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## INTRODUCTION

The hunting economy carried out in the hunting district generally consists in breeding wild game that lives in the free state. Breeding activities mainly consist in maintaining the appropriate abundance of animals depending on the capacity of the hunting ground, influencing the proper physical individual development and population development of the game, maintaining the quantitative status of game endangered with extinction, implementing activities related to reintroduction, or establishing a strategy to fighting infectious diseases, for example ASF. The breeding of animals is carried out based on hunting plans which are prepared with informations about the numbers of animals of a particular species. Therefore, all activities related to the management of populations are based on the stocktaking of animals in the hunting district. It is crucial for the correct planning of future breeding activities. The stocktaking includes the following species of big game: moose, deer, fallow deer, roe deer, wild boar, mouflon as well as small game: fox, raccoon dog, badger, marten, hare and pheasant. The stocktaking is performed on March 10 each year, which allows to estimate the condition of the game before the breeding season begins

and to plan breeding activities taking into account the planned increase in the number of individual species. The hunting breeding year runs from April 1 to March 31 each year. The rest of this article will concern methods of estimating the size of big game.

As a result of the stocktaking, we usually obtain an estimated number of animals. Due to the size of the areas inhabited by wild animals, the type of areas (forests, fields), their location and availability, it is impossible to carry out this activity in a precise manner. It is necessary to apply some simplifications resulting from terrain capabilities, technical capabilities, human resources, weather conditions, etc. Therefore, there are many methods of estimating the number of animals. Their principles, advantages and disadvantages will be discussed in the next chapter.

### REVIEW OF CLASSIC METHODS OF STOCKTAKING BIG GAME

Due to the method of observation a stocktaking of the game can be divided into direct and indirect. Direct methods are based on direct visual contact with the game, while indirect methods allow to determine the number of game based on the signs of its existence, e.g. following tracks. The best-known direct methods include: test drive, belt assessments of hares and partridges, aerial counting, counting on feeding grounds and feeding places, spring counting of roe deer in fields and meadows and year-round observations. In turn, indirect methods include: tracking branches, tracking on transects, determining the areas of tagged individuals, counting roaring bulls, counting voices of tooting pheasant and partridges, DNA determination from faeces, counting deer pellets, registration of beaver lodges, counting badger colonies, etc. (Okarma et al., 2008).

In practice, the most frequently used methods of stocktaking large game are: test drive method, tracking on transects, counting on feeding grounds and feeding places, and the method of year-round observation.

#### Test drive method

This method consists in counting the driven game in a specific area of the investigated forest or field, called a litter. This area is surrounded by stationary and mobile observers, as shown in Fig. 1.

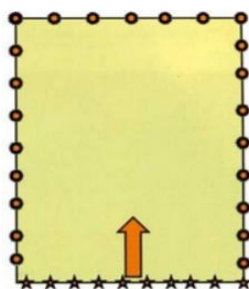


Fig. 1 Scheme of placing the participants during the direct counting of animals on the sample plot

Source: (Okarma et al., 2008)

Mobile observers pass through the litter, driving the game outside the study area. Only individuals leaving the litter are counted. The area to be driven is determined randomly or systematically. It should constitute at least 10% of the entire surveyed area.

The advantage of this method is relatively high accuracy and the ability to determine the age and sex of driven game. The larger the forcing area, the more precise the results are. The disadvantage, however, is that to conduct it, you need a very large number of observers with appropriate knowledge about the recognition of the game (age or sex). It is therefore cost-intensive and difficult to organize. Due to the random selection of areas, there is a risk of encountering a cluster population or omitting this group of animals due to their temporary migration, which has a negative impact on the credibility of the results (Zalewski et al., 2018).

### **Tracking on transects method**

It consists in counting game tracks on permanent transects. The number of tracks allows to determine the number of animals in the hunting district. This method is best used in winter as the tracks are clearly visible in fresh snow. It does not require engaging such large forces and resources as in the case of test drive method. An additional advantage of the method is the possibility of studying the changes in the population size of species that occur in small numbers. It is possible to collect information about the abundance, distribution and mobility of the game in the winter, as well as its behavior and reactions to certain environmental factors. However, it depends on the season and weather conditions, because local snow melting causes gaps in observations, and its absence or continuous precipitation prevents it completely (Okarma et al., 2008).

