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The requirements of three co-existing woodpecker species (Picidae) in relation to forest features in the agricultural landscape of SE Poland

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Abstract

The occurrence of woodpeckers in European forests depends on many forest stand characteristics. During the study conducted in 2013 in the agricultural landscape of SE Poland (in an extremely deforested area with a 5% share of forest area), the habitat requirements of Middle Spotted Woodpecker *Dendrocoptes medius*, Great Spotted Woodpecker *Dendrocopos major* and Syrian Woodpecker *Dendrocopos syriacus* were described. For this purpose, the degree of occupation by individual species of 73 forest patches was assessed over an area of 355 km^2. To determine the habitat requirements of the woodpecker species, a set of 7 parameters characterizing the studied forests and their surroundings were determined, viz. forest patch area, average age of the tree stand, etc.). Generally, the Syrian Woodpecker inhabited small forest patches surrounded by a significantly larger proportion (2.3–5.6%) of orchards, compared to forests uninhabited by this species. The most important factors that positively influenced the occurrence of the Middle and Great Spotted Woodpeckers were the forest patch size, average age of the forest patch stand, and area of forest stands aged older than 80 years. The Great Spotted Woodpecker preferred forest patches with an area exceeding 15 ha, but the Middle Spotted Woodpecker occurred only in forest patches over 42 ha. Such minimum forest patch areas should be considered essential for protecting the two mentioned species in a heavily deforested landscape. Small-sized forest patches should also be protected, enabling refuge for the Syrian Woodpecker.

Keywords: bird conservation strategy, forest management, habitat selection, primary cavity nesters, rural landscape, woods, woodpeckers, SE Poland

Introduction

Deforestation of Europe has a significant influence on the occurrence of many specialised species such as woodpeckers (Picidae) (Mikusiński and Angelstam 1997, 1998). One of the main factors influencing the presence of woodpeckers in landscapes transformed by human activity could be the size of forest patch (Salvati et al. 2001, Myczko et al. 2014, Michalczuk et al. 2018). Reduction of forest area can negatively affect the occurrence of species with large individual territories, such as the Black Woodpecker *Dryocopus martius* or the Grey-headed Woodpecker *Picus canus* (Imhof 1984, Rolstad and Rolstad 1995, Bocca et al. 2007), which can also occasionally occupy small and scattered forest patches (Tjernberg et al. 1993, Michalczuk et al. 2018). The negative impact of the reduction in forest patch area is seen in the case of species that have even relatively small individual territories. The Middle Spotted Woodpecker *Dendrocoptes medius*, occupying breeding territories with an average area of several hectares (Buchmann and Pasinelli 2002), is usually found in forests with a minimum area of 15 ha (Kosiński 2006). Drastic reduction of forest areas may limit the occurrence of even the Great Spotted Woodpecker *Dendrocopos major* (Myczko et al. 2014), which can also nest in forests of several hectares (Salvati et al. 2001, Michalczuk et al. 2018, Michalczuk and Michalczuk 2022).

However, the fragmentation of forested areas in the landscape may be beneficial for certain European woodpeckers, whose populations concentrate within small forest patches. Such species include the Green Woodpecker *Picus viridis* or the European Wryneck *Jynx torquilla* (Spitznagel 1990, Weisshaupt et al. 2011, Dorresteijn et al. 2013). Even though these species nest in various types of forest stands (Glue and Boswell 1994), they obtain food – mainly ants

Formicidae – in a variety of forest habitats or open areas (Cramp 1985, Rolstad et al. 2000, Mermod et al. 2009, Coudrain et al. 2010). Such foraging preferences determine the presence of these species in a semi-open landscape (Mermod et al. 2009, Weisshaupt et al. 2011). Moreover, woodpecker occurrence in forests may be limited by significant spatial isolation. A barrier negatively affecting the presence of woodpeckers in forest patches is tree-less habitats or urbanised areas, which woodpeckers generally avoid (Myczko et al. 2014) and in such landscapes, they occupy only the prolific treed areas (Mošanský and Mošanský 1999, Figarski and Kajtoch 2018, Fröhlich et al. 2022). Such habitats are especially tolerated by the Syrian Woodpecker (Ciach and Fröhlich 2013), which in Europe can also colonise small forest patches (Michalczuk and Michalczuk 2016b, Kajtoch and Figarski 2017, Michalczuk et al. 2018).

