

African swine fever and detection dogs for wild boar carcasses

This is part of a broader study on the possibilities for deploying detection dogs to locate wild boar carcasses in the event of an outbreak of African swine fever (by Hilde Vervaecke and Manon De Meester, Odisee University of Applied Sciences, Belgium; steering committee members: Uta Kielau, Ellen Van Krunkelsven, Kristof Baert, and Arno Thomaes).



Search dogs and drones as a method for detecting wild boar carcasses:

A comparison and exploration of their
complementarity

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Search dogs as a detection method

Advantages of detection dogs: Information from the literature

The use of dogs for detection work is a method that has long been used for a variety of purposes and generally yields good results. Detection goals range from explosive detection to finding cryptic or rare animal species, with countless other examples of other goals that are not discussed here (Johnen et al., 2013). The use of search dogs to track wild animals (known as wildlife detection dogs or WDDs) has proven to be highly successful. Dogs are therefore used worldwide for more than 400 different taxa (Grimm-Seyfarth et al., 2021). Thanks to WDDs, species distribution and population density can be mapped. In addition, the use of detection dogs on faeces from the target species is particularly advantageous because these faeces can provide additional information about the individual's food intake, the type of parasites, hormone levels and possibly also DNA (DeMatteo et al., 2019; Kerley, 2010; Wasser et al., 2004). The method is efficient, cost-effective and non-invasive (Grimm-Seyfarth et al., 2021). The use of detection dogs would be more cost-effective than many other methods (Smith et al., 2001). When it comes to detecting pathogens, dogs appear to be faster and cheaper than PCR testing (Jendry et al., 2020; Wiersinga et al., 2020) and, moreover, less invasive and much more accurate (Hag-Ali et al., 2021).

This high accuracy was also demonstrated in conservation research and during species monitoring. For example, detection dogs were shown to be 98% accurate in detecting active nests of fire ants (*Solenopsis*) (Lin et al., 2011), and the yellow crazy ant (*Anoplolepis gracilipes*) was also successfully found in another study (Hoffmann et al., 2022). They also achieved 100% accuracy in detecting the San Joaquin fox (*Vulpes macrotis mutica*) (Smith et al., 2001; Smith et al., 2003) and during a study on the detection of larvae of the brown spruce longhorn beetle (*Tetropium fuscum*) (Hoffman, 2014). A sensitivity of 100% was achieved in detecting European otters (*Lutra lutra*) (Oldenburg Jr et al., 2016). The specificity is also very high. Dogs were able to distinguish bullfrogs from other frogs with a specificity of 98.6% (Matthew et al., 2021) and a specificity of 95% in detecting European otters (*Lutra lutra*) (Oldenburg Jr et al., 2016), and 93% in detecting fisher martens (*Martes pennanti*) (Long et al., 2007b). A study by Grimm-Seyfarth et al. (2019) once again emphasised the ability of dogs to distinguish between the faeces of similar species (such as the European otter and American mink). The study showed that non-experts scored no more than 72% accuracy, and experts achieved a maximum of 89% accuracy, while the four detection dogs in the study achieved 95% accuracy (Grimm-Seyfarth et al., 2019).

Using detection dogs to monitor species is a more effective method than other monitoring methods such as camera traps, scent stations, track plates and hair traps (Clare et al., 2015; Harrison, 2006; Long et al., 2007a, 2007b; Tom, 2012). Results obtained by wildlife detection dogs are less spatially biased than more traditional methods, which are fixed (Gorman & Trowbridge, 1989; Hassler et al., 2024; Long et al., 2007a, 2007b; Long et al., 2012; MacKay et al., 2008; Tom, 2012; Wasser et al., 2004). According to Grimm-Seyfarth et al. (2021), the use of dogs generally scores 90% better than the above-mentioned methods (Grimm-Seyfarth et al., 2021). Dogs also perform better than humans during searches for the target. Dogs rely on their sense of smell and not just their visual ability. For this reason, they are said to be 4 to 12 times better than humans at finding the target species (Rutter et al., 2021), with a success rate that is 30% higher (Böcker, 2016) and a time saving of 99.6% (Roda et al., 2021). In addition, the method is also less invasive for many target species because fewer people are needed, thereby reducing the threat, and because the dog can give their indications from a distance, eliminating the need to handle the target species or disturb the nest (Chambers et al., 2015; Hoyer-Tomiczek et al., 2016; Mosconi et al., 2017). Although the hourly wage for a dog team with its own dog was found to

be 40% higher than for a person without a dog, the above-mentioned advantages compensate for this price difference. A dog team with its own dog may ultimately be cheaper, because time is money, and a dog team is clearly more efficient according to the literature. It should be emphasised that this concerns dog teams with their own dogs, as the cost, training and maintenance (food, care, veterinary costs) of a dog are very high and the cost-effectiveness can be called into question (Domínguez del Valle et al., 2020; Roda et al., 2021).

An additional major advantage is that dogs are able to learn to recognise and refer to more than 40 different scents without losing specificity, and they can remember all these scents even if they have not been trained for 12 months (with the exception of one scent, occasionally). and they have been shown to need less time to complete discrimination training for each new scent they learn (Lazarowski et al., 2021; Waggoner et al., 2022). Finally, dogs are able to detect bones in addition to live animals, carcasses and faeces for ecological research purposes. This has already been proven in forensic investigations and during the detection of human remains. This is remarkable because the intensity of volatile organic fatty acids in bones differs greatly from earlier stages in the decomposition process when soft tissue is still present. For this reason, the dry stage, which contains only skeletal remains, is more difficult to detect. Nevertheless, dogs proved capable of detecting them, and although there were more false positives in the first trial, the detection rate increased by 100% after one day. This indicates that dogs not only have the ability to detect and identify very subtle scents, but can also make new connections and learn new scents in a short period of time. A prerequisite for this is that there is sufficient training material available with enough variety to carefully achieve both generalisation and discrimination (Ouimet et al., 2025). In addition, dogs are able to detect targets in densely vegetated areas with a lot of undergrowth, and this dense vegetation appears to have little influence on the dogs' accuracy. However, dense vegetation does influence the search time, as dense vegetation such as brambles is difficult to traverse. The fact that scent clouds in environments with dense vegetation are more likely to "hang" and spread less far over a distance did not prove to be as big a problem for detection dogs as initially thought, although knowledge of air movement is very important for the dog handler in order to get the most out of the search (Hassler et al., 2024; Leigh & Dominick, 2015; Osterkamp, 2020; Snovak, 2004; Syrotuck, 1972).

