Aerial ungulate surveys with a combination of infrared and high–resolution natural colour images

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Abstract

Aerial ungulate surveys with a combination of infrared and high–resolution natural colour images.— Information on animal population sizes is crucial for wildlife management. In aerial surveys, we used a silent light aircraft (microlight) and a combination of a computer–linked thermal infrared camera (640 x 480 pixels) to detect ungulates and high–resolution visual images (5,616 x 3,744 pixels) to identify specific species. From winter 2008/2009 to winter 2010/2011, we flew 48 missions over three German national parks and a German/French biosphere reserve. Within each study area, we followed non–overlapping linear transects with a flying altitude ~450 m above ground level and scanned 1,500–2,000 ha every two hours of flight time. Animals best detected and identified were red deer and fallow deer. Detection rates with respect to the type and density of vegetation cover ranged from 0% (young spruce) to 75% (young defoliated beech) to 100% (open land). This non–invasive method is cost–effective and suitable for many landscapes.

Key words: Aerial survey, Infrared camera, Microlight aircraft, Ungulates, Wildlife monitoring.

Resumen

Estudios aéreos de ungulados mediante una combinación de imágenes infrarrojas y naturales en color y alta resolución.— La información sobre el tamaño de las poblaciones animales es crucial para la gestión de la fauna salvaje. En los estudios aéreos, utilizamos un avión ligero y silencioso (ultraligero) y una combinación de una cámara infrarroja térmica (640 x 480 píxeles) conectada a un ordenador para detectar a los ungulados, e imágenes visuales de alta resolución (5.616 x 3.744 píxeles) para identificar las especies. Desde el invierno 2008/2009 al invierno 2010/2011 volamos en 48 misiones sobre tres parques nacionales alemanes y una reserva de la biosfera franco–alemana. En cada área de estudio, recorrimos transectos lineales no solapados con una altitud de vuelo aproximada de 450 m sobre el nivel del suelo, y escaneamos 1.500–2.000 ha cada dos horas de vuelo. Los animales que mejor se detectaron e identificaron fueron el ciervo común y el gamo europeo. Las tasas de detección con respecto al tipo y densidad de la cubierta vegetal fueron del 0% (píceas jóvenes), pasando por el 75% (hayas defoliadas jóvenes) al 100% (terreno abierto). Este método no invasivo tiene unos costes ajustados y es adecuado para muchos tipos de paisajes.

Palabras clave: Estudio aéreo, Cámara infrarroja, Avión ultraligero, Ungulados, Estudio de la fauna salvaje.

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Introduction

Data on the population size and/or density of larger mammals, such as ungulates, is essential for wildlife management, forestry, wildlife conservation, and land–use development (Apollonio et al., 2010). Several methods can be used to determine population densities of red deer (*Cervus elaphus*), fallow deer (*Dama dama*), roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*), such as pellet counts, track surveys, spotlight counts and genetic capture recapture surveys (Tottewitz et al., 1996; D'Eon, 2001; Campbell et al., 2004; Garel et al., 2010; Ebert et al., 2012). However, in densely forested areas, there is as yet no accurate, robust and cost–effective method to count ungulates in a practical way (Strandgaard, 1972; Pielowski, 1984; Gaillard et al., 1998; Smart et al., 2004; Borkowski et al., 2011). Coordinated counts and drive counts are not very reliable and staffing costs are high. Track counts are restricted to a period with snow cover. Spotlight counts depend on a road network and good visibility in the forest stands (Focardi et al., 2001), Capture–Mark–Recapture studies are labour intensive and the laboratory work of genetic studies is currently still expensive. However, both methods could deliver accurate and precise results (Gill et al., 1996; Cederlund et al., 1998; Lukacs & Burnham, 2005; Curtis et al., 2009).

Although aerial infrared surveys have been conducted in the past (Garner et al., 1995; Naugle et al., 1996; Haroldson et al., 2003; Bernatas & Nelson, 2004), they are not yet widely used to monitor animals, probably because of the relatively high costs and the lack of species–specific identification using only infrared images. Until now, in most aerial surveys, the camera operator actively searches for ungulates (Havens & Sharp, 1998; Bernatas & Nelson, 2004; Potvin & Breton, 2005). The disadvantage of this method is that the results depend heavily on the experience of the operator (Garner et al., 1995; Naugle et al., 1996; Haroldson et al., 2003).