Forest stand characteristics also have a decisive impact on the presence of woodpeckers in forests (Hågvar et al. 1990, Angelstam and Mikusinski 1994, Kosiński 2006, Roberge et al. 2008, Robles and Ciudad 2012, Wiesner and Klaus 2018). The existence of forest stands, especially over 80 years of age and even single trees larger than other trees available in the habitat, are particularly important for the presence of Middle Spotted or Black Woodpeckers in forests (Kosiński 2006, Kosiński and Kempa 2007, Walczak et al. 2013, Basile et al. 2020). Many woodpeckers require large, old trees in bad health condition, including dying fragments or dead wood with fungi, often used for foraging or nesting (Fernandez and Azkona 1996, Kosiński and Winiecki 2004, Kosiński and Kempa 2007, Michalczuk and Michalczuk 2016a, 2020a, b). For these reasons, they occur primarily in mature forest stands or in protected areas, e.g. in national parks or forest reserves (Angelstam et al. 2002, Kosiński and Kempa 2007, Wiesner and Klaus 2018). Therefore, understanding the requirements of woodpeckers for various parameters of forest stands is crucial in planning the protection of woodpecker habitats in Europe. In addition, the primary cavity nesters as keystone species play a crucial role in many forest stands delivering nest placements for secondary cavity nesters (Cramp 1985). Some woodpecker species included in Annex 1 of the so-called Birds Directive (Directive 2009/147/EC) also require protection in the European Union countries and for this reason they need practical recommendations which can help protect them.

The aim of this study was to assess the characteristics of forest patches that may have an impact on the occurrence of Syrian, Great Spotted and Middle Spotted Woodpeckers in the extensively deforested agricultural landscape of SE Poland. They are the three most common woodpecker species found in this area (Michalczuk et al. 2018). We hypothesised that the large-size forest patches may positively influence the occurrence of all studied woodpeckers. In addition, the abundance of these species in scattered forest patches may be associated with the availability of old-growth forest stands or could also be supported by other forests surrounding forest patches. Recognition of such basic habitat requirements of these three sympatric woodpeckers may be beneficial in developing recommendations for the protection of these species in various rural landscapes with scattered forests.

Materials and methods

The study area of approximately 355 km^2 is situated in south-eastern Poland, closer to the Ukrainian border (50°32'N, 23°48'E; Michalczuk and Michalczuk 2016a, Michalczuk et al. 2018; Figure 1). This area as a part of the Wołyń Upland lies at an altitude of 195–263 m a.s.l. BSE (Kondracki 2000). Due to the very fertile soils, the area is mainly dedicated to agriculture (Bański 2010), where arable land predominates and accounts for ca. 75% of the total study area. Meadows occupy ca. 15% of the land, located mainly in the small valleys. Forests in this region are scattered and highly fragmented (the average area of a single forest patch is 25.7 ha, *SD* = 56.6, ranging from 0.20 to 284.51 ha, n = 73). Most forests represent the mesic maple-hornbeam forest community (EEA 2007), with