Just as vegetation influences the movement of odours, the weather also has an effect on this. For example, turbulence caused by heated soil on warm days can disrupt odour clouds (Chiacchia et al., 2015; Graham, 1994). Rain, fog, wind speed and direction also have a direct effect on the movement of odour particles and could therefore indirectly affect the performance of search dogs. However, it is not only the dogs' search skills that are decisive for a good result, but also the handler's knowledge of odour dispersion and the ability to adapt the search strategy accordingly (Osterkamp, 2020). The extent to which weather conditions have a negative effect therefore also depends on this and is therefore relatively minor. According to some studies, the weather has little to no effect on the dogs' performance (Hassler et al., 2024; Leigh & Dominick, 2015; Long et al., 2007a). However, it should be noted that extreme temperatures, both heat and severe frost, can be harmful to the health and well-being of dogs, and therefore naturally affect their performance (Long et al., 2007a; Reed et al., 2011; Reindl-Thompson et al., 2006). In addition, it should not be forgotten that heavy rain causes degradation of faeces, which is detrimental when this is the target (Reed et al., 2011). In general, mild temperatures, gentle winds and dry days are ideal for tracking, but these are not the only times when search dogs can be deployed or when reliable results can be obtained. Search dogs as a detection method can be used in a wide range of varied environments and weather conditions (Hassler et al., 2024; Leigh & Dominick, 2015; Osterkamp, 2020).

Advantages of detection dogs: Information from interviews conducted at TCRH Mosbach

According to the responses obtained during the interviews at TCRH Mosbach, dogs are the best choice for detection in wooded areas. Human chains searching areas encounter limitations when there is a lot of low vegetation such as brambles or bushes. Movement is more difficult, which also slows down progress. Another problem arises when the target is hidden under this dense vegetation. People often miss it. In addition, it was estimated that 10 to 80 times more people are needed than a single dog team (dog, handler and possibly a second person to communicate the coordinates of the carcasses) to search an area for wild boar carcasses. Work with rescue dogs has already shown that one dog is equivalent to 50 to 80 people in terms of detection potential (Interviews TCRH Mosbach). It is also emphasised that dogs can find small pieces of carcass that people often overlook. With proper and thorough training, detecting bones should not be a problem for a good detection dog. Although searching alongside a river in areas such as the Ardennes is a difficult task because it often constitutes difficult terrain for the dog team (both for humans and dogs), dogs are sometimes deployed on the water from a boat to pick up the scent. These dogs are specially trained for this purpose. A well-trained dog team could search 3 hectares in about 20 minutes. However, this time depends on the accessibility of the area, the condition of the handler, the number of carcasses found (it takes time to send coordinates and take photos) and whether or not the dog is searching on a leash.

(Source: TCRH Mosbach report)

Disadvantages of detection dogs: Information from the literature

A disadvantage of using dogs is that the performance of detection dogs can vary greatly and is highly dependent on the dog (and human) as an individual, the training the dogs have undergone and the knowledge and skills of the trainer and handler. The training process for detection dogs has not yet been standardised in many places, including Flanders. In addition, there is often no standardised quality test that a dog team must pass. This standardisation is necessary to guarantee quality and reduce excessive performance differences (Elliker et al., 2014; Gadbois & Reeve, 2016; Jezierski et al., 2015). It is also clear that training is extremely important. Much of what goes wrong during the actual work can be traced back to problems during training. This does not necessarily have to do with the training method or certain steps that have been skipped; many problems can also be found in the handling of training materials. Handling training materials such as samples during investigative work is a delicate matter. Cross-contamination is unacceptable and must be avoided at all costs. For this reason, it is best to work using sterile forceps to handle samples, or (not necessarily sterile) disposable gloves (PVC, latex, etc.) that only come into contact with the target scent and are discarded after contact to prevent the scent from spreading. The target odours must also be stored safely in such a way that the odour cannot spread or mix with other odours, so that the odour remains as pure as possible (Cablk & Heaton, 2006; DeMatteo et al., 2019; Gauthier et al., 2022; Johnen et al., 2013; Matthew & Relton, 2021). It should be noted that the scent diminishes as the sample ages (Matthew et al., 2021).

It is also very important that samples are unambiguous. This means that they are clear and that there is absolute certainty that they contain what is expected. When a dog is trained for biomedical odour detection, and previously PCR-tested samples are used as training material, it is very important, for example, that a sample presented to the dog as negative is indeed negative and has not been incorrectly tested beforehand (which can certainly happen). It is impossible to know what the dog is actually smelling and what you are actually rewarding in the dog's scent experience. When samples are contaminated by other scents, negative samples are contaminated with the target scent, or samples are false negative/positive, the dog may unknowingly be rewarded for imprinting incorrect scents. This

can only be noticed when further training gets stuck, many incorrect signals are made, and it becomes apparent that something is not right (Grandjean et al., 2020; Li et al., 2020; Tahamtan & Ardebili, 2020; Xiao et al., 2020). Another problem with using samples as training material is the potential lack thereof. Certainly in WDDs, the target is often quite rare, as are the samples used as target scents. Too little training material can lead to a lack of generalisation, which only really becomes apparent when the dog is deployed in practice or when new samples are introduced (Lazarowski et al., 2020). The caution with which the training samples must be handled and the implications of selecting the wrong samples or having insufficient training material can therefore be seen as a disadvantage when using detection dogs as a detection method.

