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Crop Harvesting Can Affect Habitat Selection of Wild Boar (*Sus scrofa*)

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Abstract: One of the basics of effectively managing a wild boar population is knowledge of its home range, spatial patterns, and habitat use. However, little is known about the reaction of wild boar to changes in the agricultural landscape during the time of harvesting. In this study, we assessed the impact of crop harvesting on habitat selection of wild boar. For this reason, we analyzed radio-collared animals in four summer months (from June to September) in an agricultural landscape in Poland. We analyzed the habitat selection by wild boar with a generalized linear model and Jacob's selectivity index. The wild boar preference for arable land, pastures and the "other" category showed clear monthly dynamics. In contrast, a stable preference for forests and mosaics was observed throughout all months. The preference of wild boar to arable land dropped significantly in August, which we interpret as the impact of the harvest. We conclude that intensive agriculture contributes to significant changes in the frequency of wild boar in various habitats. This, however, does not apply to all habitats, because forest habitats are constantly visited by wild boar as their main daytime refuge. Moreover, extensive farming, although less attractive for wild boar, is rather neutral and does not alter the abundance of animals in habitats.

Keywords: wild boar; habitat selection; crop harvesting

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1. Introduction

The wild boar (*Sus scrofa*) undoubtedly belongs to the group of large herbivores for which the increase in agricultural areas has proved to be very beneficial. The colonization of the mosaic of farmlands and forest patches, as well as the adaptation to urbanized environments by this species, has been reflected in the wild boar's population dynamics in recent decades [1]. Wild boars have become herbivores whose food is very often based on arable crops [2]. Furthermore, the food found in arable fields is of such good quality (high protein and energy content) that it allows wild boar to start breeding even in the first year of life [3]. For these reasons, the number of wild boars throughout Europe has increased dramatically since World War II [4,5]. In Poland, a rapid increase in the wild boar population has been observed since the end of the 1950s. Fruziński and Łabudzki [6] estimated that in the 42 years from 1960 to 2002, the yearly hunted number of wild boar increased tenfold.

One of the basics of effectively managing a wild boar population is knowledge of its home range, spatial pattern and habitat use in different types of environments and in

different seasons of the year [7,8]. The size of the home range of wild boar may depend on the season, food availability or human pressure, including, for example, hunting intensity [9–11]. Furthermore, these home ranges can differ a lot, even on a small spatial scale or at different times of the year [12–15]. Dinter [16] and Keuling et al. [17] showed that the size of home ranges may also differ as a result of the sex and age of wild boar, but also depend on group structure. Nevertheless, little is known about the reaction of wild boar to changes in the agricultural landscape as a result of harvesting. According to the opinions and observations of some hunters in Poland, wild boar find shelter in fields from the second half of April until harvest time. Initially, they forage in meadows, then they forage intensively in fields of corn [18]. If they have water for wallowing, they do not use the forest until harvest time [18]. Wild boars tend to consume crops at their peak nutritional value, i.e., after planting or before the harvest [19–21]. Therefore, crop harvest can be treated as a dynamic disturbance that directly affects the composition and abundance of plant and animal species in agricultural ecosystems [22,23]. For wild boars, fields formerly rich in food and cover become unattractive and unsafe.

In this study, we aimed to assess habitat selection of wild boars as a result of crop harvesting. For this reason, we analyzed collared animals in four summer months (from June to September) in an agricultural landscape in Poland. We hypothesized that habitat selection would show high monthly dynamics as a result of crop harvesting. The highest changes (shift in habitat selection) were expected in August, when most crop harvesting occurs in Poland.