To date, mainly helicopters or twin– or single–engine aircrafts have been used. Helicopters, in particular, have the disadvantage that they potentially disturb wildlife, leading to biases in data aquisition.

In 2004, we began to test thermal infrared cameras mounted on a silent and cost–effective microlight aircraft, which under German regulations is a light airplane with a maximum takeoff weight (MTOW) of 472.5 kg. In 2008 we began to improve and test the methodology. Our aim was to develop and test a standardized, non–invasive, observer–independent, and cost–effective method to count large mammals, especially in forested areas. Here we present the first results obtained while establishing the system.

Material and methods

Study sites

Starting in 2004, we flew more than 60 missions over various types of areas, from flat land to mountainous regions and from land with open shrub cover to 100% forested regions with 60% coniferous trees. From winter 2008/2009 to winter 2010/2011, we flew 48 missions over three German national parks and a German/French biosphere reserve.

The Bayerischer Wald National Park in south–eastern Germany is 24,250 ha with altitudes ranging from 600 to 1,450 m a.s.l. The vegetation consists mainly of high montane Norway spruce *(Picea abies*) forests and mixed mountain forest with European beech (*Fagus sylvatica*), Norway spruce, and white fir (*Abies alba*). The land cover of the southern part of the park is 16% coniferous forest, 25% deciduous forest, 26% mixed forest, 30% dead–wood stands as a consequence of an ongoing bark beetle (*Ips typographus*) outbreak (Lausch et al., 2010) and 3% open land. The northern part is covered with 39% coniferous forest, 19% deciduous forest, 31% mixed forest, 10% dead wood, and 1% open land. The following ungulate species occur in the park: red deer, roe deer, and wild boar (Heurich et al., 2011).

The Hainich National Park is 7,500 ha and lies in central Germany. It consists of 51% deciduous forest, 30% open land, 16% pioneer forests, and 3% coniferous forest. Lying at around 450 m a.s.l., the park has only small altitude differences. It is inhabited by red deer, fallow deer, roe deer, and wild boar.

The Kellerwald–Edersee National Park is 5,700 ha and is situated in central Germany. Altitudes range from 200 to 626 m a.s.l. It consists of 78% deciduous forest, 15% coniferous forest, 4% open land, and 3% undefined landscape. It is inhabited by red deer, fallow deer, roe deer, and wild boar.

The central part of the German/French biosphere reserve Pfälzerwald–Vosges du Nord contains a 10,400 ha wildlife investigation area in south–western Germany. Altitudes range from 210 to 609 m a.s.l., and the area consists of 61% mixed coniferous forest, 29% deciduous forest, 6% open land, and 4% undefined landscape. It is inhabited by red deer, roe deer, and wild boar.

Technical equipment

For the aerial surveys, we used a silent, slow–flying microlight airplane (S–Stol) that has very low operating costs (fig. 1). The cost of operating the aircraft without technical equipment is about 100 €/h, compared to approximately 1000 €/h for a helicopter.

The microlight plane was equipped with two camera mounts that provided a nearly vertical view towards the ground and a computer–linked camera system consisting of a JENOPTIC® infrared camera (640 x 480 pixels) and a Canon 5D Mark 2® high–resolution RGB camera (5,616 x 3,744 pixels). The infrared camera used a microbolometer detector that is sensitive to wavelengths of 7.5–14 µm and resolves temperature differences of 0.08 Kelvin. The lens had a field of view (FOV) of 12 x 9°, thereby providing a 96 m wide swath when flying 450 m above ground level.

Data acquisition

Sampling design

To guarantee a standardized and transparent method,

Fig. 1. Microlight aircraft used for aerial wildlife monitoring.

Fig. 1. Avión ultraligero utilizado para el estudio aéreo de la fauna salvaje.

we flew pre–designed, non–overlapping transects that cover each investigation area completely (see example in fig. 2). The transects were 250 m apart, thus having about 150 m between two transects not scanned by the cameras. In mountainous regions, we planned the transects along the contour lines to minimize large altitude differences. The aircraft flew at approximately 100 km/h, and the cameras scanned 1,500 to 2,000 ha of study sites of 5,000 to 10,000 ha within two hours of flight time. We divided larger areas like the Bayerischer Wald National Park into two areas to maintain sampling sizes of one–third to one–fifth of the investigation area.

