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Comparison of Methods for Estimating Damage by Wild Ungulates on Field Crops

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Abstract: High numbers of large ungulates are locally accompanied by high levels of damage to field crops, causing economic losses and increased costs for the protection of agricultural fields. Quantifying the levels of damage can be problematic, with the degree of accuracy depending on the method used. The aim of this study was to compare the accuracy, workload and cost of four methods commonly used for estimating damage to wheat fields caused by large ungulates (esp. wild boar) in the Czech Republic. The results suggest that the manual processing of aerial photographs ("Uncrewed Aerial Systems [UAS] with Operator Delineation Method") was very laborious and the least accurate method, with a high risk of error. In comparison, the automatic evaluation of aerial images ("UAS Crop Height Method") and the "Ground-Based Assessment" both provided similar results when carefully analyzed and were equally demanding. The "Yield Method", comparing the net yield from damaged and undamaged areas, provided the same result of assessment and was the least laborious, although it does require the existence of comparable areas and for the conditions to be created in advance before the method is used. Equivalent results were achieved by the UAS Crop Height Method, which we recommend using in cases where the Yield Method cannot be applied.

Keywords: crop yields; wheat; wildlife damage; Uncrewed Aerial Systems; drone

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1. Introduction

At present, the Central European landscape is characterized by a high number of large ungulates that are able to find sufficient food and shelter [1–3], despite significant changes to their habitat and strong anthropogenic pressure. The existing regulatory factors, such as unfavourable environmental conditions, natural mortality and hunting, are insufficient for significantly reducing their abundance; indeed, populations of some species are growing [4,5], leading to increased conflicts with human interests [6–8]. The most significant issues at present include health risks to humans and livestock [9,10], traffic accidents [11], impacts on biodiversity and the ecological stability of ecosystems [12] and, perhaps the most widespread and economically significant issue, damage to field crops and forest stands [13,14].

Field crops and woody plants in forests are a very often preferred component in the diet of large ungulates. These feeding preferences reduce crop yields and threaten forest growth and species composition [15,16]. In addition to direct consumption, other activities, such as trampling, lying [17,18] or uprooting [19], can be a serious source of damage. At sites with a high number of ungulates, their overall impact may fundamentally limit landscape management [20,21]. Therefore, there is a real need for the development of tools that will reduce the damage to tolerable levels, such as an increased regulation of herbivore populations, improving local environmental conditions and/or increasing the supply of alternative natural food and preventative measures to reduce the risk of damage, alongside the use of reliable and practicable damage estimation methods [22,23]. Damage estimation methods are particularly important for farmers as they provide direct evidence of the scale of damage and can provide indisputable data on the amount of damage when negotiating for compensation. At present, however, there is no standard methodology available, especially for field crops, and the methods that are used tend to be too laborious, expensive or imprecise. We therefore decided to evaluate the accuracy, labor and cost of the most frequently used methods for estimating damage to agricultural crops by large ungulates. The most commonly used method for the estimation of field crop damage in use today is the "Walking Method", also known as the "Ground-Based Assessment". This requires the observer to walk through the crop and estimate the extent or proportion of damage to partial plots [24]. This method can be very laborious in the case of large fields or the need for high precision. In more recent years, walking has often been replaced by aerial photography using unmanned aerial vehicles, or drones ("UAS Crop Height Method" and "UAS with Operator Delineation Method" [25]), which are easily available and are constantly being updated with sensors and software that can also be used to calculate the actual damage caused by game to the field crops [26–29]. Using a drone to determine the damage in fields is not laborious, but it requires special equipment and knowledge of the calculation, which makes this method difficult to access for common practice. In addition to the methods listed and tested by us, there is also a great potential for using images taken from drones in the use of vegetation indices obtained from multispectral images (e.g., Normalized Difference Vegetation Index [30], Enhanced Vegetation Index) and textural feature extractions [25]. The indices are additionally usable for verifying the homogeneity of the conditions of the compared fields within the last method, which we tested. The use of these methods in practice is very suitable for estimating the overall extent of damage, but very problematic from the point of view of quantifying the resulting damage [31]. Therefore, in our study, we also included a method that calculates the value of the loss, regardless of the overall extent of the damage. A fourth option is the "Yield Method", which is based on a comparison of the yields from damaged and undamaged areas [32]. The Yield Method is promising as it can accurately show low level or difficult to detect damages at relatively low cost; however, its applicability is limited by two factors, i.e., the requirement of comparative areas with the same potential yield and the need for verification that the damage in the area was not caused by other factors.

The aforementioned methods have their advantages and disadvantages or require the fulfilment of specific conditions for their use. If it is necessary to quantify wildlife damage to field crops, it is necessary to take into account the degree of accuracy required, as well as the costs, labour and a whole range of other factors, in addition to the environmental conditions of the area of interest and the surrounding area.

Therefore, the aim of this study was to compare the accuracy, workload and cost of the four commonly used methods, i.e., the Ground-Based Assessment, the UAS Crop Height Method and the UAS with Operator Delineation Method, compared to the reference Yield Method, in an effort to identify the most appropriate method for estimating the damage to agricultural crops by large ungulates, using the example of winter wheat.