In addition, there are problems that can arise during the training itself. An example of this is a degree of bias in the dog, which can result in many false positive or negative signals being given. It is therefore important to take into account the fact that dogs have good memories, learn contextually, can form habits and, as a result, may also have biases towards a possible location and the presence or absence of a target scent (Gazit et al., 2005; Martin & Pear, 2019; Williams & Johnston, 2002). For example, dogs that were always presented with one positive sample and several negative samples during training with line or circle setups will have difficulties with blank setups without a positive sample and will be more likely to give false positive indications, or in setups with multiple positive samples, give false negative indications when one positive sample has already been referred. Dogs that have only been trained with the same number of negative and positive samples will have more difficulty in practice during fieldwork and achieve lower sensitivity and specificity than dogs that have also been trained on a random number of positive and negative samples (Amundsen et al., 2014; Hackner et al., 2016). Other examples of bias in dogs during training and fieldwork stem from their ability to learn in context. For example, dogs can remember where targets were hidden in the past and may refer to these places more quickly due to the association between place and reward, with an increased chance of false positive indications. On the other hand, if a target has never been hidden in a certain place and the dog has often inspected this place without success in the past, the dog may lose interest in this place and associate the absence of reward with this place, and consequently score a false negative when something is hidden there. In addition, dogs may also perform less well in new locations, simply because the context is different from the training context. This is called the context shift effect (Bouton & Ricker, 1994; Gazit et al., 2005; Martin & Pear, 2019).

Another disadvantage of a dog's good memory during training is their ability to remember individual samples and their characteristics. This hinders generalisation and, consequently, the entire training process and its results. Dogs can easily remember at least 10 different samples and thus also remember which individual scents they have been reinforced with and which they have not, without associating the reinforcement with the generalised scent profile (Williams & Johnston, 2002). Another study showed that dogs can be taught at least 40 different scents, and that this number may be much higher (Waggoner et al., 2022). Although imprinting scents and discriminating and remembering different scent samples may involve different learning processes, it is likely that dogs can learn to remember many more than ten individual samples. It is therefore very important to train with sufficient samples, in different forms and phases, to promote generalisation (Lazarowski et al., 2020). Another problem that may arise is the result of dogs' "will to please" and keen eye for subtle changes in the body posture of their handler or owner. Dogs rely heavily on their handler, and when the handler thinks they know the location of the target, the handler will unconsciously behave accordingly. Dogs are highly sensitive to these unconscious bodily changes and will follow them, resulting in a false positive referral. It is therefore advisable to select or train dogs with a good work ethic but also a high degree of independence and self-confidence, as well as to train handlers to adopt a neutral body posture and to follow and trust the dog rather than the other way around (Birks et al., 2005; Cristescu et al., 2015; Lit

et al., 2011). In this respect, a strong bond between dog and handler could be seen as a disadvantage, but it is much more disadvantageous for the handler to be associated with indifferent or, in the worst case, aversive emotions by the dog. When dogs had to work with people they did not know at all and therefore displayed an indifferent attitude or were even fearful, they scored much lower than with their own regular handler with whom they did have a bond. Changing handler is therefore not recommended and this can in some cases cause practical problems, for example if the handler is ill but the dog is fit enough to be deployed but performs poorly with someone else (Hemsworth et al., 2009; Jamieson et al., 2018; Rohlf et al., 2010; Rohlf et al., 2012; Zubedat et al., 2014).

In addition to the disadvantages resulting from the bias of the dogs and their handlers, there are also external factors that can have a negative effect on performance. These include distractions in the form of sounds, visual triggers or scent trails that arouse the dog's interest (Grandjean et al., 2020). In addition, the decline in the dog's motivation when there is no target, such as during long searches without finding a carcass, is also a problem to be taken into account. When motivation declines, this can also potentially affect accuracy or search efficiency. Good training with sufficient blank trials and the use of dogs that enjoy tracking itself is therefore highly recommended (DeMatteo et al., 2019; Gazit et al., 2005; Matthew & Relton, 2021; Porritt et al., 2015; Stanhope, 2015). Another factor to consider is that dogs, like humans, are living organisms with the limitations that a biological body entails; after considerable exertion, both from walking long distances and processing many stimuli, the body becomes exhausted. This also reduces efficiency and accuracy, but more than that, it has adverse effects on animal welfare when even more is expected of the dog at that point. It is therefore recommended not to let the dog track intensively for longer than 20 minutes and to take breaks in between or possibly switch dogs (Stanhope, 2015).

Disadvantages of detection dogs: Information from interviews conducted at TCRH Mosbach

During the interviews at TCRH Mosbach, several points were raised that could be seen as disadvantages of using search dogs. First and foremost, it appeared that using dogs to search for wild boar carcasses could pose a certain risk to the dogs. For example, when searching in wolf territory, there is a chance that dogs could have a lethal encounter with wolves in particular in the case of free roaming hunting dogs at a distance of the owner that approach or attack the wolves. In addition, there has also been an incident involving raccoons, in which several raccoons attacked a dog standing in the water, and as a result of the attack, the dog almost drowned. The wild boars themselves also pose a danger. In Hesse, for example, there was an incident in which two hunting dogs were attacked by a boar. Although they were wearing protective vests, one of the dogs was hit under the vest in the stomach/groin and had its stomach torn open during the attack. This dog did not survive. There is also the risk of injury due to difficult terrain. It is therefore important that the dogs (and people) are in good physical condition, have good proprioception and coordination, and carry a first aid kit. Finally, there is the risk of transmissible diseases and parasites when dogs come into contact with a carcass. The importance of indications from a distance is therefore important. The transmissible Aujeszky's disease is particularly worrying because it can be fatal to dogs. However, the prevalence of infected wild boar in Belgium and the likelihood of a dog contracting the disease through contact with a carcass are unclear. The presence of ticks, which can cause Lyme disease, must also be taken into account. The message is to treat your dog adequately.