2. Materials and Methods

The study was performed in two provinces in Poland: Mazowieckie and Lubelskie (Figure 1). In Mazowieckie Province, the field study was carried out in hunting district no. 456 (Piaseczno powiat). The total area of this district is 4655 ha, including 1396 ha of forest habitats. In Lubelskie Province, the field study was carried out in hunting districts no. 1 and 4 (Biała Podlaska powiat), which directly borders the eastern border with the territory of Belarus. District No. 1 covers an area of 6515 ha, including 2049 ha of forest habitat; district No. 4 covers 7030 ha, including 2193 ha of forest habitats. All three hunting districts are "rural districts" with a domination of open habitats, mainly arable lands. In both powiats, cereals are the dominant type of cultivation; they constitute 47.0 and 18.3 percent of the cultivated area of Biała Podlaska powiat and Piaseczno powiat, respectively (of known cultivation type). In Piaseczno powiat, however, 41.9% is covered by grasslands (including barren), and orchards. Maize constituted 5.7 and 4.4 percent of the cultivated area (of known cultivation type), respectively (https://rejestrupraw.arimr.gov.pl/ (accessed on 21 March 2022)).

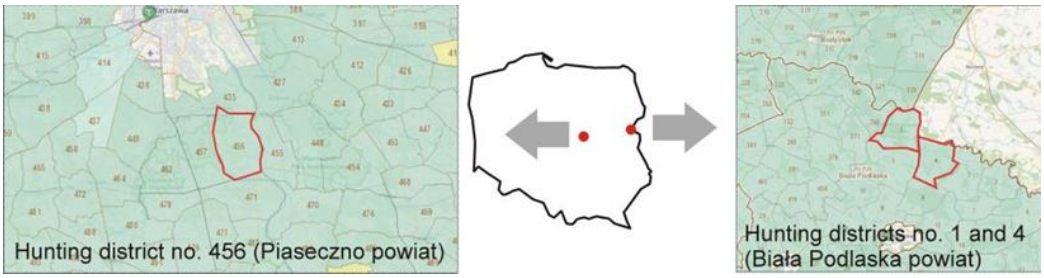

Figure 1. Location of study sites.

In 2020, ten wild boars (six females and four males) were caught and collared with GPS/GSM transmitters. These animals were captured with the permission of the Minister of the Environment for the fitting of telemetry collars (permit number: DL-ZŁ.4142.16.2019.ABR). These wild boars were attracted to capture pens where maize was exposed. The selected animals were collared immediately after being caught. During the procedure, no drugs were used to immobilize the animals. For this study we used all locations from all wild

boars in the period from 1 June to 31 August. The collars were originally set to transmit one location measurement every 2 h; however, due to technical problems (intermittent module operation, no GPS signal), the number of measurements per day was irregular. Moreover, not all collars provided information for all months as a result of technical issues or because the collared individuals were killed. In total, we accessed 2496 items of location data for all four months (Supplementary Table S1), but the largest amount of data was collected in July and August, with over 700 locations for each of these months.

Prior to the analysis, the raw data were assessed in order to eliminate duplicate or erroneous records. The habitat selection by wild boars was assessed based on all records within the home range area (KDE95%). All records from collars within the given home range were assigned to land cover types based on Corine Land Cover (CLC) for 2018 (https://land.copernicus.eu/ (accessed on 21 November 2021)). For further analysis, five basic cover types were selected, representing cover types in CLC: forests (codes 3.1.1, 3.1.2, 3.1.3 and 3.2.4 in CLC), arable land (code 2.1.1 in CLC), pastures (code 2.3.1 in CLC), mosaics (codes 2.4.2 and 2.4.3, i.e., heterogeneous agricultural areas in CLC) and other (codes 1.1.2, 1.2.1, 1.3.2, 1.4.2, 3.3.1, and 5.1.1. in CLC). To verify the habitat selection (i.e., if the occurrence of wild boar in a given cover type was non-random) we used the same number of random control points within each home range as the number of records from the collars (ratio 1:1). These random points were assigned to the same cover types as the records from the collars. The data elaboration was performed in Quantum GIS (version 3.4.5).