2. Materials and Methods

2.1. Study Area

The 208,700 m^2 field monitored in this study lies in the south-eastern part of the Czech Republic, near the town of Vyškov (49°19′13.7″ N 16°56′39.5″ E). The field, which was sown with winter wheat (*Triticum aestivum*; JINDRA CPG variety, Limagrain Central Europe Cereals, s. r. o.), is bordered on two sides by extensive forest, the other sides being bordered with fields of barley (*Hordeum vulgare*) and wheat. No mechanical means for preventing animals from entering the monitored area (e.g., fences) were in use, nor any means for disturbing or repelling animals. In addition to wild boar (*Sus scrofa*), roe deer

(*Capreolus capreolus*) also occur sporadically in the monitored area, although their impact on the field is believed to be negligible. Prior to monitoring, the wheat crop was growing well and evenly, and there was no sign of damage by herbivores until ripening. From the milky ripeness stage on, however, the field was regularly visited by wild boar, and visible damage, in the form of laid and trampled areas of various shapes and sizes, gradually developed (see Figure 1).

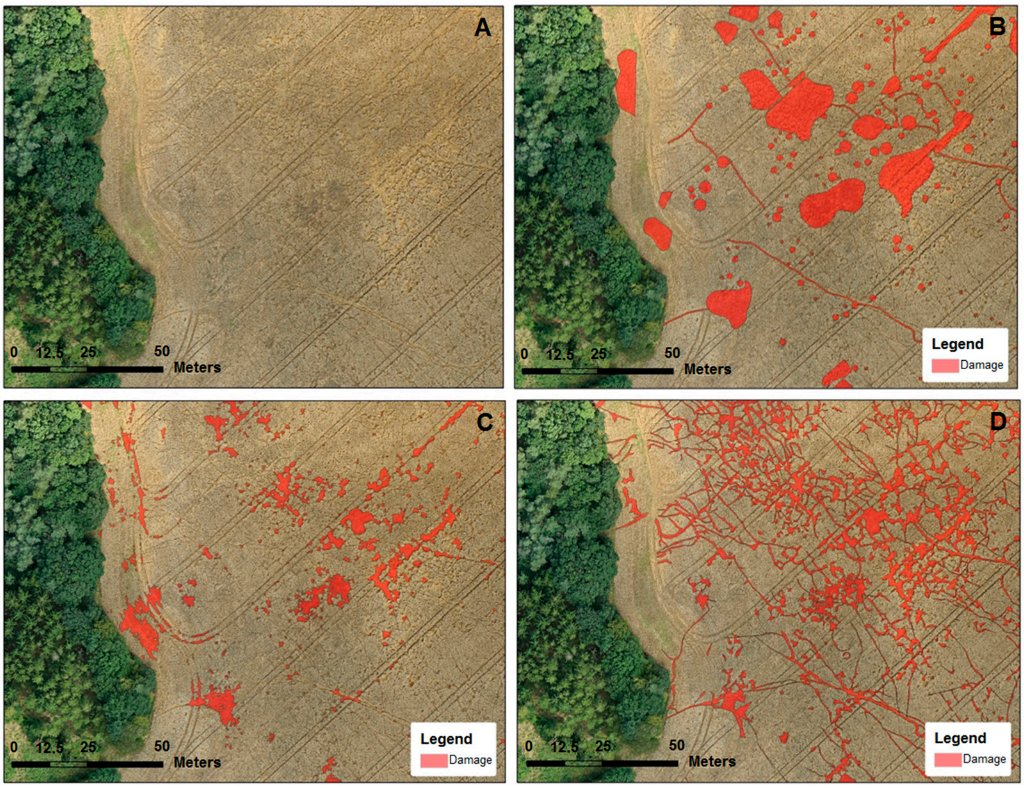

Figure 1. Part of the study area, showing different levels of damage detection based on the three methods. Note: (**A**) = orthophoto of part of the damaged field, (**B**) = damage detected using the Ground-Based Assessment, (**C**) = damage detected using the UAS Crop Height Method, (**D**) = damage detected using the UAS with Operator Delineation Method.

A neighbouring field with a similar area (21.04 ha), on which the same crop was grown using identical technology, was used as a comparative area for the Yield Method. Both fields had almost identical soil conditions (Haplic Cambisol), southern exposure and altitude (380–420 m ASL) and had been cultivated with the same crops in the previous few years. This comparison field was not damaged by wild boar as disturbance factors (e.g., road, cycle path and sidewalk) ensured the animals remained in quieter fields closer to the forest edge. Similarly, there was no damage attributable to other factors, such as mistakes when using agricultural equipment. Due to their similar environmental conditions and recent yields, the two areas were therefore considered to be comparable in terms of their production potential.

2.2. Ground-Based Assessment

Damage to the field (damaged area was defined as an area with trampled plants whose height was lower than 30 cm—this height corresponded to the height of the combine cutter bar; it was not possible to collect the plants with the harvesting machine) was mapped two days before harvest in the month of July, at which time the entire area was checked by assessing adjoining 12 m wide strips. To collect the data, observers systematically followed a line through the center of the strip and used a hand-held GPS device to record any damage to the vegetation (esp. trampling and lying of wild boar). The size (in m^2) of each damaged part of the study area was then determined, along with the percentage of damage in relation to the total area.

Small damaged areas of up to 15 m^2 were recorded on the GPS device as a point at the approximate center of the area, and the actual size (in m^2) and proportion of damage were estimated directly in the field. Larger damaged areas were recorded in the GPS device as polygons whose shape and size corresponded to the area damaged. In this case, the observers walked along the border of the damaged area. The extent of damage in these larger areas was estimated in the field and the actual area damaged was calculated later. At the same time, the entire area was checked (within the assessment in the 12 m wide strips) for the presence of yield losses caused by factors other than wild boar, such as agricultural machinery (e.g., tracks from the machines).