Another aspect that could be seen as a disadvantage is the extensive preparation required, both logistically, organisationally and administratively. First and foremost, there is the organisation of the training sessions and teaching days for the dog teams. In order to organise this, candidates must first

be found who are willing to volunteer for this project. Suitable trainers, and trainers for the trainers, must also be appointed. In order to have 100% availability, 200% training is required. A location must be found where the training sessions can take place, preferably with the possibility of overnight accommodation if candidates have to travel from far away. It must also be considered whether the dog teams (both handler and dog) can be insured. Easy and ongoing contact between dog handlers and trainers must be ensured via social media channels, WhatsApp groups, etc. The legislation must also be carefully checked with regard to areas where dogs are not normally allowed, such as some nature reserves or military domains. Even when searches need to be carried out on private property, permission must be requested. All these requests must be submitted to the appropriate authority in good time. There is also a lot to organise during an outbreak. Arranging the zones and decontamination showers, washing cars, people and dogs, booking hotels in the vicinity that are located in the zone, dealing with complaints from people living in the zones, covering unforeseen costs such as accidents (car accidents, fractures, veterinary costs for injuries to dogs, ...), installing GPS apps that transmit the location of the boars and teaching people how to use them, and much more. Good organisation is essential to ensure that everything runs smoothly.

Another disadvantage is fatigue in both dogs and humans. The literature recommends allowing the dog to rest after 20 minutes (Stanhope, 2015). At TCRH Mosbach, it was reported that 3 hectares could be searched in 20 minutes, that searches were conducted for 3 consecutive days and that these search days lasted 7 hours, but that the breaks should be at least as long in total as the total search time. The breaks are important for both dogs and humans in order to prevent feelings of overexertion and possible burnout in humans.

(SOURCE: TCRH Mosbach report)

Drones as a detection method

Advantages of drones: Information from the literature

Drones are a versatile technology and have therefore already been used for many different purposes (Al-Emadi et al., 2019; Getzin et al., 2012; Koh & Wich, 2012; Singh et al., 2020; Yang et al., 2019; Zweig et al., 2015). They can cover long distances in a relatively short time. In the study by Larsen et al (2023), the DJI Matrice 300© with infrared camera (used for that study) was able to screen four square kilometres of surface area in 45 minutes (Larsen et al., 2023).

A major advantage of drones, besides providing a broad overview, is the possibility of using sensors. Although RGB sensors are well known, infrared sensors offer more advantages when used to find wild boar carcasses. Wild boar carcasses are too well camouflaged for RGB sensors, while infrared sensors excel at finding animals, both alive and dead, with sufficient larval infestation, also known as the “larval mass effect” (Charabidze et al., 2011; Haroldson et al., 2003; Howell et al., 2021; Rahman et al., 2020; Rietz et al., 2023; Shewring & Vafidis, 2021; Slone & Gruner, 2007). Infrared sensors can therefore be used to locate both recently deceased wild boar carcasses and carcasses that are in the decomposition phase, due to the metabolic heat emitted by the numerous larvae. If a carcass could not be found because it had cooled down too much, it may still be found later when it is in the decomposition phase (Hohmann et al., 2021; Rietz et al., 2023; Sandor et al., 2025). In addition, different animals have different heat signatures, and carcasses infested with larvae may also have a characteristic signature. This is advantageous when large numbers of photographs have been taken with other possible heat sources in the image, such as other animals or heated objects, and an AI detection model needs to be trained to recognise wild boar carcasses in images. This heat signature can then be used as a feature by the model (Larsen et al., 2023; Wäldchen & Mäder, 2018).

However, a carcass does not remain warm. At a certain point, we enter the “dry phase” when all the tissue has already decomposed and only bones remain. Unfortunately, bones can still carry the virus, so it is very important to find very old carcasses and loose bones (SOURCE Report: TCRH: Mosbach). Spectroscopy and hyperspectral imaging could be useful in this regard. When a body has decomposed, the plants in the vicinity of this body absorb the decomposed nutrients from the soil, such as nitrogen (N). Hyperspectral imaging can be used to map the subtle differences between plants that have not absorbed these extra nutrients and those that have because they are near the carcass, thus allowing the location of the carcass to be determined more or less accurately (Beck & Cowley, 2011; Cavalli et al., 2007; Doneus et al., 2015). Although these differences in nitrogen concentration can only be detected after 2 to 4 months, they remain noticeable in the plant for years after decomposition (Brabazon et al., 2020; Silván-Cárdenas et al., 2021; Silván-Cárdenas et al., 2017). This is therefore particularly advantageous when searching for bones, and thus the use of hyperspectral sensors complements the use of infrared sensors, which only have added value immediately after death and during the decomposition process (which is too early for hyperspectral sensors) (Brabazon et al., 2020; Hohmann et al., 2021; Rietz et al., 2023; Sandor et al., 2025; Silván-Cárdenas et al., 2021; Silván-Cárdenas et al., 2017). In addition to potentially locating wild boar bones, imaging spectroscopy with hyperspectral or multispectral sensors also proves useful in displaying the status of arable crops or the location of beech, hazel or oak trees. These are, after all, locations where wild boars are more likely to be found. Based in part on this knowledge, a search strategy can then be developed or adapted (Bergmann et al., 2023).

In addition to RGB, infrared and hyperspectral sensors, LIDAR sensors can also be used. LIDAR has a major advantage over other sensors because it can penetrate through foliage if it is not too dense, thus gaining access to the locations of carcasses that might otherwise be missed (Hu et al., 2020; Masini et al., 2022). Artificial olfactory sensors in the form of multi-gas sensors can also make a significant contribution when AI models can be tuned and trained to recognise and signal in real time the signature VOC composition of the target, such as decomposing boar carcasses or boar bones. This has already proven successful for other targets (Kim et al., 2022; Lee et al., 2022; Noh & Oh, 2025; Yuan et al., 2019). All these technologies and methods are very promising, but as far as we could ascertain from the literature, LIDAR, imaging spectroscopy and multi-gas sensors have not yet been used in practice to locate wild boar carcasses. Further research is therefore needed to confirm (or refute) the usefulness of these sensors in practice. Although there are also reservations and disadvantages, which will be discussed later in this document and have already been discussed elsewhere in the document: Eyes on the target: the use of drones to detect wild boar carcasses for the control and prevention of swine fever, 2025, the potential is great. The fact that drones can be equipped with these sensors is therefore a major advantage in itself.