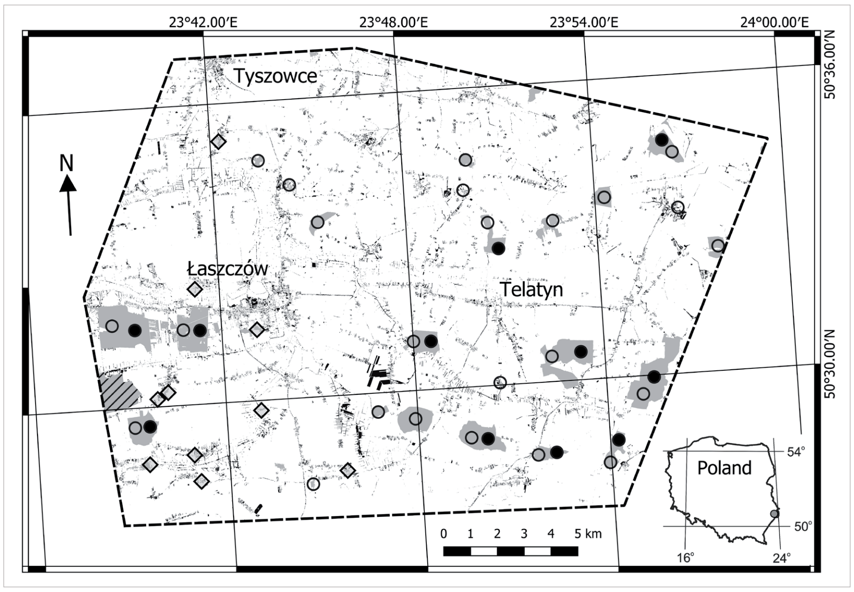


Figure 1. Distribution of the forest patches investigated in the study area

Denotations: dashed line – border of the study area, black line – non-forest stands, grey – forests (a fragmentary forest marked with skew solid line was excluded from the study), black dot – Middle Spotted Woodpecker site, black circle – Great Spotted Woodpecker site, diamond – Syrian Woodpecker site.

a significant share of hornbeam *Carpinus betulus,* maple *Acer platanoides*, linden *Tilia* spp., and oak *Quercus* spp. in the eastern part of the study area, while in the west there are also mixed forests with their canopy dominated by Scots pine *Pinus sylvestris* (BDL 2015). Non-forest stands, such as orchards, gardens, and groups of trees, are located mainly in built-up areas and only occasionally met in fields and meadows. One rarely finds tree rows and tree alleys along roads. Only sporadically in the study area, parks and cemeteries occur (Michalczuk and Michalczuk 2016a, b, 2020a, b). In the study area, six woodpecker species occur (see Michalczuk et al. 2018). The most common species is the Great Spotted Woodpecker; its mean density reaches 19.3 breeding pairs/100 ha of forested area. The Middle Spotted Woodpecker and Syrian Woodpecker reach a density of 3.5 and 0.1 breeding pairs/100 ha, respectively, in the forested areas. The Eurasian Wryneck, Lesser Spotted Woodpecker *Dendrocopos minor* and Black Woodpecker were observed less frequently, with 18.0, 14.0, and 8.0 breeding pairs in the whole study area, respectively, according to 2017 census data (Michalczuk et al. 2018).

The occupation of forests by individual species was assessed in 2013. During fieldwork, all forest patches (n = 73, except one fragmented forest patch that covers more than 600 ha and the smallest part of it was included in the study area), located in the research area, were surveyed (Figure 1). The research was focused on three most abundant species of woodpeckers: the Great Spotted (GSW), Middle Spotted (MSW) and Syrian Woodpeckers (SW) (Michalczuk et al. 2018). The search for woodpeckers within forest areas was conducted from March to May using the cartographic method combined with bird call playbacks (Michalczuk and Michalczuk 2006). In the case of small forest patches (< 1.0 ha), playbacks were staged from one point. Such stimulation points were placed most often on the edge of every forest patch because it ensured that the entire grove was surveyed and listened to. A regular grid of points evenly covering the area of larger forest patches was used for the survey. Playback points for the MSW were in the forest patches at every 150–200 m (n = 567; Kosiński et al. 2004), and for the SW at every 200–400 m (n = 179), *see* details in Michalczuk and Michalczuk (2006). The survey points were delineated on forest maps using QGIS 2.16 software package (QGIS Development Team 2013), and their locations in the field were determined with the aid of GPS receivers and maps at scales of 1 : 1000, 1 : 2000 or 1 : 5000.