2.3. UAS Crop Height Method

In this case, the level of damage was estimated based on differences between two 3D models of the terrain surface, i.e., the damaged field and an undamaged control. The model surfaces were created using automatic image scanning of the area of interest by an unmanned aircraft (drone), one model surface being without vegetation and the other being of the pre-harvest field. Imaging with wheat crops was carried out two days before harvest and the uncropped soil was imaged one month after harvest (in the month of August). Prior to scanning, seven ground control points were affixed over the entire area, allowing the assignment of coordinates and an altitude system to the models. In this case, the accuracy of the model was determined by the accuracy of the ground control point specification [33]. To ensure maximum accuracy, the points were specified using a Topcon Hyper Pro geodetic GNSS station using the RTK method of the CZEPOS network, with a resulting accuracy of 20 mm in the horizontal component and 30 mm in the vertical component.

The images were taken using a DJI S800 drone [34] equipped with a Sony NEX 5R 16 Mpix digital camera fitted with a Voygtlander Super Wide Heliar 15 mm lens. The flight path of the drone was set so that the entire area was systematically covered by individual images (377 in total), with a 95% overlap longitudinally and 75% overlap transversely. The drone automatically adhered to a set flight level of 150 m above the ground (ground resolution = 4.31 cm pix^{-1}). This procedure guaranteed the visibility of each point of the area of interest in at least nine images, allowing for the creation of a very accurate 3D model.

Two 3D models of the surface were created from the acquired images using the Agisoft PhotoScan software, version 1.4.4, and according to the SfM method [35]. The models thus created were then subtracted from each other in ArcGIS 10.1, the resulting threshold being based on a selected limit value of 30 cm (which corresponded to the height of the combine cutter bar). Vegetation higher than 30 cm was considered undamaged and vegetation less than 30 cm was considered damaged (esp. trampling and lying of wild boar).

2.4. UAS with Operator Delineation Method

The orthophoto images taken using the UAS Crop Height Method were also used for this method. With the images displayed at a 1:100 scale in ArcGIS 10.1, the damaged polygons were manually marked using the Shapefile Feature Class tool. In this case, damage detection of lying and trampling depended on the subjective assessment of the observer.

2.5. Yield Method

As both fields were harvested at the same time and using the same harvesting technique, any loss in production caused by damage was determined as the difference in the yields between similar areas of the undamaged and damaged fields. The sufficient similarity of these comparative areas is determined using yield potential maps and is determined statistically. The applicability of both fields for this method was also verified by comparing their historical yields (five-year series), which in the case of wheat, were 5.4 ± 0.3 t ha^{-1}.

The percentage damage for the Yield Method was calculated from the yield loss in t ha^{-1} damaged and undamaged part (see [32]).

2.6. Data Analysis

The Ground-Based Assessment, UAS Crop Height Method and UAS with Operator Delineation Method were all based on a basic square unit of 100 m^2, of which there were 2173 square units in total. The damage percentage of each square was obtained from the ratio of the damage to the total area of the square. The damage of the square was calculated in ArcGIS 10.1 for each method separately (from manual recording in the GPS device within the Ground-Based Assessment; from 3D model within the UAS Crop Height Method; from manual marking within the UAS with Operator Delineation Method). Squares with a defined damage percentage were grouped into classes of damage rate (0–5%, 5–10%, etc.) for comparison with the number of damaged squares between methods. The total size of the damaged area was determined using these individual squares. Finally, the average damage with 95% confidence intervals was also calculated for each method (from the damage percentage of squares). As the data obtained did not meet the conditions of even distribution, the non-parametric Kruskal-Wallis test and the multiple comparison test were used to determine whether these three methods all gave the same results. All calculations were performed in STATISTICA 12 [36] and evaluated for a significance level of $\alpha = 0.05$.

3. Results

In total, 109.87 tons of wheat (5.265 t ha^{-1}) were harvested from the damaged wheat field, and 116.69 tons (5.546 t ha^{-1}) from the undamaged field. Damage in the monitored area caused by factors other than wild boars was insignificant and was not taken into further consideration.

The damage calculated using the UAS with Operator Delineation Method was almost two times greater than that described by the other methods (Figure 2, Table 1), the percentage damage being significantly different at $p < 0.001$ (Kruskal-Wallis), while a multiple-comparison test indicated no significant difference in the percentage damages detected by the Ground-Based Assessment and UAS Crop Height Method ($p > 0.05$). A significantly higher damage rate was recorded in the 0–5% class using the Ground-Based Assessment and UAS Crop Height Method, whereas the UAS with Operator Delineation Method recorded around half this rate. On the other hand, the damage rate was significantly higher in classes covering damage of 5–40% using the UAS with Operator Delineation Method (Figure 3). In the case of the UAS with Operator Delineation Method, the occurrence of higher categories was less frequent and the UAS Crop Height Method found the highest value.