Finally, according to various studies, drones do not appear to have a pronounced negative effect on the welfare of wild fauna. This assertion is based on the lack of a flight response in the target species when the drone flies overhead (Goebel et al., 2015; McMahon et al., 2021; Vermeulen et al., 2013). However, a study by Ditmer et al (2015) emphasises that the absence of a flight response does not rule out stress and therefore does not rule out the possibility that drones have a negative effect on the welfare of wildlife (Ditmer et al., 2015) . In some other studies, certain animal species did show clear signs of stress behaviour (Larsen et al., 2023; Nath Tripathi et al., 2024). Nevertheless, the use of drones as a monitoring method is considered more animal-friendly than ground counts by a large group of people and certainly less invasive than capturing and handling individual animals to fit them with a transmitter (Del Giudice, 2018; Livezey, 1990; McMahon et al., 2021). Given that the composition of dog teams poses a natural threat to wildlife (1 search dog and 2 to 3 people), it could be assumed that this method is also more disruptive than a drone during a responsibly conducted flight, in which the drone does not

fly too low, too close or directly above animals. However, this must first be investigated before conclusions can be drawn. However, since fewer people are needed when working with dog teams than when only humans are deployed during searches, the pressure on wildlife may also be lower with the search dog method than when using only humans (Report: TCRH Mosbach) & (Chambers et al., 2015; Hoyer-Tomiczek et al., 2016; Mosconi et al., 2017).

The fact that using drones to screen an area or monitor a species requires fewer people than using the sample plot method during a ground census with only people (where at least 50 are needed) also means that the cost may be lower, especially when the purchase and maintenance of the drone is carried out by the UAV operator or pilot. In addition, there are the advantages of faster movement, more accurate screening through the use of infrared or other sensors, a better overview and access to places that cannot be reached on foot (Chabot & Bird, 2015; Ditmer et al., 2019; Frąckowiak & Goraj, 2023; Larsen et al., 2023).

Advantages of drones: Information from the online surveys and interviews at TCRH Mosbach

In addition to the advantages discussed above, the online surveys and interviews at TCRH Mosbach revealed other benefits. For example, it was strongly emphasised that drones offer enormous added value when the terrain is difficult or even impassable, such as at the bottom of cliffs or along dangerous riverbanks. It was also reported that the use of drones is logistically easy to organise and requires few people (the drone pilot, possibly a second observer so that the pilot does not have to remain within visual line of sight, and possibly someone to analyse the data). In addition, there is less risk of contamination and spreading the virus, as the drone does not come into contact with the environment, unlike dog teams. It was also mentioned that drones do not tire in the sense that the accuracy of the sensor does not decrease as the battery runs out, and that when the battery is empty, it can easily be replaced with spare batteries that have been brought along. The added value that drones offer in terms of providing an overview was also emphasised. A comparison was made between hunters who had to count the number of wild boars in a certain area and drones that did the same. The hunters counted 5 to 6, while the drone pilot spotted 40 wild boars. Many wild boars were not seen by the hunters, and sometimes they assumed they saw the same wild boar several times when in fact they were different animals. Another major advantage is the large area that a drone can screen. In one hour, a drone could check 60 hectares during an automatic grid flight. The higher the drone is allowed to fly (in combination with sensors that take images with sufficiently high resolution at such an altitude), the greater the distance that can be covered.

(SOURCE: TCRH Mosbach report and qualitative information from online surveys)

Disadvantages of drones: Information from the literature

Previously, one of the major advantages of drones as a monitoring and detection method was discussed: the possibility of using many different sensors, each with their own strengths and added value depending on the task and circumstances. However, a major disadvantage is the significant limitations encountered by almost every sensor when searching for animals or objects under dense foliage and possibly dense undergrowth. Although infrared cameras are recommended when animals are partially hidden and therefore too well camouflaged for RGB cameras, overly dense canopy cover is very limiting for infrared sensors (Dunn et al., 2002; Kissell & Nimmo, 2011). There is a negative correlation between the density of the canopy and the probability of detection. For example, a study by Rietz et al. (2023) found that searching for wild boar carcasses in forests with less than 29.3% openness resulted in a detection probability of less than 25% (Rietz et al., 2023). LIDAR sensors are

recommended when there is a lot of cover because the narrow laser can penetrate the canopy, between individual leaves, and thus take ground points. However, when the canopy is too dense and there are not enough openings, LIDAR is unable to reach the ground. In addition, it is not always possible for LIDAR to distinguish between dense undergrowth and the effective ground, which can result in false ground points. A carcass lying under low undergrowth will therefore not be found (Corcoran, 2016; Hu et al., 2020; Koopman et al., 2025; Silván-Cárdenas et al., 2021).

Another disadvantage of using drones is their dependence on weather conditions. When using infrared sensors, it is important to take into account the “hot crown effect”. This is when tree canopies heat up on warm, sunny days and this is then seen on the thermal images as heat spots that are difficult to distinguish from animals or carcasses infested with larvae. The same can also occur with other objects that are in direct contact with sunlight, such as rocks, bushes or the ground itself (Frąckowiak & Goraj, 2023). In addition to the limitations imposed on the infrared sensor by excessive sunlight, other weather conditions also impose major restrictions on the drone itself. Wind, for example, is a major concern as it can undermine the stability of the drone, causing it to lose control. In addition, turbulence also causes blurry and unclear images for any sensor (McMahon et al., 2021; Weissensteiner et al., 2015). Rain and fog also cause blurred images, especially with infrared sensors. The use of LIDAR is also virtually impossible on rainy days due to the problem with reflective or translucent materials, including raindrops. It goes without saying that non-waterproof drones can be damaged when flown in heavy rain or even fog (Burke et al., 2018; Duffy et al., 2017; Gordon et al., 2007; Koopman et al., 2025).