Non–overlapping transects reduced the chances of double counting. To reduce the chances of double counting further, we had a closer look at the species, group size, and behaviour when detection events were close to each other on neighbouring transects.

As infrared radiation does not penetrate vegetation, we flew most missions after leaves had fallen, from November to April. We also flew some missions in summer in areas where there was less tree coverage. In addition to testing the effect of the time of the year and the ambient temperature on the recording, we tested the time of the day and external radiation.

Data recording and interpretation

Both camera systems were connected to an onboard computer. The infrared camera produced a film, and the data was stored on a hard disk in real time. The advantage of digital data is that the temperature level and range can be later changed as appropriate, which is not possible with older systems where the data is stored on video tape. As weather and radiation conditions can change frequently during one flight, there was then no need to calibrate the temperature level and range during the flight. The visual images were stored on a compact flash card. Whenever a visual image was taken, the file number was written in the infrared data stream to enable an easier association of infrared and visual images. A global positioning system (GPS) enabled the pilot to fly the predefined transects and to store the actual flight path. These data were used to geo–tag the detection sites.

The data were analysed on a computer with two screens, one showing the infrared film (fig. 3A), and the other showing the visual images (fig. 3B). Whenever something raised the attention of the observer in the infrared film, the visual image was used to verify the detection. This enabled differentiation, for example, between an animal lying on the ground and a recently vacated and still warm resting area. If the observation was uncertain, the detection was not counted. As the detected radiation of an animal and its surrounding can vary, it was necessary to change the temperature level and ranges frequently and to rewind sequences to double check. The data were stored for reinterpretation or interpretation by another person.

Test of dependence of detection rates on the degree of vegetation cover

We worked only with the number of animals actually counted as a minimum number; we did not use correcting factors, such as the detection probabilities. Nevertheless, we tested the dependence of detection rates on the degree of coverage. We used mid–sized dogs as test animals at 116 positions on test transects with different types of vegetation cover: old spruce with animal close to the trunk, old spruce with animal between two trees, old defoliated beech with animal close to the trunk, old defoliated beech with animal between two trees, young spruce, young defoliated beech, and thicket, and open land as a reference. At each position, the degree of coverage was calculated by transforming a photograph taken vertically from the

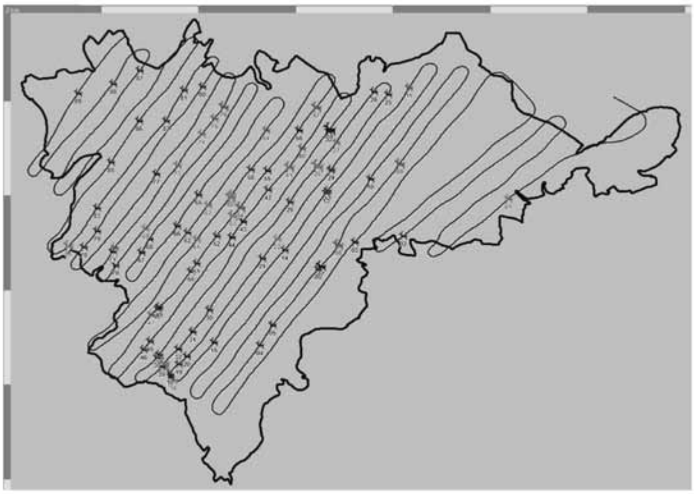

Fig. 2. Flight path along transects over the approximately 6,000 ha study site of the Kellerwald–Edersee National Park. All 89 detection sites are shown with one or several animals per site.

Fig. 2. Trayectoria de vuelo a lo largo de los transectos, sobre aproximadamente 6.000 ha de la zona de estudio en el Parque Nacional Kellerwald–Edersee. Se indican los 89 lugares de detección, con uno o varios animales por lugar.

ground towards the sky into a binary black–and–white picture. We defined the degree of coverage as the ratio of pixels that showed the vegetation to the number of all pixels. Vegetation cover ranged from 0% for open land to 97% for young spruce forest. For each position, the degree of vegetation cover and the detection by the IR camera (yes or no) were noted.