Based on the data obtained using the four methods, a cost table was compiled that included time consumption as a factor (Table 2). The most expensive method, although the least work intensive for the contracting party, was the evaluation by drone imaging, which was provided by an external service (at a fixed price of EUR 740). While it was possible to use our own drone, we lacked the necessary knowledge of damage assessment using geoinformation procedures and statistical systems. Our results suggest that the UAS with Operator Delineation Method was 12 times more time-consuming than the other methods, with working with the map proving particularly exhausting. Overall, therefore, the UAS Crop Height Method appeared to be more efficient and, potentially, more accurate than the other methods. Although the classic Ground-Based Assessment tends to be the most laborious, requiring a large amount of time spent in the field to obtain reliable data, it provided accurate results (compared to the reference Yield Method) when damaged surfaces were carefully assessed. The Yield Method, costing only EUR 70, proved to be both the cheapest and the least laborious method; however, it not only requires appropriate harvesting equipment, but also the availability of an equivalent comparison area.

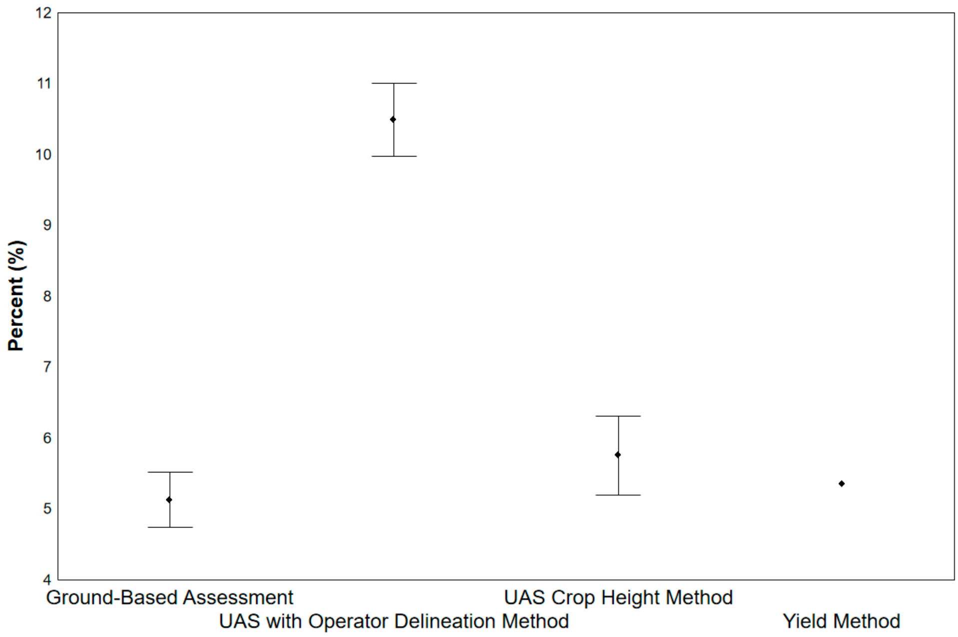

Figure 2. Comparison of mean percentage damage (with 95% confidence intervals) for the four damage evaluation methods used. Note: Confidence intervals could not be calculated for the Yield method because the percentage damage was calculated in a different way than for the three remaining methods.

Table 1. Calculation of loss of production in the damaged field.

Method	Loss in Yield (%)	Loss in Yield (tons) *
Ground-Based Assessment	5.13	5.94
UAS with Operator Delineation Method	10.49	12.14
UUAS Crop Height Method	5.76	6.67
Yield Method	5.36	5.89

Notes: * Loss in yields (tons) was recalculated from the net yield of the undamaged field (5.546 t ha^{-1}).

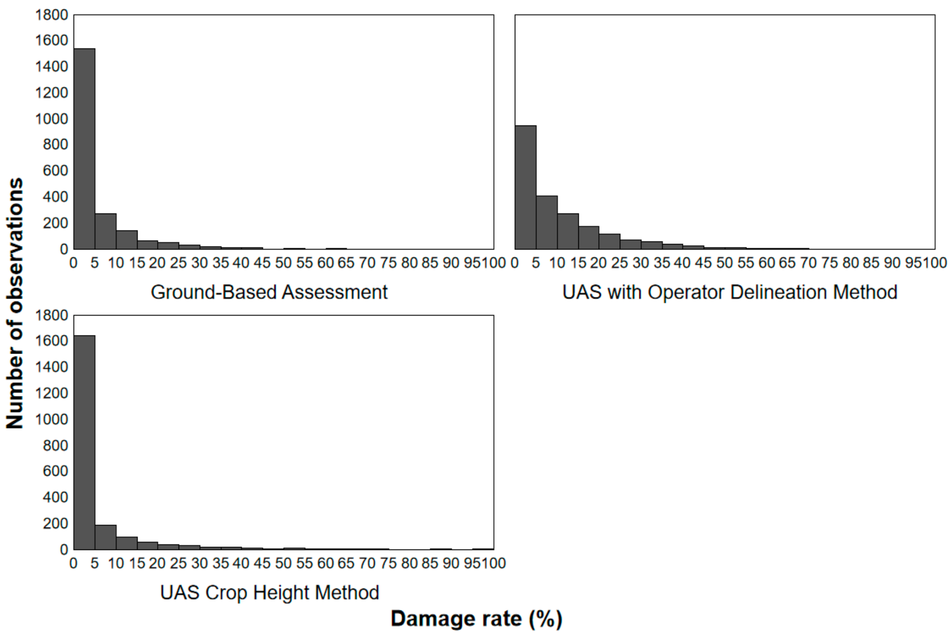

Figure 3. Damage rate estimated using three of the damage estimation methods.