Drones are most effective at locating wild boar carcasses when they use infrared sensors in semi-open to open areas. However, a disadvantage of this is that the bodies of dead wild boars cool down too much after 1 to 2 days to be detected. The carcasses can be detected again when there is sufficient larval mass present. The noticeable difference only becomes apparent during the advanced decomposition phase, and is noticeable from day 12 to 21 after death. This means that the period during which carcasses can be found is limited (Hohmann et al., 2021; Rietz et al., 2023; Sandor et al., 2025). In addition, it has also been observed that the use of infrared sensors for the detection of small carcasses or body parts is insufficiently effective because smaller bodies attract fewer larvae. Finding bones with infrared sensors is impossible for the same reason – the absence of larvae. Furthermore, there is a chance that bones and body parts will be moved or buried by scavengers (Henry et al., 2021; Santos et al., 2016; Spicka et al., 2011; Trumbo & Sikes, 2021). The use of imaging spectroscopy based on hyperspectral sensors could compensate for this disadvantage. Unfortunately, visible anomalies only become apparent in the environment after two to four months, which is problematic when rapid action is required (Brabazon et al., 2020; Silván-Cárdenas et al., 2021; Silván-Cárdenas et al., 2017). In addition, applying this method is also very time-consuming because real-time results are not possible and analysing the data requires a lot of time and knowledge. Furthermore, the maximum permissible load with such sensors is quickly exceeded by most standard drones (Aasen et al., 2018; Krekeler et al., 2023; Lasaponara & Masini, 2012; Opitz & Herrmann, 2018). Artificial olfactory systems in the form of multi-gas sensors could also help detect bones or small body parts, but this sensor is not without its drawbacks either. Due to the complexity of VOCs, the sensitivity of neural networks is not always optimal (Albert & et al., 2000; Peris & Escuder-Gilabert, 2009; Röck et al., 2008; Sung et al., 2024). There are also fairly frequent problems with sensor drift (Vergara et al., 2012; Verma et al., 2016; Yan & Zhang, 2016; Zhang et al., 2018), the rotors cause the “downwash effect”, which is detrimental to the collection of odour particles (Brinkman et al., 2020; Burgués & Marco, 2020; Sarghini & De Vivo, 2017), the sensor quickly becomes saturated (Kaliszewski et al., 2021), and the weather plays an important role not only during flight and for the drone itself, but also for the sensor, as the dispersion of odour particles is influenced by weather conditions (Ayaz & Topuk, 2021; Mahdavi et al., 2021; Noh & Oh, 2024; Sitar et al., 2024).

The following disadvantages of using drones are mainly related to legislation. An example of this is the rule concerning Visual Line of Sight (VLOS), which states that the drone must always remain in sight of the drone pilot. In some cases, a second person may be deployed to maintain visual contact with the drone when the pilot is unable to do so (Implementing Regulation (EU) 2019/946 'on the rules and procedures for the operation of unmanned aircraft', Article 4, § 1, point d). Exceptions to the VLOS rule may be requested (BVLOS rule), but the conditions are strict. For example, flights must be conducted with a class C6 drone and only above a "controlled environment" (the only people present in the area are those involved). The pilot must also hold an STS certificate and have obtained STS-O2 accreditation. Furthermore, the other conditions listed in Appendix 5 of Implementing Regulation (EU) 2020/639 must be taken into account (<https://mobilit.belgium.be/nl/luchtvaart/vliegen-met/drones-uas/categorieen/categorie-specific/standaardscenarios>).

Another disadvantage is that every drone has a Maximum Take-off Weight. The higher this MTOW, the stricter the rules. For drones with a low MTOW, the problem is that some sensors are too heavy, and the MTOW is therefore exceeded when the drone flies in a loaded state ((EU) 2019/946; Annex Part A: UAS.OPEN.060, §1: point e). The laws governing geographical zones must also be taken into account. Some zones are off-limits to drones. It is important to check during flight planning and prior to flight execution that the flight route does not pass through such zones. In certain cases, an application for permission to enter may be submitted ((EU) 2019/946; Article 15, § 1 & 2). Another disadvantage is the extensive preparation required before a flight can take place, such as registering the drone and the operator, developing procedures for the flight, appointing a pilot who is familiar with the UAV manual and the procedures drawn up by the operator, ensuring that the UAV has an EU declaration of conformity and a label referring to its class, the pilot must have a certificate of competence, the drone must be checked, the environment must be examined for risks, and the persons involved must be informed (including about any risks). geographical zones must be taken into account, the drone must have RemoteID and a geo-awareness system, distance must be kept from uninvolved persons (minimum distance varies per category), and so on. In the "specific" and "certified" categories, an application must be submitted prior to flight execution and a thorough risk assessment must be drawn up in combination with risk mitigation measures. In addition to the effort involved in preparing risk analyses and applications, it also takes a great deal of time for everything to be reviewed and approved by the competent authority. It is important to start on time, especially when special exemptions are requested (Implementing Regulation (EU) 2019/946 'on the rules and procedures for the operation of unmanned aircraft').

Disadvantages of drones: Information from the online surveys and interviews at TCRH Mosbach

A drone could monitor 60 hectares in one hour. The higher the drone flies (in combination with sensors that take images with sufficiently high resolution at such altitudes), the more area can be screened. Unfortunately, the legal maximum altitude in Europe is 120 metres. However, there are companies that employ drone pilots who are allowed to fly higher than the maximum altitude. However, the cost of hiring these pilots is very high, namely 4,000 euros per day (Report TCRH Mosbach and Implementing Regulation (EU) 2019/946 'on the rules and procedures for the operation of unmanned aircraft', Article 4, § 1, point e). The surveys also showed that few pilots are enthusiastic about flying in wooded areas. Flying between trees is strongly discouraged due to the risk of the drone hitting a branch, which is possible even with obstacle detection (some small twigs are not detectable). Flying lower than 5 metres above the treetops is also considered highly inadvisable. Take-off would also be difficult in wooded areas, as 10m² of free space is recommended as the minimum area required for safe take-off. In addition, concerns were raised about the effectiveness of drones in detecting "objects" under tree

canopies. Infrared would not be sufficiently effective if the canopy is too dense. There was insufficient knowledge about the other technologies (multi-gas sensors, LIDAR and imaging spectroscopy) to draw any concrete conclusions. This lack of knowledge about these methods also shows that finding a drone pilot who is familiar with this knowledge and has a drone equipped with (one of) these sensors (multi-gas sensors, LIDAR and/or hyper- or multispectral sensors) is not so straightforward.