Results

Equipment and flight parameters

To determine the footprint of the cameras and their geometrical resolution, we tested flying at altitudes of 300, 450, and 600 m above ground level over an enclosure with red deer. An altitude of 450 m provided

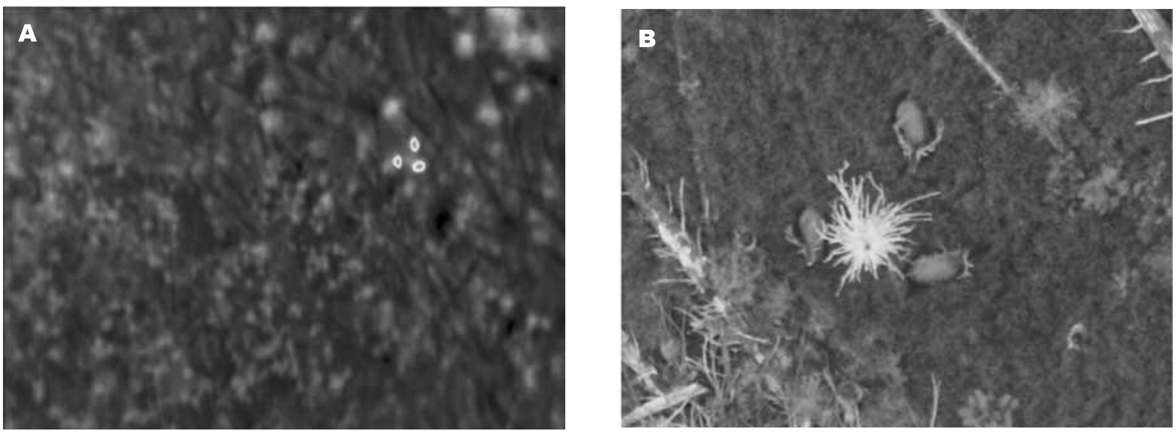

Fig. 3. Detection of animals using infrared camera (A) and close up of visual image taken in parallel to the infrared image, showing three male red deer (B).

Fig. 3. Detección de animales utilizando la cámara infrarroja (A) y ampliación de la imagen visual tomada en paralelo con la imagen infrarroja, mostrando a tres ciervos comunes machos (B).

the best combination of the size of the scanned area and geometrical resolution.

At this flight height we did not observe any disturbance to wildlife caused by the aircraft either during our flights across enclosures or in any of our video recordings during our survey flights.

Time of year/day and meteorological conditions

We hypothesized that cold winter days with a snow cover would be the best time of the year to use thermal infrared since the temperature difference (ΔT) between the animal and the background should be at its highest. Unexpectedly, we observed, for example, small ΔTs on a winter flight at –13°C with snow–covered ground and large ΔTs on a summer flight with ambient temperatures of approximately 20°C. The ambient temperatures, therefore, were a weak factor at most.

We tested the effect of the time of day on the recordings by flying from early morning to late evening. The best results were obtained around midday.

One of the strongest influencing factors was the external radiation from sunlight. In bright sunlight, other objects, *e.g.* tree trunks and rocks, were sometimes misinterpreted as animals, and the emission of treetops sometimes prevented the detection of an animal standing underneath them. The best conditions found for the thermal infrared survey during the day was an 8/8 cloud cover (overcast).

Table 1. Species of animals clearly identified using infrared and visual cameras mounted on a microlight aircraft. The data are from 28 flights flown from II 09 to IV 11: Na. Number of animals; Nd. Number of detections; Na/d. Number of animals per detection.

Table 1. Especies de animales claramente identificados utilizando cámaras infrarrojas y visuales montadas en un avión ultraligero. Los datos proceden de 28 vuelos del II 09 al IV 11: Na. Número de animales; Nd. Número de detecciones; Na/d. Número de animales por detección.

Species	Na	Nd	Na/d
Red deer	495	150	3.3
Fallow deer	249	52	4.8
Wild boar	239	80	3.0
Roe deer	20	15	1.3
Foxes	12	11	1.1
Wolves	6	2	3.0
Badgers	1	1	1.0
Total animals	1,022	311	3.3

Species detection and identification

The success rate of verifying the thermal images with the visual, natural colour images increased from 60% in 2008/2009 to over 90% in 2010/2011.