### **Spring counting of roe deers in fields and meadows method**

Spring counting of roe deer is performed in early spring, when the first vegetation after winter appears and the animals go out into the fields. Observations are made in the evening or in the morning, from fixed positions or while on the move. Roe deer are territorial animals, therefore this method is used in small and medium-sized forest complexes (up to 1 kilometer wide). Thanks to the tests carried out in the open space, the animals are clearly visible to the observers. It is worth noting that this method carries a high probability of mistake, because it is not certain whether all animals have left the forest. There is also the possibility of accidentally scaring the animals off (Okarma et al., 2008).

### **Counting on feeding grounds and feeding places method**

Counting at feeders and feeding grounds is a very similar method to the one described above. It allows you to count large species of animals, where individual herds are identified based on their abundance or size of individuals. Counting takes place on frequently visited feeders or farmlands. Mistakes in the

results may appear due to difficulties in counting single individuals or finding herds of the same size. This method works well especially in winter for counting fallow deer and deer, when bulls and doe with calves stay in separate swarms (Okarma et al., 2008).

### **Year-round observation method**

The year-round observation method is mainly a complementary method to other, which is used to study the number of animals. It is based on recording the species, sex and the amount that is encountered during the year. After recording the results, an analysis is performed at the end of the inventory period that presents the results of the observations (Okarma et al., 2008).

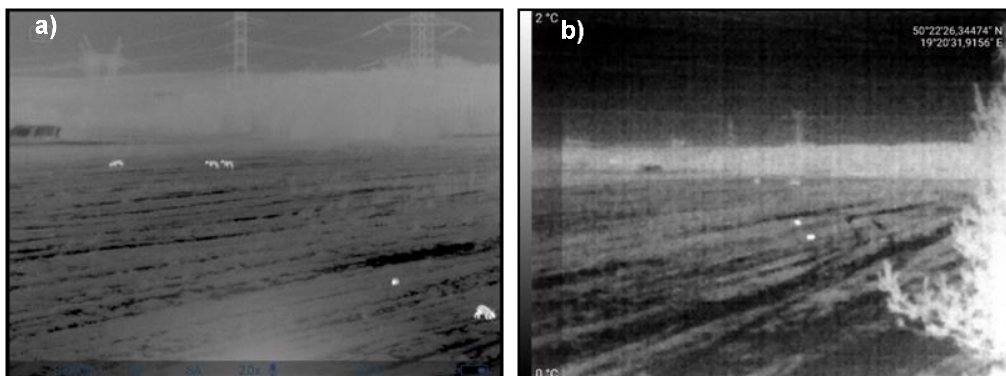
### **THE USE OF THERMOVISION FOR THE ANIMAL IDENTIFICATION AND ESTIMATION OF THE POPULATION SIZE**

The direct methods of animal inventory, described above, are based on counting individuals with which we are in direct eye contact. During some observations binoculars are used, but they do not guarantee to see animals obscured by branches or grass. This way a lot of animals can be missed in observations. The quality and effectiveness of observations can be significantly increased by using the technology of observation of thermal (infrared) radiation, which can provide us with an image of the temperature distribution of studied objects and its surroundings. Accessibility of this technology is common nowadays and the prices of thermal cameras range between one and several thousand zlotys. However, not all thermal cameras are suitable for these applications. An important feature of thermal imaging cameras is the resolution of the bolometric transducer, the size of the lens and the optical approximation. Cameras designed for typical night observations, e.g. Pulsar Thermion XP50 (telescope), Helion 2 XP50 Pro (monocular), or Accolade 2 XP50 LRF Pro (binoculars) have sensors with a resolution of 640x480 pixels with a pixel size of 17  $\mu\text{m}$ , which with a 50 mm F lens/1.2 and 2x optical magnification gives the possibility of detection from a distance of 1800m. The 50 Hz image refresh rate ensures smooth images in motion. The weight of such cameras ranges from 600 to 700 grams. There are also slightly smaller and cheaper observation cameras available on the market, e.g. Hikvision Lynx LH15, LH19 and LH25, with transducers with lower resolutions, e.g. 384x284 pixels with a pixel size of 12  $\mu\text{m}$ , optical magnification 1.5x, 1.7x to 2,5x respectively, and 15, 19 and 25mm lenses, making it possible to recognize a human-sized object from a distance of 375, 475 and 625 m, respectively. Their weight is slightly smaller and amounts to about 300 grams. HIKVision cameras are also available with larger lenses and higher transducer resolutions. The smallest and cheapest thermal imaging cameras are cameras that can be connected to a mobile phone via USB, e.g. Seek Thermal Compact Pro with a resolution of 320x240 pixels, refresh rate of 9 Hz and a detection range of 500 m. The manufacturer does not specify the lens diameter, the base magnification is 1x.