We analyzed the habitat selection by wild boar with a generalized linear binary model. In this model, the dependent variable was binary: the locations of wild boar were marked as 1 and random points were marked as 0. The explanatory variables were habitat (HABITAT), month (MONTH) and interaction of habitat and month (HABITAT*MONTH). This interaction allowed the monthly habitat selection dynamics of the wild boar to be assessed. We did not use a mixed logistic model with the ID of each wild boar as a random factor because the model presented extremely high AICc values (higher than the null model) and an uncertain fit. We performed the full model selection, where all model permutations (including the null model) were tested with regard to AIC values. The model with the lowest AIC values was regarded as the best model. We presented the wild boar preferences as the marginal means in the binary model, expressing the probability of wild boar presence in a given habitat. The random use of a given habitat was represented by a similar proportion of wild boar observations (1) and random points (0) in a given habitat type. The higher proportion of wild boar observations in a given habitat is treated as a preference and the lower proportion as avoidance. Marginal means were compared with the LSD test. To support our approach, we have added Jacob's selectivity index (ranging from −1 to 1) for the entire June–September period and for each month [24].

In the absence of official data on the timing of harvest in the fields, an indirect method was used to visualize the variability of this phenomenon between months. For this purpose, satellite images were used, based on which the percentage of bare ground in Biała Podlaska powiat and Piaseczno powiat was calculated as an indicator of harvest. We followed previous studies where satellite images were used to crop dynamics assessment, including the use of the bare ground as an indicator of crop harvest [25–27]. A total of 17 available satellite images for all months (June to September) were used (Supplementary Table S2). Only images of acceptable quality were used, i.e., mainly images without or with only low cloud formation. The images were from the Sentinel database (https://scihub.copernicus.eu/ (accessed on 23 September 2022)), and the analysis area was adjusted to the boundaries of the powiat. Then, the urbanized area was excluded based on the latest Corine Land Cover layers (https://land.copernicus.eu/ (accessed on 21 November 2021)). Satellite images were classified in Quantum GIS 3.26 using the semi-automatic classification plugin with the Short-Wave Infrared (band combination of SWIR (B12), NIR (B8A), and red (B4)) [28]. Of the distinguished classifications, the "bare ground" class was used, representing the area

not covered with vegetation (Supplementary Figure S1). The percentage of bare ground area in the study area was calculated.

3. Results

The analysis of satellite images showed that the largest share of bare ground cover occurred in August (Figure 2). The general trend in both areas was similar. The bare ground share decreased from June to July, whereas the greatest increase in this cover type occurred in August. In September, there was another slight decrease in the share of this cover type in the analyzed areas.

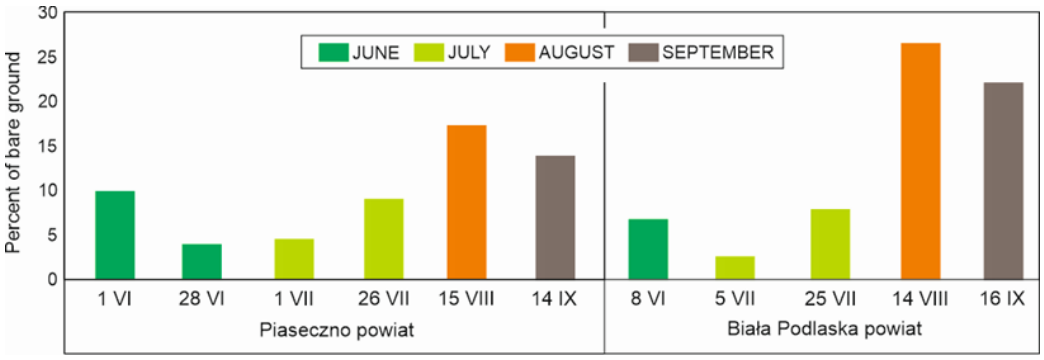

Figure 2. The percent of bare ground cover in the analyzed area of Biała Podlaska powiat and Piaseczno powiat in given months.

A clear dynamic of habitat preferences was found in the wild boars. Habitat selection was significantly explained by the variables included in the model ($\chi 2 = 251.66$, df = 19, $p = 0.000$), i.e., by HABITAT, MONTH and HABITAT*MONTH. The highest ranked model showed significantly lower AIC values compared to the smaller models and the null model (Supplementary Table S3). The wild boars, without taking monthly variability into account (JUNE–SEPTEMBER), showed no clear preference for particular habitat types, and only the OTHER category was clearly avoided (probability of presence = 0.32, D = −0.36) (Figure 3). The probability of the presence of wild boars in most of the categories ranged from 0.50 to 0.54 (Jacob's index ranged from −0.03 to 0.15), which indicates random use or only a slight preference (mainly for FORESTS).