In most study sites, different species were present. Therefore, a clear distinction between the species was necessary. Infrared data alone did not suffice to distinguish between, for example, red deer and fallow deer in one study site, but with the visual imagery in addition, we were able to identify nine different species (table1). The species of animals detected was identified in 50% of cases. Animals in groups, *e.g.*, red deer or fallow deer, were easier to detect than single animals. It was also easier to identify the species of a group, assuming that all animals in the group belonged to the same species, than to identify the species of a single animal, since the chance of having one animal clearly visible in the image increased with the number of animals in the group.

Although the infrared signature of wild boar was also easy to distinguish, it was difficult to count exact numbers of animals because they often clustered close together.

In all our surveys, roe deer were obviously underestimated, as we counted only 0 to 4 individuals per flight and harvest rates indicated much higher numbers.

Successive flights and representativeness of samples

We surveyed each of the four areas three times within as short a period as possible and every year for three years, originally to obtain a statistical repetition. We soon realized that many factors influenced the results. The main factor influencing the aerial infrared surveys was the weather, which could allow us to fly two missions in one day or force us to wait a week between flights. Therefore, it was difficult to treat three successive flights as a statistical repetition, as the weather was seldom the same over several days. The repetitions were thereafter used to obtain one survey with the highest numbers only. Here we present the results of two examples of three successive flights over two different areas (table 2).

The three flights over the Kellerwald–Edersee National Park were conducted during similar weather conditions (overcast, 12°C). The minimum population densities of red deer and fallow deer ranged from 5.5 to 6.6 animals/100 ha. With a coefficient of variation (CV) of 10%, the three flights yielded similar results.

The three flights over the Hainich National Park were conducted during different weather conditions. There were overcast skies and ambient temperatures of 7°C during the first two flights and a 3/8 becoming a 5/8 cloud cover during the third flight with ambient temperatures of 13°C. The minimum population density of red deer and fallow deer was 4.4 animals/100 ha during the first two flights and only 1.3 animals/100 ha during the third flight. The CV was 52%.

To check our samples for representativeness, we used statistics for one typical survey flight of the Hainich National Park, where we estimated a minimal

Table 2. Comparison of the variation of data from three flights, each for two investigation areas: Min. Minimum number of red deer and fallow deer; DN(100). Population density (number/100 ha) (Mean, standard deviation [SD] and coefficient of variation [CV]).

Table 2. Comparación de la variación de datos de tres vuelos, cada uno para dos áreas de investigación: Min. Número mínimo de ciervos común y gamo europeo; DN(100). Densidad de población/100 ha (Media, desviación estándar [SD] y coeficiente de variación [CV]).

					DN(100)		
Site	Date	Min.	Area scanned	DN(100)	Mean	SD	CV[%]
Hainich	16 III 2009	47	1,074	4.4			
	18 III 2009	74	1,673	4.4	3.4	1.8	52%
	30 III 2009	23	1,709	1.3			
Kellerwald	09 IV 2010	111	1,680	6.6			
	10 IV 2010	97	1,768	5.5	6	0.6	10%
	14 IV 2010	103	1,768	5.8			

density for all ungulates of 13.9 animals per 100 ha. From the flight data, we evaluated ten random subsamples of each sample size (P80, 80% of the whole flight; P70, 70% of the whole flight; P60, 60% of the whole flight, and P50, 50% of the whole flight) (fig. 4). The largest variation of 10.6 animals/100 ha to 13.9 animals/100 ha (23.7%) was found as expected within the P50 plot. The ten subsamples did not differ significantly, which is the first evidence that for this particular survey, the flight work could be reduced without losing representativeness.

Test of dependence of detection rates on the degree of vegetation cover

As expected, the detection rates increased with a decrease in forest cover (table 3). The detection rates ranged from 0% (young spruce) to 75% (young defoliated beech) to 100% (open land). We divided positions in old spruce and old beech forests into two subclasses —with the test animal close to the tree trunk and with the test animal between two trees— to check whether the detection of an animal is blocked by a large tree trunk or by the many branches of neighbouring trees. In beech forests, the detection rate was best when the animal was located close to the trunk; in spruce forests, the detection rate was highest when the animal was located between two trees.