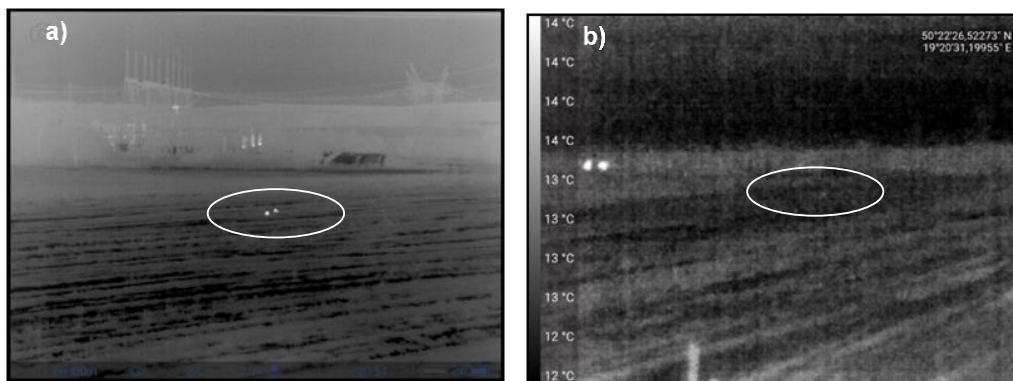
The described thermal imaging cameras were subjected to field tests involving the observation of the game at a known distance and subjective assessment of the image quality and the possibility of correct recognition of the game species. As part of the work of PBL, four types of thermal imaging cameras were tested, namely: Pulsar Thermion XP50, Pulsar Accolade 2 XP50 LRF Pro, HKVision Lynx LH15 and Seek Thermal Compact Pro. During the tests, the animals were observed from different distances, and then the clarity of the images was compared and the optimal distances at which the animal can be easily recognized were determined.

As a result of the tests, it was found that all compact cameras do not meet the expectations and they cannot be used to recognize the game at a distance bigger than 10-20 m. The reason here is mainly the small diameter of the lens and the poor optics of the camera.

Figure 2 shows a comparison of images obtained from thermal imaging cameras the Pulsar Thermion XP50 and Seek Thermal Compact Pro. In the foreground you can see 2 hares at a distance of 60 m from the observer, while at a distance of 200 m there are 3 roe deer. The first of the cameras has x2 optical magnification, while the second one has x1. In Figure 3, on the other hand, there are pictures of 2 hares in the field at a distance of 150 m from the observer.

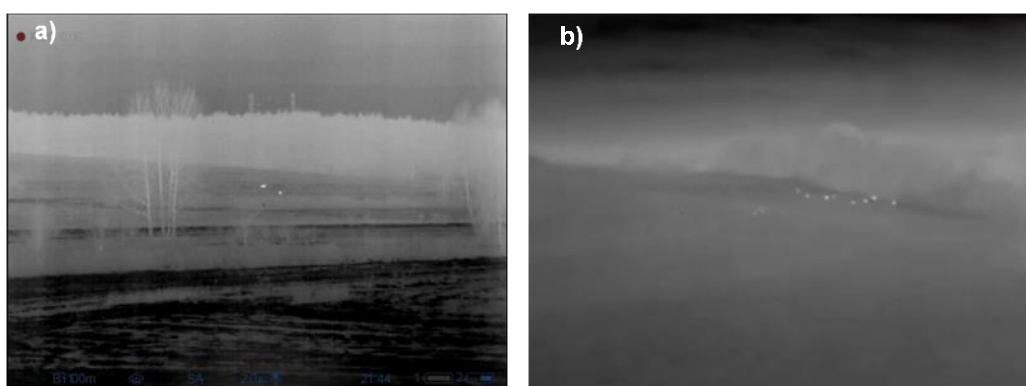


**Fig. 2** The photo of 2 hares at a distance of 60 m and 3 roe deer at a distance of 200 m, taken with cameras: a) Pulsar Thermion XP50, b) Seek Thermal Compact Pro