However, when analyzing individual months, there were large differences in the frequency of wild boars in the habitats (Figure 3). In the FORESTS category, this change is not clear and wild boars still present a weak preference for this habitat, the probability of presence ranged from 0.52 in July to 0.57 in June, and only these two months were statistically significantly different from each other ($p = 0.030$). Similarly, Jacob's index for FORESTS ranged from 0.07 to 0.34. In the case of the ARABLE category, the monthly preference dynamic was significant. Wild boars show a clear preference for this habitat in July and September (probability of presence equaled 0.66 and 0.58, respectively, and Jacob's index equaled 0,40 and 0.21, respectively). The frequency of wild boar in these months did not differ statistically from each other, but it differed from the frequency in June ($p = 0.000$ for July and September) and in August ($p = 0.000$ for July and $p = 0.001$ for September). In June and August, wild boars showed a tendency to avoid arable land (probability of presence equaled 0.38 and 0.43 and Jacob's index equaled −0.31 to −0.21).

The wild boars showed a completely different preference for the PASTURES category (Figure 3). In months when they avoided the ARABLE category, the wild boars showed a preference for PASTURE. The strongest preference occurred in June (probability of presence equaled 0.81 and Jacob's index equaled 0.64), which was significantly higher than in August (probability of presence equaled 0.57, $p = 0.001$, Jacob's index equaled 0.14), in which wild boars also preferred PASTURE. In the months when ARABLE was preferred, i.e., July and September, the wild boars avoided PASTURE (probability of presence equaled 0.25 and 0.39, respectively, and Jacob's index equaled −0.51 to −0.27, respectively), and these

months did not differ statistically from each other ($p > 0.050$). The frequency of wild boars in pastures in these months was significantly lower than in June ($p = 0.000$ for July and September) and August ($p = 0.001$ for July and $p = 0.015$ for September).