Table 2. Time and financial cost of individual methods for evaluating field damage.

Method	Field Data Collection for the Total Area (h)	Office/Data Analysis (h)	Total Time (h)	Human Labor Costs (35 EUR per h) [1]	Technical Equipment	Know-How
Ground-Based Assessment	20	1	21	735	GPS device, computer	**
UAS with Operator Delineation	2	60	62	2170	drone + camera, computer	**
UAS Crop Height	2	3	5	175	drone + camera, computer	***
Yield	1	1	2	70	appropriate harvesting machine, yield data	*
Drone (contractually)	-	-	-	740	-	-

Notes: [1] The cost of human labor without taking into account know-how and technical equipment; Know-how requirements * low, ** medium, *** high; h = hours.

4. Discussion

4.1. Comparison of Method Results

We found very similar damage ranges for wild boar in the monitored field using the Ground-Based Assessment, UAS Crop Height Method and Yield Method, while the UAS with Operator Delineation Method produced results approximately two times greater than those obtained using the other methods. Overall, the Yield Method appears to provide the most accurate estimate, particularly as the conditions for its application proved ideal. As such, we consider the Yield Method to be the reference level for our study. The damage levels estimated using the Ground-Based Assessment and UAS Crop Height Method were very similar to those provided by the Yield Method over the 5–6% range, indicating that both of these methods may be used in practice in terms of accuracy, with both methods providing results close to reality when carefully executed under ideal conditions, i.e., over a relatively small area (ca. 20 ha in our case) with no other sources of damage other than from the species in question. Wild boar mainly damage grain crops by creating trampled and rolled areas that are clearly distinguishable from undamaged areas of the field [18]; however, where the crop has been damaged by wild ruminants, such as roe deer, for example, then the assessment of damage will be less accurate as ruminants only tend to nibble the wheat ears, meaning any damage is generally less noticeable. Furthermore, damaged areas may be "diffused" or non-continuous where wild boars have not rolled in the field and, consequently, the wheat remains at almost its original height. Consequently, ruminant damage can be difficult to detect using either the Ground-Based Assessment or through image analysis [17]. This inability to detect less distinct diffused damage is the main reason that damage estimates based on walking and visual inspections often lead to significantly lower estimates than other methods [37]. Owing to the lack of damage caused by other species, the damaged areas in the field being monitored were therefore easily distinguishable visually, whether using the set height directly in the field or using automatic evaluation methods. Under such conditions, the UAS Crop Height Method has a high potential for accurately estimating wild boar damage (including grazing [27]) as the damage caused can be relatively easily detected by the drone's sensors, thereby significantly reducing the need for time in the field.

One factor that can impair the damage accuracy of both the Ground-Based Assessment and the UAS Crop Height Method is the ability of plants to partially compensate for damage caused in the early stages of growth [38]. In such cases, damaged and undamaged plants may be of equal height; however, the difference in production can be significant [39]. Consequently, damage assessment using drones requires close inspection. While it is possible to obtain an even higher resolution using the UAS Crop Height Method, and thus an even more precise resolution of damage, by imaging from a lower flight level, this would require a significant increase in the desktop analysis of the resultant data.

The significant overestimation of damage when using the UAS with Operator Delineation Method could be explained by an inaccurate determination of damaged area boundaries from the aerial photograph, which proved particularly difficult in our case. When walking through the crop, for example, damaged areas were clearly identifiable from a close range, whereas it was difficult to accurately distinguish damaged and undamaged areas in the image due to the relatively low resolution.

While the damage estimates obtained using the Yield Method were considered to be the most accurate in this study, the results cannot be simply generalized. Although the method can be very accurate, even when damage is less noticeable, such as when caused by ruminant species or caused in the early stages of development [38,40], applying the method under inappropriate conditions [32] could significantly distort the damage estimate or even lead to clearly meaningless results. The validity of this method and the accuracy of the estimate are largely dependent on the existence and use of two fields with the same conditions, one of which will be undamaged. This can be very problematic in practice and can represent potential sources of significant error. When searching for a comparison field (without damage), yield potential maps (or vegetation indices, etc.) can be used, which indicate similar soil productivity based on known variables. If only part of the harvested field is damaged, the yield can be obtained for both the damaged and the undamaged part of the field, and these results can then be compared. Of course, the conditions of homogeneous production of both parts must be fulfilled [32].

4.2. Economic Evaluation of the Methods

The estimated damage using the four methods in this study varied greatly in terms of the time, cost, technical equipment and know-how needed. The Yield Method proved to be the cheapest and least laborious and required no specialized equipment (Table 2). However, to be successful, two essential conditions must be fulfilled: (i) the existence of a comparable area that can be credibly demonstrated to have a similar yield potential; (ii) a visual inspection of the damaged area proving that there has been no other cause of damage other than the factor of interest [32]. If these two conditions are met, it is possible to use the differences in yield to estimate the total damage. Multiple data sources can be used to compare the yield potential of the two areas being compared, including the evaluation of the soil and habitat conditions, agricultural technology employed, total achieved yields, yield maps in recent years, yield comparisons of small areas from both stands, multispectral satellite data from Sentinel-2A/B and Landsat 8 [41] and estimates of the total biomass from aerial photographs [42].