**Fig. 3** The photo of 2 hares at a distance of 150 m, taken with thermal imaging cameras: a) Pulsar Thermion XP50, b) Seek Thermal Compact Pro

Cameras having slightly better transducers and a larger diameter provide more clear image of objects observed from a longer distance. For the purposes of correct and unequivocal identification of larger animals, it seems, however, that the limit observation distance should not exceed 200 m (maximum 300 m). Of course, recognition of the game at longer distance is also possible, but it is based on an additional analysis of the behaviour and the way the animals move. Figure 4 shows images from thermal imaging cameras recorded at different distances. Figure 4a) shows 2 roe deer at a distance of 500 m, seen in the Pulsar Thermion XP50 camera (50 mm lens), while in Figure 4b) we have roe deer at a distance of 300m, observed with HKVision Lynx H15 (15 mm lens). The first photo is quite clear, but the distance of 500 m seems too big to clearly recognise the game.

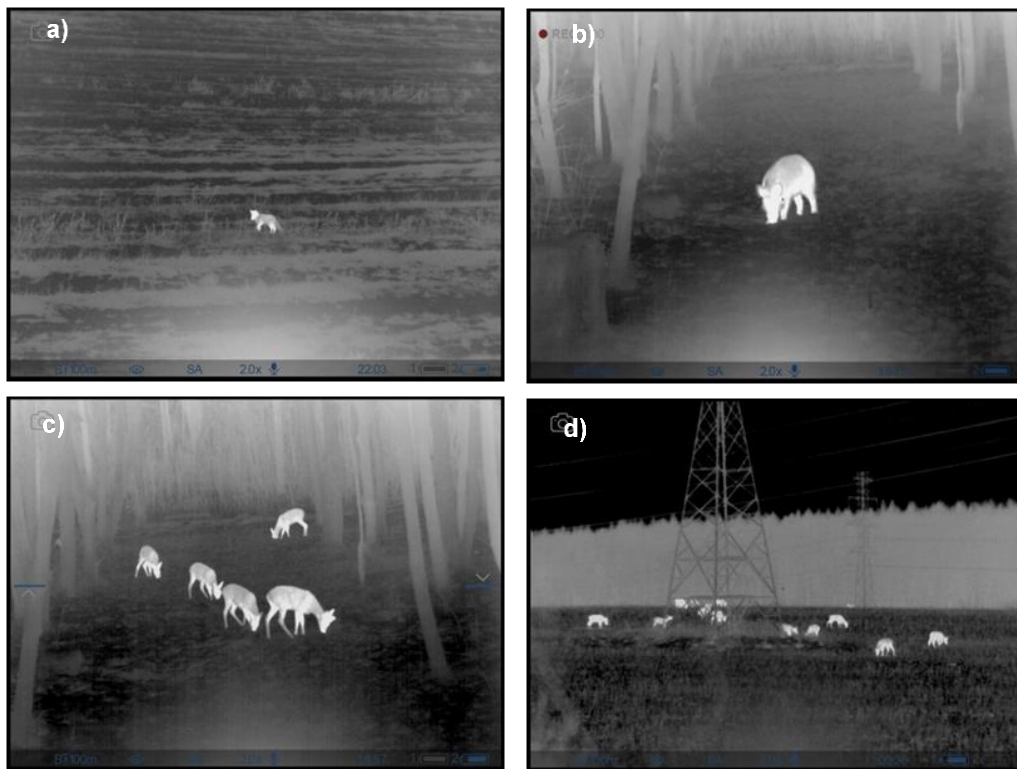


**Fig. 4 The photo of roe deer taken with thermal imaging cameras: a) Pulsar Thermion XP50 – at a distance of 500 m, b) HKVision Lynx H15 – at a distance of 300 m**

In the case of distances less than 200 m, the recognition of the game is much more reliable and unambiguous. Therefore, the use of such observation distances in combination with the use of cameras with bolometric transducers 640x480 pixels and lens with a diameter of 50 mm will allow to obtain images of appropriate quality, which would be analysed, for example, using artificial intelligence methods. Fig. 5 shows examples of images of large and small game recorded with the Pulsar Thermion XP50 and Pulsar Accolade XP50 cameras (devices comparable with each other in terms of parameters).