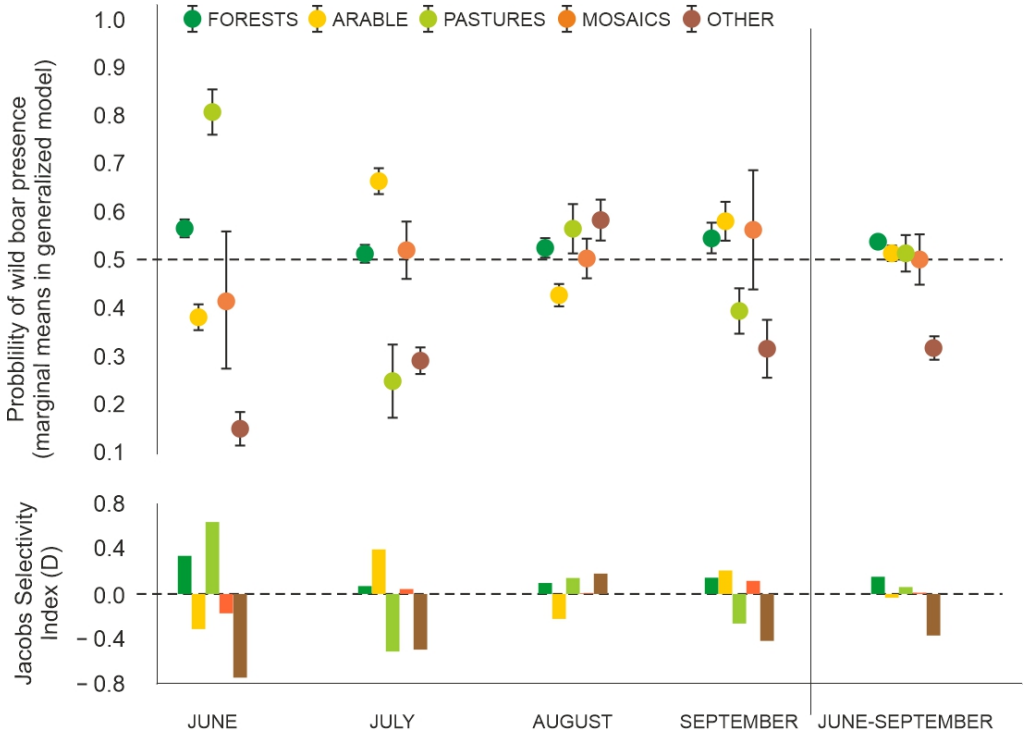

Figure 3. Probability (marginal means ± SE in the generalized linear binary model) of wild boar presence in habitat categories from June to September and in selected months from June to September and Jacob's selectivity index for the same periods; the dashed lines represent random habitat use.

For MOSAICS, no significant differences in the frequency of wild boars were found between months ($p > 0.05$ in all cases), and only in June did the wild boars avoid this habitat, but this category was characterized by a high standard error. High dynamics were observed in the OTHER category. The wild boars preferred this category only in August (probability of presence equaled 0.59, and Jacob's index equaled 0.19), and in the remaining months, they avoided the habitats in this category. Wild boar frequency showed statistically significant differences between almost all months except July and September.

4. Discussion

According to our hypothesis, wild boars would present highly dynamic monthly preferences for selected habitats. However, this monthly change in their preferences did not concern forests and mosaics. We also hypothesized that August, i.e., the main harvest period, would be significantly different from the other months. This hypothesis was confirmed only partially because June also clearly differed from the other months. However, the obtained results are consistent and are logically related to the life demands of wild boars and the quality of individual habitat types.

Our results showed that these wild boars have a strong preference for pastures and a slightly stronger preference for forests in June than in other months. Moreover, the wild boar avoided crops on arable land in this month, which is consistent with studies on the diet of wild boar [18,20,29–32]. June is the transition month of the spring and summer periods, when crops are still mostly immature, and, more often than in other seasons, wild boar eat nonagricultural plants (mainly grasses), underground parts of plants, and invertebrates, even in intensive agroecosystems [20,29,30], when grasses and herbs have the optimum quantity and the best proportion of nutrients [31]. In their search for insects, invertebrates

and edible parts of green plants, wild boar cause damage to meadows and pastures in early spring with relatively small interest in grains [18,32].

In July, wild boar showed a high preference for arable land and avoidance of pastures. This result is not surprising because grains are already ripening in July and are an attractive food for wild boar. At that time, wild boars also most eagerly feed in fields, as confirmed by numerous studies from both Poland [18,32] and other European countries [20,33–36]. Moreover, in Poland the end of June is the period of the second harvesting of hay [37] and vegetation in pastures is almost disappearing due to harvesting [38]. Spring and winter cereals, except maize, are consumed by wild boar in greater amounts from June to August, i.e., until harvest [39]. Moreover, most cereals are tall enough in the summer to provide cover for wild boar [40,41]. For this reason, arable fields in peak growth can provide a permanent refuge for this species [42], therefore these animals can forage even in daylight [43].

In August, the second month of the middle of summer, there was a change in the preference of wild boar compared to July. They avoided arable land but preferred pastures and other habitats. This result was expected as August is harvest time. The quality of this type of habitat has changed dramatically due to a significant decrease in available food and a significant reduction in the cover that is offered by crops. As a result of the change in the quality of arable lands, wild boars use more grasslands, which are probably safer as they are located near forests [43]. As demonstrated by previous studies [33,44,45], buffer zones near forests are frequently damaged by wild boars. Wild boars probably also moved to other areas as alternatives to arable fields as they showed a high preference for the OTHER category in August. This mainly includes urban fabric, industrial or commercial units and watercourses. The results indicate that wild boar forage more intensively in the vicinity of human settlements. Moreover, the presence of wild boar near watercourses and densely urbanized and industrial areas suggests the dispersion of these animals. Linear elements, especially watercourses, constitute convenient migration habitats for wild boars [46,47]. During migration, wild boars probably encounter untypical habitats such as continuous urban fabric and industrial or commercial units.