The respondents also agreed with the concerns about the weather that were mentioned earlier in the literature study. However, they also emphasised that increasingly weather-resistant models are coming onto the market, such as models that are water-resistant or have a heavier, more stable weight, making it possible to fly in 4 Beaufort winds (Survey results). However, it goes without saying that the more a drone has to offer, the more expensive it is to purchase. Many respondents also saw legislation as a problem. This mainly concerns the maximum altitude of 120 m, the legislation on VLOS, the ban on flying near or over uninvolvement persons and the ban on flying over certain zones. Obtaining the correct permits and authorisations is also said to be difficult and slow. Both survey respondents and experts at TCRH Mosbach reported that wild boars are increasingly inclined to forage in people's private gardens in villages or on the outskirts of villages. Obtaining permission to fly a drone over private property (and thus possibly over uninvolvement persons) is not a straightforward matter (Interviews TCRH Mosbach and survey results). Finally, the drone expert at TCRH Mosbach stated that drones with infrared sensors are ineffective if wild boar carcasses are (partly) in the water. They would then have cooled down too much to be visible on the infrared images. According to the experts at TCRH Mosbach, this is a problem because wild boars infected with the ASF virus and already suffering from fever tend to seek cooling in the water, where they often die (Interviews TCRH Mosbach). At TCRH Mosbach, only drones with RGB and infrared sensors were used. They recommend search dogs for finding wild boar carcasses at the water's edge or in the water. They also believe that finding small carcass parts and bones using a drone equipped with an infrared and RGB sensor is not possible. They also use dogs for this purpose (interviews with TCRH Mosbach).

(SOURCE: Interviews with TCRH Mosbach and qualitative information from online surveys)

Clear comparison of both methods

All information below is a repetition of information from the previous sections. The purpose of this chart is to provide an overview. Therefore, not every piece of information in this grid is linked to its source. To find the source of the mentioned knowledge, it is recommended to read the entire document.

	Search dogs	Extra information	Drones	Extra information
Accuracy and probability of detection.	Generally high.	Depends on: - Level of dog and handler. - Wind direction. - Temperature. - Training. - Motivation of the dog. - Distractions. - Fatigue. - ...	Fairly high.	Depends on: - Openness of the area. - Knowledge and trained eye of the pilot. - Sunlight (hot spots). For AI models, this depends on: - Learning curve. - Quality and quantity of training images.
Threat to wildlife?	Not very high but present.	Fewer people are needed than searches with only people = less pressure on wildlife. Threat depends on: - Obedience. - Hunting behavior. - Loose vs. long-leash work. - Barking behavior.	Not very high but present.	Fewer people required than searches with only people = less pressure on wildlife. Threat depends on: - Distance between drone and wildlife. - Height. - Position relative to wildlife (directly above = greater threat). - Sound of the drone.
Possible to find bones?	Very possible.	With intensive training. Bones are harder to detect than a carcass in the decomposition phase.	Impossible to very difficult.	Depending on the sensor, however, infrared sensors are used in practice at TCRH Mosbach. These cannot detect bones. Experience with other sensors is too limited to draw definitive conclusions.
Real time target confirmation possible?	Yes.	The dog's indication signal immediately confirms the presence of the target, that is, if the handler recognizes it.	Yes, but not always.	Depending on the sensor. With infrared, this is real-time. If the target is (partially) present in the images but not recognized in real time by the pilot, data

		If there is any doubt, the target can be analyzed post-find.		analysis can still take place (possibly with AI).
Is searching in wooded areas with a lot of canopy and undergrowth possible?	Very possible.	- Dogs move easily between bushes. - They can find small objects under dense undergrowth.	Not possible to very difficult.	- Depending on the density of the treetops and the presence of significant undergrowth. - There is also a risk of collision with branches.
Is searching possible in all weather conditions?	Mostly.	Exceptions: - Extreme heat - Extreme cold - Storms The distribution of scent particles is influenced by the weather (heat, thermals, wind direction, humidity), and thus also the search strategy.	Not possible.	Danger to the drone: - Excessive wind (depending on the model) → Loss of control (risk of collision). - Rain and fog (water damage). - Frost or snow (damage to the propellers). Detrimental to good imaging: - Sunlight and heat (hotspots). - Wind (unstable images). - Rain and fog (blurry images). Required: Low wind and cloudy.
Is searching in or near water possible?	Difficult but sometimes possible.	Depending on accessibility: - Along rivers, the terrain can sometimes be difficult to navigate (precipices, uneven terrain, loose rocks). - The water itself is often also difficult to navigate (too deep, strong currents). - Dogs could be deployed from a boat. The target's scent may be picked up and signaled.	Difficult but sometimes possible.	No trees in the water = no canopy → better visibility for the drone. However: Carcass in the water = cooled = undetectable with infrared + chance of body wax = no larval mass. RGB sensors may be helpful.