Discussion

The microlight airplane proved to be a good camera platform for wildlife surveys. The fact that the animals were not disturbed by the aircraft can be explained by the very low noise level of 59.1 db(A) of the used aircraft (noise certificate). In comparison, the noise level of an EC 135 helicopter we used for night flights some years ago 84 db(A) was marked on the noise certificate. Moreover, the microlight plane can use a great variety of airstrips, including very small ones; it can be operated freely, and transfer times can be kept very short. In some countries, microlight aircrafts are allowed to land in any field with the consent of the owner. Costs are kept to a minimum because of the low fuel consumption.

In the aerial surveys of Bernatas & Nelson (2004) and Haroldson et al. (2003), the flight pattern was determined by active searches for animals. This method has the advantages of large areas being covered and probably higher detection rates. Depending on the camera system, an active search also enables the operator to change to near field of view (NFOV) to identify the species with the IR camera only, thus also enabling night surveys with species–specific identification; however, only a small area can be surveyed while in the NFOV mode. The results of Haroldson et al. (2003) were highly variable; the sensor operation was inconsistent, the two operators had difficulty panning the cameras systematically, and the thermal contrast was variable. In an attempt to achieve a higher degree of standardization, we instead decided to use a predefined flight route with fixed cameras. The advantages of our standardized transect flight pattern were that there was no bias between different operators during the data acquisition and that the digitally stored data allowed multiple evaluations by different interpreters, thus making the method more transparent.

Daniels (2006) assumed that fresh snow, complete cloud cover and low temperatures were optimal conditions for the IR technology, whereas our results indicated that the thermal IR technology can be used throughout the year in terms of temperature differences between animal and background. This is in agreement with Bernatas & Nelson (2004), who found that the

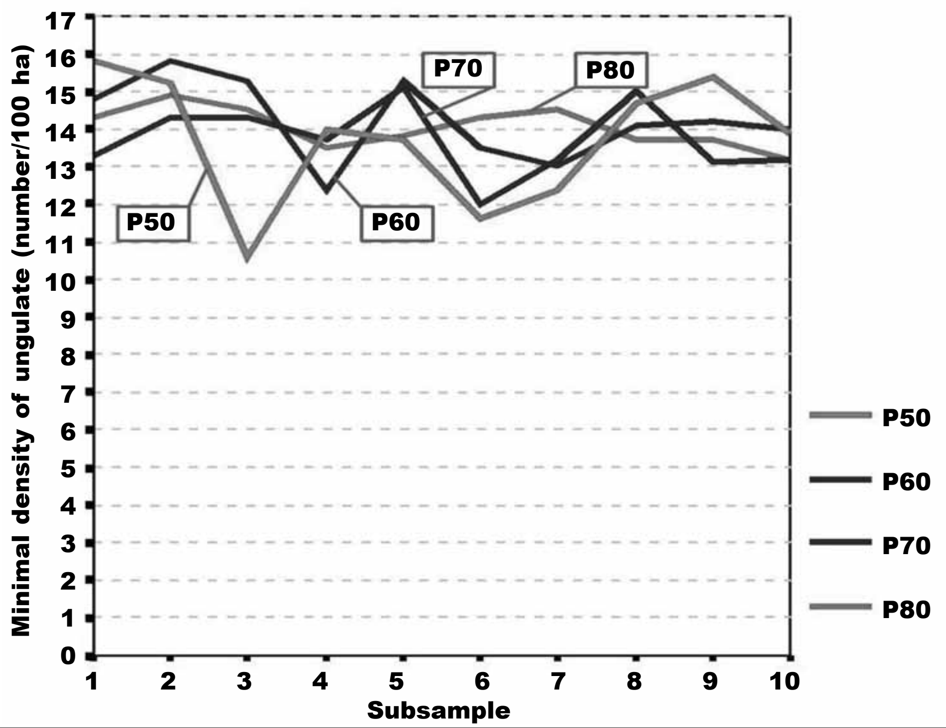

Fig. 4. Representativeness of survey. Ten random subsamples of sample sizes of 80% (P80), 70% (P70), 60% (P60), and 50% (P50) of one entire survey flight over Hainich National Park were chosen, and the minimal density of all ungulates for each subsample of each sample size was calculated.