In September, after the harvest is over, the wild boars again prefer arable land. In this month, wild boars have probably returned to arable fields, where they can feed on crop remains, but above all on maize and other crops which are already ripening [35,48]. In September, the wild boar's preferences seem to be much closer to that of July than of August. Such a change in preferences in July to September indicates a significant role of crop harvesting in shaping the structure of habitats frequented by wild boars. According to the results of Vercauteren and Hygnstrom [49], which were based on 30 radio-collared white-tailed deer females, the size of home ranges increased 32% after the corn harvest. According to Marboutin and Aebischer [50], European hare used cultivated areas more than was expected by chance, their habitat use did not differ as a result of crop harvesting.

Despite significant monthly differences in the habitat preferences of wild boars, no significant change was found in the case of forests and mosaics. Forest habitats constitute a refuge for wild boars during the day when they avoid contact with humans [43]. For this reason, this habitat is constantly visited by wild boars [51,52]; therefore, as shown in our study, the forest habitat is preferred regardless of the stage of the summer period. It is true that wild boars can stay in arable fields around the clock, but this applies to areas with large-scale agricultural crops where there is not much forest habitat [43]. Many researchers indicate that an important factor determining the composition of the wild boar's diet is the availability of forest tree seeds, such as acorns, chestnuts or beechnuts [52,53]. High availability of forest fruits is preferred in relation to agricultural crops, even maize, and to food supplied at feeding sites [54,55]. The wild boars also showed a consistent preference for the heterogeneous agricultural areas included in the MOSAICS category. Perhaps this is because fragmented extensive agriculture probably does not cause such large changes in the dynamics of wild boar preferences as intensive farming does. This also confirms that harvest time is a determinant of changes in wild boar habitat preferences. In

a natural mosaic of crops, it can be expected that any changes in food abundance and the availability of shelter affect relatively small areas, which can be compensated for by adjacent resources. Moreover, natural cover appears more often in such a mosaic, which does not cause dramatic changes in the environment. However, a more accurate comparison could be made by taking an area completely free of crops but with hunting as a study site.

Attention should be paid to the limitations of our study. The primary source of potential bias is the limited sample size, which did not allow us to add the sex and age effect to the model. We used wild boars of different ages, so we are not able to answer to what extent the age effect could affect our results. Perhaps younger individuals will react to harvest in a different way than adults or females leading young. Despite the above limitations, we believe that the trends we have demonstrated reflect real processes that, in our opinion, are logical and supported by previous findings.

5. Conclusions

Our study shows that intensive agriculture contributes to significant changes in the frequency of habitats use by wild boars. This, however, does not apply to all habitats, because forest habitats are constantly visited as their main day refuge. Moreover, extensive farming, although less attractive for wild boars, is likely to be neutral and does not alter the abundance of animals in these habitats. The obtained results are of practical importance because they show that, depending on the month, the frequency of wild boars in different habitats may vary and one should pay attention not only to the time of crop disturbance (in the form of harvest), but also to the type of farming.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142214679/s1, Table S1: A number of GPS records for each animal in selected months: * individuals killed during the study; Table S2: Satellite imagery used for the analysis of land cover Biała Podlaska powiat and Piaseczno powiat in subsequent months of the summer period 2020; Table S3: Model selection (A) and parameter estimates (B) of wild boar presence locations and random points; Figure S1: Satellite images presenting the dynamics of crops in three consecutive months in infrared: June (plant development in the green phase), July (matured grain fields without chlorophyll), and August (mostly bare soil is visible).

Author Contributions: Conceptualization, B.P. and D.K.; methodology, B.P., D.K. and P.K.; formal analysis, D.K., M.S. and P.K.; investigation, B.P., K.G. and L.P.; resources, L.P.; writing—original draft preparation, D.K., P.N., M.S., W.O.; writing—review and editing, P.K, K.G. and L.P.; visualization, D.K.; project administration, L.P.; funding acquisition, L.P. All authors have read and agreed to the published version of the manuscript, except B.P.—an author passed away before they could accept the final version of the article.

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Informed Consent Statement: Not applicable.

Data Availability Statement: Data is available on request from the corresponding author.

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