During the fieldwork, the MSW was the first species with which the playback was used at the designated points, followed by the SW. For the MSW, 45 seconds of playback were followed by 30 seconds of listening (Kosiński et al. 2004). A 5-minute playback was used for the SW, reproducing its voice and drumming, followed by one minute of listening (Michalczuk and Michalczuk 2006). Such a voice stimulation pattern was played back at the point, just once per control. Due to the similar mating behaviour and breeding biology of the SW and GSW (Cramp 1985), playbacks of the GSW were not applied to determine their presence. We assumed that reproducing the voice and drumming of the SW would indicate the presence of the second twin species, which was also confirmed in other studies of both species (e.g. Michalczuk and Michalczuk 2016b, c, 2022, Michalczuk et al. 2018). If the birds were detected before beginning the playback, the vocalisations of the species were not reproduced. The playback was also discontinued when the woodpeckers were detected before the end of the playback session. When none of the studied species was found at a point after playback and listening, we moved to the next point to determine the presence of individual species. The playback was performed until at least one territory of the given woodpecker species was confirmed or excluded within the entire controlled forest patch. If birds were found while walking from one point to another, their position, direction of movement, and behaviour suggesting an occupied territory or nest, were also recorded, and indicated on the map.

Six field surveys for the SW and GSW were conducted from 1 March to 3 May 2013 (Michalczuk and Michalczuk 2006). The occupation of the forest patches by breeding pairs of the GSW and SW was determined based on a minimum of three confirmations of the bird presence within the surveyed forest patches (Michalczuk and Michalczuk 2006). Three surveys were conducted for the MSW between 20 March and 20 April 2013 (*see* Kosiński et al. 2004). Occupation of a forest patch by a breeding pair of MSW was assessed based on a minimum of two confirmations of the bird presence within the studied forest patches (Kosiński et al. 2004).

The assessment of forest patches and the habitats surrounding the forests that could potentially affect the occurrence of woodpeckers was performed using QGIS 2.16 software package (QGIS Development Team 2013). For this purpose, orthophoto maps available as a WMS layer (Geoportal 2013) were utilised. The forest area was calculated based on the outline of the crown of trees visible in the aerial photographs. The same method was applied to assess the area of other forests surrounding the individual studied forest areas in a 2 km-wide buffer strip, which was determined around each studied forest (*see* Myczko et al. 2014). The orchard area surrounding the particular studied forest patch was measured by the same method. This measurement was carried out according to the outline of the tree crowns in a 500 m radius buffer strip around the edge of the studied forest patch. Because the surface area of the buffer strip was derived from the forest patch size and its perimeter, we standardised this habitat measurement as a percentage proportion of the buffer strip area. The degree of forest isolation was also assessed by measuring the distance from the edge of the studied forest to the edge of the nearest forest area.

During the research, the average age of stands growing in a given forest area was also assessed. For this pur-

Table 1. Environmental parameters of 73 forest patches evaluated in the study and included in the analysis

Variable	Code	Unit of measure	Description	Average ± *SD*, (min–max)
Forest patch size	Area	ha	Area of forest patch, covered by tree crowns, measured using polygonal vector layer	25.75 ± 56.64 (0.20–284.51)
Forest area surrounding a given forest patch	Forest cover	%	Forest area, measured as an outline of the tree crowns, which belong to other forest patches in a 2-km radius buffer strip around the edge of the studied forest patch – expressed as percentage proportion	8.3 ± 13.6 (0.3–55.4)
Orchard area surrounding a given forest patch	Orchard cover	%	Orchard area, measured as an outline of the tree crowns in a 500-m radius buffer strip around the edge of the studied forest patch – expressed as percentage proportion	2.3 ± 2.2 (0.0–11.0)
Distance to the nearest forest patch	Other forest	m	Distance to the nearest forest patch measured as the distance from the edge of the investigated forest patch to the edges of the neighbouring forest	640.0 ± 536.0 (52.0–3046.0)
Average age of the forest patch stand	Trees age	years	Average age of trees in the forest patch, assessed using 2–30 random points, for which age was estimated on the basis of the age of the oldest stands present within the forest divisions visible on the forest maps retrieved from the BDL (2015)	33.0 ± 15.8 (10.0–80.0)
Area of tree stands > 80 years of age	> 80 forest	ha	Area of trees with age over 80 years, measured within the studied forest patch, visible on the forest maps retrieved from the BDL (2015)	8.5 ± 27.8 (0.0–180.0)
Area of oaks *Quercus* sp. stands > 80 years of age	> 80 oaks	ha	Area of forest stands with a share of oaks Quercus sp. aged > 80 years over 40%, measured within the investigated forest patch visible on the forest maps retrieved from the BDL (2015)	1.6 ± 7.7 (0.0–53.7)