If, for some reason, it is not possible to use the Yield Method, significantly more time and/or technology will be needed to obtain sufficiently credible results. Among the three other methods tested (see Table 2), the most laborious was the UAS Crop Height Method, followed by manual marking of the damaged areas (UAS with Operator Delineation Method), with the latter being the least accurate. While the careful inspection of the images obtained could provide relatively accurate results, we do not recommend this method due to the high risk of error and the level of work intensity required.

A significantly more accurate estimate was achieved, with less cost, by the Ground-Based Assessment and using the UAS Crop Height Method. The difficulties associated with the UAS Crop Height Method can be divided into three components: (i) the actual field work required; (ii) the office work required; (iii) the time needed to calculate the models. In our case, field work meant the distribution and measurement of ground control points and the actual drone photography time, totalling around 1 h per photography session (before and after harvest). The manual office work consisted of marking the insertion points on the images and the actual analysis of the data, totalling around 3 h, while the time needed to calculate detailed 3D models of the surface and terrain came to around 10 h. On the other hand, the model calculation required no manual input and, as such, the 10 h refers only to "machine time". The second drone session, used to obtain a terrain model, can be omitted when a detailed terrain model of the area of interest is already available, e.g., from aerial laser scanning.

The Ground-Based Assessment proved to be more laborious and expensive. However, the need for professional staff and the time required makes this method unsuitable at a larger scale. Further, the damage assessment must take place just prior to harvesting, and it is usually not possible to spend so much time evaluating damage during this period. In addition, walking in dense stands may not be possible and it is likely that the observers themselves will cause secondary damage during the walk [32]. On the other hand, the method can be used to refine the total damage estimates using other methods, and could also identify damage caused by ruminant species [37] or other factors (e.g., wind, water or nutrient deficiencies, machinery, grain falling from the ear due to overripening).

Most estimates of damage are carried out to quantify any economic losses to production [27]; thus, the cost of the selected method and its accuracy will also significantly affect its potential use in practice. For example, in our model calculation, we estimated 6% damage to the wheat crop, with an estimated value of approximately EUR 1210 (Table 2). Consequently, the method used for quantifying damage should not be disproportionately costly as it would unnecessarily add to the economic cost to the farmer.

4.3. Management Implications

Our study compared the results and costs of estimating damage to field crops caused by large herbivores. In addition to the precise economic evaluation of all the evaluated methods, the results of this study are particularly important in terms of the potential use of two cost-effective damage estimation methods. These are a method based on 3D models of the terrain obtained using drones and a method using a comparison of yields on damaged and undamaged plots (Yield Method). The principle of the Yield Method is simple, but its use is significantly limited by the lack of suitable comparison plots. We propose conditions that significantly expand the use of this method. 3D models of the terrain are advantageous in cases where the crops are greatly damaged. The higher the evaluated stand and the lower its damaged parts, the more accurate the result can be achieved. The optimal case is corn damaged by wild boars, which break whole plants. We suggest 30 cm as the minimum difference in the height of the damaged and undamaged part. The Yield Method, on the other hand, makes it possible to estimate damage even where the damage is not visually obvious. For the applicability of this method, it is advisable to have accurate data on the crop yields in recent years, to grow crops in smaller, separate areas with a precisely defined size and, if necessary, to have smaller areas in reserve on which damage will be excluded by fencing. Such a setting will enable the reliable application of the very cheap and accurate Yield Method.

5. Conclusions

Damage on field crops can be accurately estimated by all of the tested methods. The use of the traditional Ground-Based Assessment makes sense, especially for small areas and for damage that is clearly visible. If the extent of the damage can be difficult to estimate, e.g., due to the poor permeability of the vegetation, or the area is larger than several hectares and the damage is scattered over it, this method does not make economic sense. For larger areas with very clearly visible damage, we recommend the use of drones with the automatic evaluation of the size of the damaged areas. For cases where the damage is not very obvious, we highly recommend the Yield Method as the most appropriate, at relatively low cost, particularly at larger scales. The main challenge for the application of the Yield Method is the existence of undamaged plots with similar yield potential. We recommend growing crops on smaller separate areas in order to increase the probability of obtaining data from a similar undamaged area and to minimize the influence of other factors that can affect the yield potential, such as soil fertility, crop management practices and microclimatic conditions. When selecting areas that are expected to have similar productivity, yield potential maps can also be used. In areas with a high risk of damage, we recommend fencing small plots on which the yield potential will be estimated. At the same time, we recommend supplementing the comparison of yields with a full-scale inspection of stands using drones, which will exclude the influence of other possible factors that can distort the estimate. With high-quality processing, we recommend the Yield Method as the most effective method.