Is it possible to screen a large surface area in a relatively short time?	Reasonable	Depends on: - Condition of dog and handler. - Accessibility of the terrain. - Number of carcasses found (photo, location, etc.) = takes time. At 20 minutes = 3 hectares. After 20 minutes: change dogs (rest).	Very good.	Depends on: - Flying using FPV = possibly 45 minutes → 4 km² (Larsen et al. 2023) or - Flying using a grid with overlap = 1 hour → 60 ha (TCRH Mosbach report). A grid with overlap is usually required. Also depends on: - Altitude. - Battery life. - Signal strength. - Wind speed. -
Is there a need for a lot of training materials and training opportunities?	Yes, a lot.	Needed: - Plenty of training materials with a wide variety (different body parts, decomposition phases, degree of dehydration + bones, etc.) → generalization training. - Numerous training sessions. - Different locations (to prevent context-dependent learning). - Strong focus on careful handling of materials (to prevent odor contamination) → tongs, disposable gloves, etc. - Scent containers for line setups and possibly a scent carousel.	Quite a lot.	Needed: - Possibility to train in a similar environment (Survey response) - Training pilots' eyes on carcasses with larval mass effect on infrared images (live or on existing images) (Interview: TCRH Mosbach). - AI models: Training material is needed in the form of numerous images. (We assume a skilled pilot with a certificate of competence who has not been specifically trained for this purpose).
chance that someone drops out or that someone cannot participate	Well possible	Possible cause: - Illness of dog or handler. - Excessive time invested in training → not having the time or wanting to make the effort → quitting. - Long, strenuous days during a crisis.	Probably low.	A well-maintained, safely operated drone is durable. There is a risk of: - Technical problems. - Defects. - Pilot illness.

		- Showering is seen as a nuisance. - Arguments within the group (close cooperation required). According to TCRH Mosbach, however, there is little dropout. (Report: TCRH Mosbach)		
Risk of attack by wild animals or contamination (parasites, viruses, etc.)?	Susceptible, but in practice relatively low.	Potential risks: - Attacks by wild boars. - Attacks by wolves. - Infection with Aujeszky's disease (risk level unclear). - Infection with parasites, including ticks, with a risk of Lyme disease. - Carrying ASF.	Low.	Drones do not come into direct contact with or near wild animals. This limits the risk. However, there is a risk of attacks by nesting birds, according to the survey responses. Pilots are at risk of carrying ASF when operating in the black zone.
Logistical preparation.	A lot.	Required: - Food and water for both dog and human (long days with physical exertion). - First aid kit for both dog and human. - Dog's water bowl. - Rewards (toys, treats, etc.). - Long leash and harness. - E-tracker and smartphone with the appropriate apps. - Spare clothes for changing zones. - Car crate and cushion. - Arrange mobile showers for disinfection. - ...	Not much.	Required: - Drone itself with sensor. - Spare batteries. - Laptop (optional). - Smartphone or tablet with the appropriate apps.

Administrative preparation.	A lot.	Requests for access to: - Private domains - Military domains - Closed nature reserves + - Requests for potential off-leash work. In addition, there's also a lot of email correspondence and e-communication to arrange everything (organizing a team, booking hotels in designated black zones, etc.).	A huge amount.	- Prepare risk assessments. - Develop risk mitigation measures. - Develop procedures. - Drone and UAV operator registrations. - Applications for exemption from the VLOS (optional). - Applications for exemption from the maximum altitude of 120 m (optional). - Applications for access to certain geographical zones. - Pilot competency certificate. - etc.
Wide range possibilities?	Very large.	Dogs can learn up to 40 different scents, and training becomes increasingly easier. The types of scents that can be learned are virtually endless. Requirements: - Sufficient training materials/samples. - Not too difficult to obtain.	Very large.	Many possibilities arise from the use of different types of sensors, each with its own advantages. Applying AI detection models further expands these possibilities.
Access to difficult to access terrain.	Good.	It depends on the dog's "hardiness." Some dogs can navigate dense brush or brambles faster than others. But generally, both dogs and humans can easily maneuver anywhere. Both humans and dogs are limited when navigating precipices, deep water, or other forms of dangerous	Good.	A drone can fly almost anywhere, provided it's legally permitted. Whether a drone is useful everywhere is another matter. For example, a drone can fly over a forest, but not under the treetops, which limits its range to some extent → Well-balanced by dog teams.

		terrain → This is well-balanced by drones.		
Can the carcass be found regardless of its stage?	Very well possible.	Each phase has a specific scent, and therefore a dog can find it. Training for strong generalization or training for different phases (e.g., including the dry phase) is necessary.	Not possible. The period in which it is detectable is limited.	With infrared: - Immediately after death (body is still warm). - Advanced decomposition (sufficient larval mass). Be careful with bodies that are too dry (on hot days in the sun ◇ mummification) or too wet (e.g., in a river) ◇ adipocere = both have no larval mass and are therefore not visible with infrared (Carter et al., 2010; Fiedler & Graw, 2003). Other sensors: Too little experience in this topic. However, there are possibilities and potential that could be further explored.
Financial cost	High.	The cost of purchasing, training, and maintaining a dog is very expensive. Therefore, it's necessary to employ people who already have their own dogs. These individuals can then receive an hourly wage. Volunteers with their own dogs can also be employed. Handler training should be included in the cost (paying the trainers). Using search dogs could ultimately be cheaper than deploying only human searchers because fewer people	High.	The purchase price of a drone and sensor is very high. Therefore, it's best to hire a drone pilot with their own drone. Professional drone pilots are also well-versed in the relevant legislation. Using a drone to screen an area would be cheaper than deploying only human searchers because far fewer people are involved during a drone flight (1-3). Furthermore, a drone is more accurate, faster, and safer. (Chabot & Bird, 2015; Ditmer et al., 2019; Frąckowiak & Goraj,

		are needed. Furthermore, the detection rate is higher, and search dogs are more efficient (saving time) (Report TCRH Mosbach and Domínguez del Valle et al., 2020; Roda et al., 2021).		2023; Larsen et al., 2023).
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Conclusion

Both methods can offer significant added value in detecting wild boar carcasses to combat the spread of ASF. Each has its advantages and disadvantages, and they generally complement each other well. Furthermore, both methods prove superior to ground searches conducted solely by humans. To maximize search results, it is therefore recommended to use both search dogs and drones.

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