pose, depending on the forest area, from 2 (in the smallest forest patches) to 30 (in the largest forest patches) random points were determined. Then, based on forest taxation maps available in the Forest Data Bank (BDL 2015), the age of the oldest trees in the forest stand was verified at the randomised point. In the case of privately owned forest patches for which no current information about the age of the stand was available in the BDL database, the assessment was made based on our own data on forest patches, collected in the study area for the last 18 years, or on information obtained from the forest parcel owners. These forest patches most often contained trees planted in one year; in other cases, the age of the oldest trees in the random point was assessed. The study included forest patches with forest stands at least ten years old. On the ground of the information about the forest stand, the age of the forest stand was obtained for the randomly chosen points, and then the average age of the forest stands in the given forest area was calculated. Reasoning from the forest maps from the BDL database, we also calculated the size of forest stands aged more than 80 years for every analysed forest patch, as their presence could be significant for the occurrence of woodpeckers (*see* Walczak et al. 2013). Data available in the BDL (2015) were also employed for assessment of the area of stands with a significant proportion of oaks *Quercus* spp. older than 80 years, whose share in the stands was greater than 40%. A total of seven habitat parameters of the forest patches and their surroundings were characterised and included in the statistical analysis (Table 1).

Due to the abnormal distribution of the independent variables, the Mann-Whitney *U* test was applied to assess differences in individual habitat parameters between the forest patches occupied and unoccupied by woodpeckers (Table 2–4). When comparing habitat requirements of the three species of woodpeckers studied, the Kruskall-Wallis test with the Dunn post-hoc test was used. The statistical analysis was performed employing Statistica 13.1 Pl platform (Dell 2016). All statistical differences at a level of less than 0.05 were determined to be significant. To relate the impact of habitat variables on the occurrence of woodpeckers, an ordinal method was also employed. For this purpose, with recourse to CANOCO 5.0 software package (ter Braak and Šmilauer 2012), the Principal Component Analysis (PCA) was applied (Lepš and Šmilauer 2003; Figure 2). In doing so, all variables were normalised before evaluation. When performing the PCA, it was assumed that the relationship between the observed value of the indica-

Table 2. Environmental parameters of the forest patches inhabited and uninhabited by the Syrian Woodpecker

Parameter	Occupied, n = 10 average ± *SD* (min–max)	Unoccupied, n = 63 average ± *SD* (min–max)	Mann-Whitney *U* test
Area (ha)	3.1 ± 4.2 (0.4–11.1)	29.3 ± 60.3 (0.2–284.5)	*Z* = 0.62, *p* = 0.5368
Forest cover (%)	2.1 ± 2.4 (0.5–7.5)	9.2 ± 14.4 (0.3–55.4)	*Z* = 0.78, *p* = 0.4365
Orchard cover (%)	**3.3 ± 1.4 (0.8–5.5)**	**2.1 ± 2.3 (0.0–11.0)**	***Z* = –2.59, *p* = 0.0096**
Trees age (years)	28.5 ± 6.4 (15.0–35.0)	33.6 ± 16.8 (10.0–80.0)	*Z* = 0.39, *p* = 0.7002
Other forest (m)	768.0 ± 546.0 (152.0–2036.0)	621.0 ± 536.0 (52.0–3046.0)	*Z* = –0.84, *p* = 0.3996
> 80 forest (ha)	0.0 ± 0.0 0.0–0.0)	9.8 ± 29.7 (0.0–180.0)	*Z* = 0.87, *p* = 0.3819
> 80 oaks (ha)	0.0 ± 0.0 (0.0–0.0)	1.8 ± 8.3 (0.0–53.7)	*Z* = 0.39, *p* = 0.6943

Note: Environmental codes are the same as in Table 1. Significant differences are marked in bold.