Fig. 4. Representatividad del estudio. Se eligieron diez submuestras tomadas al azar con tamaños del 80% (P80), 70% (P70), 60% (P60) y 50% (P50) de un vuelo de estudio sobre el Parque Nacional Hainich, y se calculó la densidad mínima de todos los ungulados para cada submuestra de cada tamaño de muestra.

ambient temperature does not greatly influence the detection of wildlife with IR. During summer, foliage could interfere with thermal IR, but the technology can still be used if there is not much vegetation cover. In forested regions, it is necessary to conduct surveys during the months when the trees are defoliated.

Aerial surveys with thermal IR at night time have the advantage of minimal jamming by other radiation. During the day, other objects, such as rocks and tree trunks might become heated or reflect radiation and they can then be misinterpreted as a detection event. However, we had to fly between sunrise and sunset, first because microlight aircraft in Europe are only allowed to be operated during daytime, and second, because we used visual images for identification. The best results were obtained around midday. This finding is in accordance with the results of Arnold et al. (2004), who described that the subcutaneous temperature of red deer in winter could be more than 10°C lower in the early morning than at other times. But in our opinion, the most important factor for infrared surveys during the day are homogeneous conditions, preferably with an 8/8 cloud cover.

With higher numbers of visual images recorded during one flight, we were able to increase species' identification to about 50% of all detected animals. Although we only used the visual data to identify the species as these data are much clearer than IR data, if we were to use the different IR signatures of the species, we could achieve a higher percentage of species identification. If only species living in groups (*e.g.* red deer or fallow deer) are of interest, species identification would be greater than 50% because at least one animal can usually be identified in the visual image.

Roe deer were underestimated in our studies, most likely because of their solitary mode of life in forest habitats, their smaller body size, and their ability to hide in thick vegetation. We detected many smaller IR signatures, but could not identify them on the visual images. In tests with roe deer in fields and with roe deer that we positively identified, we obtained thermal IR signals; the lack of thermal radiation is not therefore the reason for their underestimation. If we disregarded all the single detection events of small animals and objects, the rate of species identification would be much higher.

Our comparisons of three consecutive flights indicated that the data cannot always be used as a statistical repetition. The data from the Hainich National Park survey showed a large variance. We think that

Table 3. Dependence of detection rates on the degree of vegetation cover. Test animals were placed at the indicated positions, and their detection by infrared and visual cameras was tested.

Tabla 3. Dependencia de las tasas de detección del grado de la cubierta vegetal. Los animales de prueba se situaron en las posiciones indicadas, y se estudió su detección mediante cámaras infrarrojas y visuales.

Vegetation	n	Average degree of cover (%)	Detection rate (%)
Old defoliated beech, animal close to trunk	16	62	94
Old defoliated beech, animal between two trees	16	62	88
Young defoliated beech	16	63	75
Old spruce, animal close to trunk	16	84	50
Old spruce, animal between two trees	16	85	63
Young spruce	16	90	0
Thicket	16	30	81
Open land	4	0	100

this is not due to the 12 days between the second and the third flight, but rather to worse weather conditions on 30 III 09. This notion is supported by the fact that the weather conditions during the three flights over the Kellerwald–Edersee National Park were similar and the results varied only little.

Our statistical test of subsamples of the survey showed that our sample size was representative, at least when all ungulates were considered together. Further tests of species often present in larger groups, *e.g.* red deer or fallow deer, are needed.

In our test of dependence of detection rates on the degree of vegetation cover, the interpreter of the infrared data was aware that dogs were present as test animals. In addition, the dogs were placed more or less on the centre line of the transect to avoid animals being outside the camera range. This knowledge and set up probably led to higher detection rates. In future evaluations, we intend to mix the images and include some showing no animals.

The use of airborne thermal and visual imagery to monitor wildlife has the advantage of sampling larger areas per time unit than other methods. Furthermore, there is no dependence on roads and tracks. The combination of a thermal infrared and a visual camera together with the stored data makes the method even more transparent. We believe that this method will be used more frequently in the future.

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