To sum up the conducted field tests of thermal imaging cameras, it can be unequivocally stated that the best effects for the recognition of the big game are obtained at the border distance of up to 200 m. Of course, at longer distances the recognition of the game is also possible, but the image becomes less clear and it is much easier to make a mistake. If you want to use the features of thermal imaging cameras in combination with flights over forest or field areas with the use of unmanned aerial vehicles (drones), you should take into consideration one more limitation resulting from the regulations of the Civil Aviation Authority, which is the limitation of VLOS flights in the open category to the limit height of 120 m. For the purposes of game inventory, this limitation is not an obstacle, as this distance ensures obtaining clear images from thermal

imaging cameras. Determining one animal observation distance will significantly facilitate its recognition also thanks to assessing its size. It is possible if the camera is installed on the drone and the flight is made at a constant height. In the next stage, it is necessary to determine the optimal flight height due to the area covered by the scanning in one flight (it depends on the angle of the camera lens, optical magnification and the flight altitude), as well as the possible scaring of the game due to the noise emitted by the drone.



**Fig. 5** Photos taken with Pulsar Thermion and Accolade cameras: a) fox at a distance of 50m, b) wild boar at a distance of 25m, c) roe deer at a distance of 40-60 m, d) a swarm of deer at a distance of 120-200 m

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## POSSIBILITY OF USING UNMANNED AERIAL VEHICLES FOR GAME INVENTORY

The use of unmanned aerial vehicles for game inventory in theory seems to be relatively simple, due to the existing mechanisms that allow for autonomous flights according to the developed scenarios. They are used, for example, in the implementation of aerial photos and orthophotomaps. Then it is possible to declare the area covered by scanning, flight routes, frequency of taking photos (depending on the height), etc. These mechanisms can be used directly to plan and execute flights, and to create high-resolution geocoded graphic files, which then need to be analysed by recognizing species and counting the number of individual animals. From the technical point of view, there are no major problems with the implementation of such a task. Figure 6 shows the Yuneec H520 drone prepared for flight, equipped with the E90 camera and the developed flight scenario.

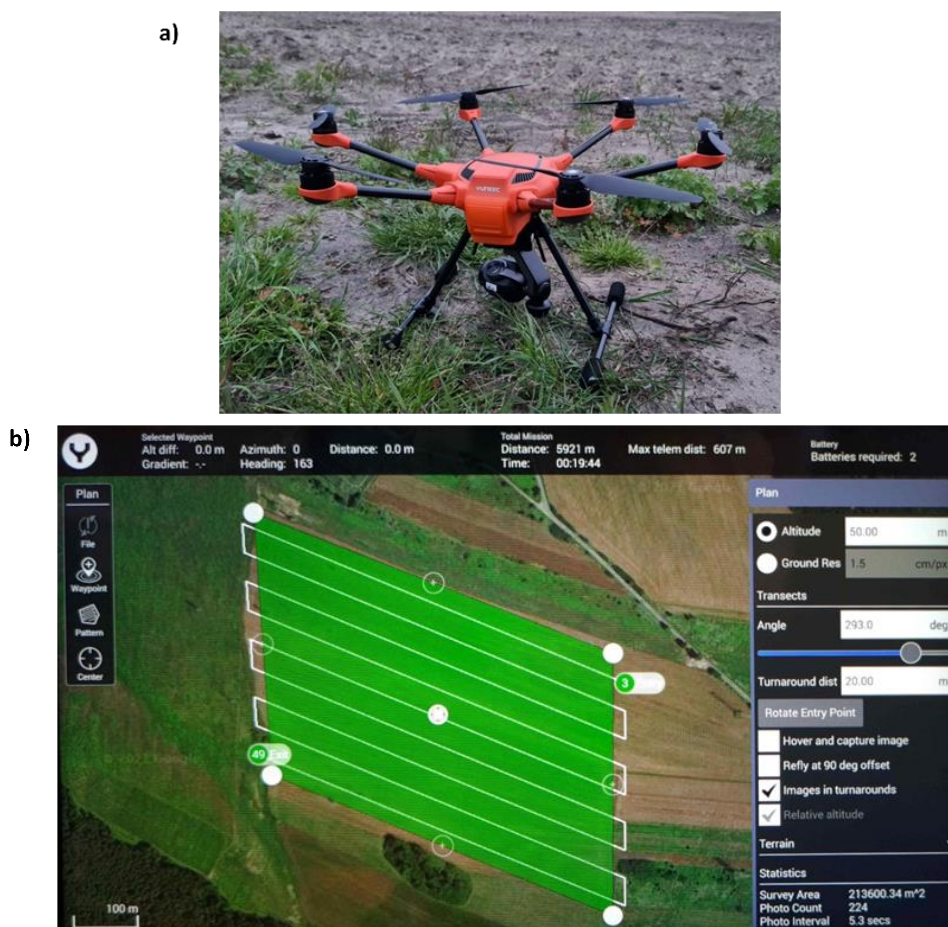


Fig. 6 Drone Yuneec H520 prepared for flight (a) with developed flight scenario (b)