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References

1. Herruzo, A.C.; Martínez-Jauregui, M. Trends in hunters, hunting grounds and big game harvest in Spain. *For. Syst.* **2013**, *22*, 114–122. [CrossRef]
2. Apollonio, M.; Belkin, V.V.; Borkowski, J.; Borodin, O.I.; Borowik, T.; Cagnacci, F.; Yanuta, G. Challenges and science-based implications for modern management and conservation of European ungulate populations. *Mammal Res.* **2017**, *62*, 209–217. [CrossRef]
3. Carpio, A.J.; Apollonio, M.; Acevedo, P. Wild ungulate overabundance in Europe: Contexts, causes, monitoring and management recommendations. *Mammal Rev.* **2021**, *51*, 95–108. [CrossRef]
4. Massei, G.; Kindberg, J.; Licoppe, A.; Gačić, D.; Šprem, N.; Kamler, J.; Náhlik, A. Wild boar populations up, numbers of hunters down? A review of trends and implications for Europe. *Pest Manag. Sci.* **2015**, *71*, 492–500. [CrossRef]
5. Wehr, N.H. Historical range expansion and biological changes of Sus scrofa corresponding to domestication and feralization. *Mammal Rev.* **2021**, *66*, 1–12. [CrossRef]
6. Bernes, C.; Macura, B.; Jonsson, B.G.; Junninen, K.; Müller, J.; Sandström, J.; Macdonald, E. Manipulating ungulate herbivory in temperate and boreal forests: Effects on vegetation and invertebrates. A systematic review. *Environ. Evid.* **2018**, *7*, 13. [CrossRef]
7. Linnell, J.D.; Cretois, B.; Nilsen, E.B.; Rolandsen, C.M.; Solberg, E.J.; Veiberg, V.; Kaltenborn, B. The challenges and opportunities of coexisting with wild ungulates in the human-dominated landscapes of Europe's Anthropocene. *Biol. Conserv.* **2020**, *244*, 108500. [CrossRef]
8. Felton, A.M.; Hedwall, P.O.; Felton, A.; Widemo, F.; Wallgren, M.; Holmström, E.; Wam, H.K. Forage availability, supplementary feed and ungulate density: Associations with ungulate damage in pine production forests. *For. Ecol. Manag.* **2022**, *513*, 120187. [CrossRef]
9. Kincheloe, J.M.; Horn-Delzer, A.R.; Makau, D.N.; Wells, S.J. Chronic Wasting Disease Transmission Risk Assessment for Farmed Cervids in Minnesota and Wisconsin. *Viruses* **2021**, *13*, 1586. [CrossRef]
10. Mallapaty, S. COVID is spreading in deer What does that mean for the pandemic? *Nature* **2022**, *604*, 612–615. [CrossRef]
11. Steiner, W.; Schöll, E.M.; Leisch, F.; Hackländer, K. Temporal patterns of roe deer traffic accidents: Effects of season, daytime and lunar phase. *PLoS ONE* **2021**, *16*, e0249082. [CrossRef] [PubMed]
12. Côté, S.D.; Rooney, T.P.; Tremblay, J.P.; Dussault, C.; Waller, D.M. Ecological impacts of deer overabundance. *Annu. Rev. Ecol. Evol. Syst.* **2004**, *35*, 113–147. [CrossRef]
13. Putman, R.J.; Moore, N.P. Impact of deer in lowland Britain on agriculture, forestry and conservation habitats. *Mammal Rev.* **1998**, *28*, 141–164. [CrossRef]
14. Weisberg, P.J.; Bugmann, H. Forest dynamics and ungulate herbivory: From leaf to landscape. *For. Ecol. Manag.* **2003**, *181*, 1–12. [CrossRef]
15. Kamler, J.; Dobrovolný, L.; Drimaj, J.; Kadavý, J.; Kneifl, M.; Adamec, Z.; Hrbek, J. The impact of seed predation and browsing on natural sessile oak regeneration under different light conditions in an over-aged coppice stand. *iForest* **2016**, *9*, 569. [CrossRef]
16. Skoták, V.; Drimaj, J.; Kamler, J. Evaluation of damage to forest tree plantations by wild boar in the Czech Republic. *Hum.–Wildl. Interact.* **2021**, *15*, 13. [CrossRef]