Table 3. Environmental parameters of the forest patches inhabited and uninhabited by the Great Spotted Woodpecker

Parameter	Occupied, n = 24 average ± *SD* (min–max)	Unoccupied, n = 49 average ± *SD* (min–max)	Mann-Whitney *U* test
Area (ha)	**74.7 ± 79.3 (0.7–284.5)**	**1.7 ± 2.5 (0.2–11.1)**	***Z* = 6.06, *p* < 0.0001**
Forest cover (%)	**4.1 ± 4.1 (0.0–15.4)**	**1.4 ± 1.6 (0.3–7.5)**	***Z* = 6.05, *p* < 0.0001**
Orchard cover (%)	**1.6 ± 1.8 (0.2–7.8)**	**2.6 ± 2.3 (0.0–11.0)**	***Z* = –2.21, *p* = 0.0268**
Trees age (years)	**45.8 ± 17.3 (22.5–80.0)**	**26.7 ± 10.6 (10.0–63.0)**	***Z* = 4.69, *p* < 0.0001**
Other forest (m)	699.0 ± 467.4 (60.0–1580.0)	612.0 ± 569.0 (52.0–3046.0)	*Z* = –1.21, *p* = 0.2365
> 80 forest (ha)	**25.7 ± 44.2 (0.0–180.0)**	**0.0 ± 0.2 (0.0–1.7)**	***Z* = 2.79, *p* = 0.0053**
> 80 oaks (ha)	**4.8 ± 13.1 (0.0–53.7)**	**0.0 ± 0.0 (0.0–0.0)**	***Z* = 3.27, *p* = 0.0011**

Note: Environmental codes are the same as in Table 1. Significant differences are marked in bold.

Table 4. Environmental parameters of the forest patches inhabited and uninhabited by the Middle Spotted Woodpecker

Parameter	Occupied, n = 11 average ± *SD* (min–max)	Unoccupied, n = 62 average ± *SD* (min–max)	Mann-Whitney *U* test
Area (ha)	**133.0 ± 81.2 (41.9–284.5)**	**6.7 ± 16.1 (0.2–101.8)**	***Z* = 5.16, *p* < 0.0001**
Forest cover (%)	**5.9 ± 5.1 (0.1–15.4)**	**3.6 ± 6.6 (0.3–37.0)**	***Z* = 5.07, *p* < 0.0001**
Orchard cover (%)	**0.8 ± 0.5 (0.2–1.6)**	**2.5 ± 2.3 (0.0–11.0)**	***Z* = –2.89, *p* = 0.0038**
Trees age (years)	**59.1 ± 14.6 (35.5–80.0)**	**28.3 ± 10.8 (10.0–63.0)**	***Z* = 4.80, *p* < 0.0001**
Other forest (m)	397.0 ± 370.0 (60.0–997.0)	684.0 ± 551.0 (52.0–3046.0)	*Z* = –1.81, *p* = 0.0700
> 80 forest (ha)	**55.7 ± 51.5 (0.0–180.0)**	**0.1 ± 0.5 (0.0–4.0)**	***Z* = 4.26, *p* < 0.0001**
> 80 oaks (ha)	**10.5 ± 18.1 (0.0–53.7)**	**0.0 ± 0.0 (0.0–0.0)**	***Z* = 2.38, *p* < 0.0001**

Note: Environmental codes are the same as in Table 1. Significant differences are marked in bold.

tors and the gradient of habitat parameters is linear (Legendre and Legendre 2012). For assessment of woodpecker requirements, the CART (Classification and Regression Trees) method was also applied (Bel et al. 2009, Therneau et al. 2019). It is one of the techniques of data mining with the aim to obtain the most accurate prediction possible with the lowest percentage of misclassifications and finally to obtain the most homogeneous sets. This analysis was applied to determine the most important factors associated with the occurrence of the studied species. Since the dependent variable was dichotomous (forest patches inhabited by woodpeckers versus forest patches uninhabited by woodpeckers), the separate tree classification was defined for each studied species. These were performed with the aid of R software (R Core Team 2019) and the 'rpart' package (Therneau et al. 2019).

Results

Collectively, woodpeckers inhabited 34 forest patches (47%, n = 73) within the study area. The most common was the GSW, which occupied 24 forest patches (33%). The MSW was found in 11 (15%) forest patches, and the SW in 10 forest patches (14%, n = 73; Figure 1).