The flight covers an area of over 20 ha, the flight height is 50 m, which gives the image resolution of 1.5 cm/px. During the flight, 224 photos will be taken. The marked lines indicate flight routes, and their density depends on the declared flight altitude, the degree of image coverage and the type of camera installed.

The fundamental problems in the implementation of flights with the use of unmanned aerial vehicles do not result from the technical capabilities of the task, but from the proper planning and organization of a flight adapted to the goal we want to achieve. Proper planning and selection of flight parameters must take into account:

- the type of game we want to inventory,
- type of area where we intend to carry out the inventory,
- determining the correct altitude of the flights,
- the time of year in which we conduct the inventory,
- other specific restrictions.

The elements mentioned above are closely related. The first and fundamental issue that should be taken into account is, of course, the type of game that we intend to inventory. In general, we can talk about a general division into big game ( elk, deer, fallow deer, mouflon, wild boar and roe deer) and small game ( foxes, badgers, hares). Usually, however, we want a more detailed inventory of big game, so we will focus on it later in the article. Each type of game has a slightly different biotype, so it will occur in a different area, which may depend on the type of habitat, season, month, day and weather conditions. Knowledge of the behaviour of animals in a given area is a very important factor that guarantees the correctness and accuracy of the inventory. As a rule, the inventory is carried out at the end of winter, determining the condition of the game on March 10 of a given year. Then the grasses in the meadows are laid and there are no leaves on the trees and shrubs, thanks to which the forests are sufficiently transparent. In such a period, the use of a thermal imaging camera will give the best results, because you can easily take inventory into both field and forest areas.

Another element is determining the altitude of flights. On the one hand, the flight should be carried out low enough to be able to correctly identify the game. On the other hand, increasing the flight altitude gives a much larger area of observation. The selection of these parameters obviously depends on the type and resolution of the camera used, the angle of view, the diameter of the lens, magnification, etc. Therefore, it is impossible to provide specific data here, although some guidelines can certainly be drawn. As part of the field research conducted as part of the PBL project, flight tests were carried out with the Yuneec H520 drone equipped with the E90 camera operating in 4K resolution at 60 FPS. These tests were aimed at determining the actual area of the terrain covered by the identification at different flight altitudes and at analysing the possibilities of recognizing the game. Figure 7 shows photos taken at different heights of the drone. The control cross has a size of 1.25x1.25 m, photos were taken in 4K resolution.



**Fig. 7 Photos taken with Yuneec H520 drone with E90 camera from a height:  
a) 10 m, b) 30 m, c) 60 m, d) 100 m**

Analysing the above photos, it was found that the best results for the identification of the game with acceptable land cover are obtained at a height of approximately 60 m for large game and about 30 m for small game in the size of a hare or fox. At a height of 60 m the 0.58 ha area covered was obtained (rectangle 95 m x 62 m), while at 30 m the coverage was 0.15 ha (rectangle 47 m x 31 m). Another important aspect is the fact that the game is scared off by the noise caused by the drone's flight. The test was carried out on roe deer and hares. Roe deer in open terrain shied at flight altitudes up to 40 m, while above 50 m they did not pay attention to the flight. In the forest area, the flight at a height of 40 m (20 m above the trees) did not cause the escape of the game. The hares, on the other hand, turned out to be exceptionally little skittish game and even a flight at a height of 20 m did not scare them away. Here, however, it should be clearly emphasized that depending on the weight and construction of the drone, as well as weather conditions, they will emit different levels of noise, and determining the optimal height of flights will always be the most difficult task. Each scare of the game during the inventory will result in the need to repeat it on the next day.

