teams and to ensure that data collected by different groups are comparable.

MANAGEMENT IMPLICATIONS

As recently highlighted by Korner–Nievergelt et al. (2011), there will be considerable uncertainty about mortality rates in cases where the number of carcasses found is small (they suggest, from simulation modeling, where $n < 10$). This uncertainty increases considerably as searcher accuracy declines and removal by predators increases. Dog surveys offer a practical alternative to human-based surveys provided care is taken in the selection and training of both dogs and handlers. However, it will be important to estimate the errors associated with dog searches at each site surveyed to adjust casualty rates appropriately. We suggest search dogs will be particularly useful at large sites, where the increased speed of surveys will allow a greater proportion of the site to be surveyed. We also recommend their use in locations where retrieval rates are likely to be low, whether because of difficult landscape characteristics, because logistic or financial constraints dictate that only a small number of surveys can be conducted, or because the target is a species of low abundance but of conservation concern. In these situations, retrieving no bat casualties at all would materially affect the management of the site: when a zero return is multiplied by correction factors, the estimate remains at zero. Although confidence intervals can be constructed around this zero estimate, using them to make a persuasive case for further expensive survey would be extremely challenging. We are therefore currently using search dogs in a national survey of wind-energy installations in the United Kingdom, where landscape conditions tend to be difficult and anticipated casualty rates are relatively low.

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