17. Kristiansson, H. Crop damage by wild boars in Central Sweden. In Proceedings of the XVIIth Congress of the International Union of Game Biologists IUGB, Brussels, Belgium, 17–21 September 1985; pp. 605–609.
18. Schley, L.; Roper, T.J. Diet of wild boar Sus scrofa in Western Europe, with particular reference to consumption of agricultural crops. *Mammal Rev.* **2003**, *33*, 43–56. [CrossRef]
19. Seward, N.W.; VerCauteren, K.C.; Witmer, G.W.; Engeman, R.M. Feral swine impacts on agriculture and the environment. *Sheep Goat Res. J.* **2004**, *12*, 34–40.
20. Rutten, A.; Casaer, J.; Strubbe, D.; Leirs, H. Agricultural and landscape factors related to increasing wild boar agricultural damage in a highly anthropogenic landscape. *Wildl. Biol.* **2019**, *2019*, 1–11. [CrossRef]
21. Spake, R.; Bellamy, C.; Gill, R.; Watts, K.; Wilson, T.; Ditchburn, B.; Eigenbrod, F. Forest damage by deer depends on cross-scale interactions between climate, deer density and landscape structure. *J. Appl. Ecol.* **2020**, *57*, 1376–1390. [CrossRef]
22. Reimoser, S.; Partl, E.; Reimoser, F.; Vospernik, S. Roe-deer habitat suitability and predisposition of forest to browsing damage in its dependence on forest growth—Model sensitivity in an alpine forest region. *Ecol. Model.* **2009**, *220*, 2231–2243. [CrossRef]
23. Bolibok, L.; Andrzejczyk, T.; Szeligowski, H.; Liziniewicz, M. New methods of oak planting require modification of tending prescriptions under high browsing pressure—A case study from north-eastern Poland. *For. Ecol. Manag.* **2021**, *497*, 119449. [CrossRef]
24. Thurfjell, H.; Ball, J.P.; Åhlén, P.A.; Kornacher, P.; Dettki, H.; Sjöberg, K. Habitat use and spatial patterns of wild boar *Sus scrofa* (L.): Agricultural fields and edges. *Eur. J. Wildl. Res.* **2009**, *55*, 517–523. [CrossRef]
25. Michez, A.; Morelle, K.; Lehaire, F.; Widar, J.; Authelet, M.; Vermeulen, C.; Lejeune, P. Use of unmanned aerial system to assess wildlife (*Sus scrofa*) damage to crops (*Zea mays*). *J. Unmanned Veh. Syst.* **2016**, *4*, 266–275. [CrossRef]
26. Fischer, J.W.; Greiner, K.; Lutman, M.W.; Webber, B.L.; Vercauteren, K.C. Use of unmanned aircraft systems (UAS) and multispectral imagery for quantifying agricultural areas damaged by wild pigs. *Crop. Prot.* **2019**, *125*, 104865. [CrossRef]
27. Rutten, A.; Casaer, J.; Vogels, M.F.; Addink, E.A.; Vanden Borre, J.; Leirs, H. Assessing agricultural damage by wild boar using drones. *Wildl. Soc. Bull.* **2018**, *42*, 568–576. [CrossRef]
28. Kuželka, K.; Surový, P. Automatic detection and quantification of wild game crop damage using an unmanned aerial vehicle (UAV) equipped with an optical sensor payload: A case study in wheat. *Eur. J. Remote Sens.* **2018**, *51*, 241–250. [CrossRef]
29. Samiappan, S.; Prince Czarnecki, J.M.; Foster, H.; Strickland, B.K.; Tegt, J.L.; Moorhead, R.J. Quantifying damage from wild pigs with small unmanned aerial systems. *Wildl. Soc. Bull.* **2018**, *42*, 304–309. [CrossRef]
30. Roznik, M.; Boyd, M.; Porth, L. Improving crop yield estimation by applying higher resolution satellite NDVI imagery and high-resolution cropland masks. *Remote Sens. Appl. Soc. Environ.* **2022**, *25*, 100693. [CrossRef]
31. Fischer, J.W.; Snow, N.P.; Wilson, B.E.; Beckerman, S.F.; Jacques, C.N.; VanNatta, E.H.; Kay, S.L.; VerCauteren, K.C. Factors and costs associated with removal of a newly established population of invasive wild pigs in Northern U.S. *Sci. Rep.* **2020**, *10*, 11528. [CrossRef]
32. Skoták, V.; Kamler, J. Estimating damage caused by wild animals to crops by comparing yields. *J. Cultiv. Plants* **2021**, *73*, 9–10. [CrossRef]
33. Caroti, G.; Martínez-Espejo Zaragoza, I.; Piemonte, A. Accuracy assessment in Structure from Motion 3D reconstruction from drone-born images: The influence of the data processing methods. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2015**, *40*, 103–109. [CrossRef]
34. DJI, Spreading Wings S800 User Manual, v.1. Available online: www.dji-innovations.com (accessed on 1 June 2022).
35. Fonstad, M.A.; Dietrich, J.T.; Courville, B.C.; Jensen, J.L.; Carbonneau, P.E. Topographic structure from motion: A new development in photogrammetric measurement. *Earth Surf. Process. Landf.* **2013**, *38*, 421–430. [CrossRef]
36. StatSoft, Inc. *STATISTICA (Data Analysis Software System)*; Version 12; StatSoft, Inc.: Tulsa, OK, USA, 2013; Available online: www.statsoft.com (accessed on 15 September 2022).
37. Bayani, A.; Tiwade, D.; Dongre, A.; Dongre, A.P.; Phatak, R.; Watve, M. Assessment of crop damage by protected wild mammalian herbivores on the western boundary of Tadoba-Andhari Tiger Reserve (TATR), Central India. *PLoS ONE* **2016**, *11*, e0153854. [CrossRef]
38. Scholes, D.R.; Paige, K.N. Plasticity in ploidy underlies plant fitness compensation to herbivore damage. *Mol. Ecol.* **2014**, *23*, 4862–4870. [CrossRef] [PubMed]
39. Skoták, V.; Kamler, J.; Cerkal, R. Herbivore damage to sunflowers (*Helianthus annuus* L.) in the Czech Republic. *Eur. J. Wildl. Res.* **2022**, *68*, 1–6. [CrossRef]
40. Thomson, V.P.; Cunningham, S.A.; Ball, M.C.; Nicotra, A.B. Compensation for herbivory by Cucumis sativus through increased photosynthetic capacity and efficiency. *Oecologia* **2003**, *134*, 167–175. [CrossRef] [PubMed]
41. Řezník, T.; Pavelka, T.; Herman, L.; Lukas, V.; Širůček, P.; Leitgeb, Š.; Leitner, F. Prediction of yield productivity zones from Landsat 8 and Sentinel-2A/B and their evaluation using farm machinery measurements. *Remote Sens.* **2020**, *12*, 1917. [CrossRef]
42. Gil-Docampo, M.D.L.L.; Arza-García, M.; Ortiz-Sánz, J.; Martínez-Rodriguez, S.; Marcos-Robles, J.L.; Sánchez-Sastre, L.F. Above-ground biomass estimation of arable crops using UAV-based SfM photogrammetry. *Geocarto Int.* **2020**, *35*, 687–699. [CrossRef]