Due to the intensive foraging of the game, it is the best to carry out the inventory at night. Then, the game leaves its daily refuges and stays in the open area looking for food. Most often these are cultivated fields sown with winter crops, covered with grasses and weeds, meadows and wastelands. Hence, the use of unmanned aerial vehicles equipped with an appropriate thermal imaging camera seems to be the best solution, allowing for a relatively easy location, identification and counting the animals. In the months of February and March,

when inventories of big game are most often carried out, forest areas are also transparent enough to make an inventory in them.

The last element of a technical nature is the selection of an appropriate thermal imaging camera. At the moment, for example, for H520 drones, 2 types of thermal imaging cameras are produced, namely the cheapest CGOET with a bolometric transducer resolution of 160x120 pixels, frequency 9 Hz, field of view of 56 degrees and sensitivity < 50 mK, and the most expensive E10TVX camera with a maximum bolometric resolution of 640x512 pixels., frequency 9 Hz, field of view 32 degrees, sensitivity < 50 mK and pixel size 12  $\mu\text{m}$ . For the purpose of the game inventory, the use of the first of these cameras should be excluded due to the insufficient resolution of the bolometer, as the image obtained from a distance of 60 m will be too imprecise. In the case of the second camera, the resolution of the bolometer is sufficient, but the refresh rate is too low. The field experiments show that the proper sharpness of the figure of a moving animal can be obtained in the case of a camera with an image refresh rate of approx. 50 Hz. The pixel size, thermal sensitivity of the camera and the viewing angle are acceptable in this case. The smaller the angle of view of the camera, the more accurate the image will be, but the smaller area of the terrain will be scanned at the same height of the flight. Apart from the camera parameters themselves, an important role is also played by the software adaptation to the intended purpose of work, the selection of an appropriate color palette, determination of the temperature sensitivity range and image scale, etc. However, the analysis of these parameters should be carried out on the basis of a specific camera model. The Yuneec H520 drone equipped with the E10TVX thermal imaging camera is shown in Fig. 8.



**Fig. 8** Yuneec H520 drone equipped with E10TVX thermal imaging camera

Source: photo [www.yuneec.pl](http://www.yuneec.pl))

## SUMMARY

The use of unmanned aerial vehicles for game inventory is an area of interest for many major research centers in Poland (Witczuk et al., 2018), (Witczuk et al., 2021) and around the world (Gonzalez et al., 2016). These studies mainly concern the accuracy of methods using thermal imaging, the possibility of recognizing animals with the use of artificial intelligence methods, etc. The

above subject is becoming more and more popular due to the emerging technical possibilities of replacing the classic methods of inventory, which are known to be inaccurate, very expensive and difficult in organisation. The increasing availability of more accurate thermal imaging cameras and technologically advanced drones with a much greater payload and flight time, gives the possibility of their more and more common use for the implementation of game inventory activities. The use of unmanned aerial vehicles (drones) equipped with a thermal imaging camera makes it possible to carry out an inventory practically by 2 people in a very short time. There is no need to engage dozens of observers and traverse the often inaccessible terrain. Research conducted in research centers also shows its high accuracy. Then, the field tests described in this article, carried out as part of the PBL work, proved that this technology can be used by such entities as hunting clubs or forest divisions to carry out annual inventory of animals. This article discusses the issue of game inventory with the use of drones equipped with a thermal imaging camera from the technical and organizational side. A number of trials and field tests were carried out with the use of available thermal imaging cameras. Preparatory works are currently underway for the implementation of flights in accordance with the guidelines provided, which will be possible to implement in the period from November to March. The obtained results will constitute material for further research.

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**Abstract:** Classic methods of stocktaking big game living in a given area have many disadvantages. The main result is the need to ensure appropriate terrain and weather conditions and also require the involvement of a large number of people, so-called observers. The development of technology makes it possible to create new stocktaking methods that will not have as many of the above-mentioned disadvantages, while reducing the cost of stocktaking and increasing its accuracy. This paper presents an analysis of the possibility of using unmanned aerial vehicles, so-called drones, in combination with the observation of game in the infrared wave range with the use of a thermal imaging camera. The paper presents the concept of such a solution, which will of course be further developed. Raids are planned with the use of thermal cameras over areas according to strictly defined transects and subjecting the obtained images to analysis, also with the use of artificial intelligence methods. This article was written as part of the PBL project carried out by a group of students from the Silesian University of Technology under the supervision of dr inż. Arkadiusz Boczkowski.

**Keywords:** stocktaking of big game, wild animals, thermal imaging camera, dron