The SW inhabited forest patches surrounded by a significantly larger proportion of orchards as compared to uninhabited forest patches (Tables 2 and 3, Figures 2 and 3). Other habitat measurements were not significantly differentiated between the forest patches inhabited and uninhabited by the SW (Table 2). However, in comparison to the uninhabited forest patches, this species seemed to occupy young-growth forest patches without stands over 80 years old. The SW inhabited small forest patches with a maximum area of 11.1 ha (Table 2). The forest patches inhabited by the SW were located at a greater distance from other forest patches and were also surrounded by smaller forest cover compared to the unoccupied forest patches, but mentioned differences were not confirmed statistically (Table 2, Figure 2).

The forest patch size was the most important factor that determined the occurrence of the GSW and MSW in the study area (Figures 4 and 5). The GSW occurred also in the small forest patches, but this species was especially

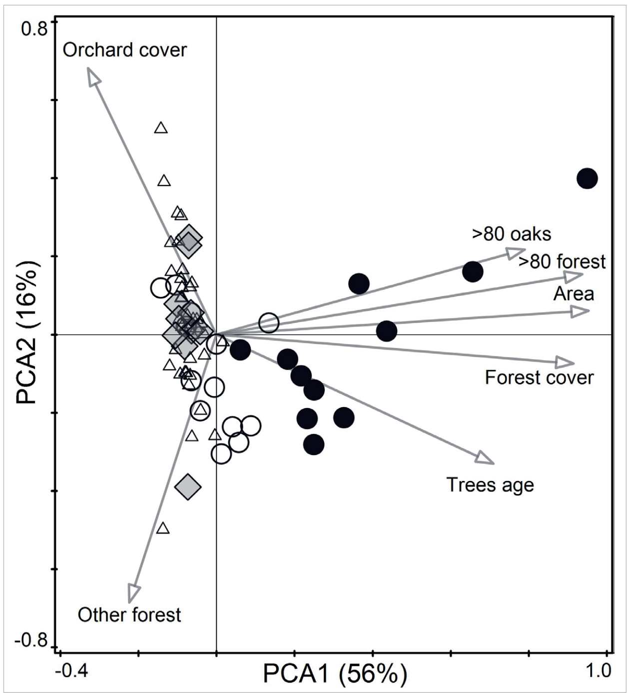
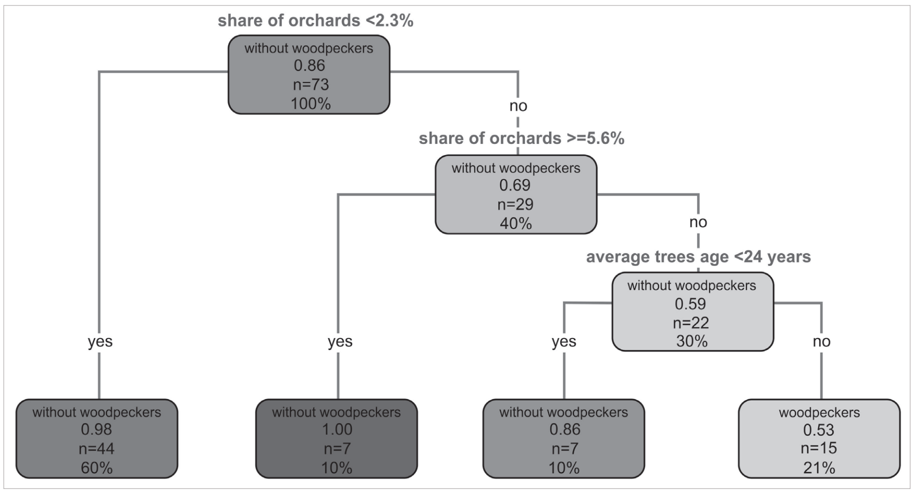


Figure 2. A PCA scatter plot of forest patches inhabited and uninhabited by woodpeckers along seven gradients of environmental variables (grey arrows)

Uninhabited forests were marked by triangles, Syrian Woodpecker locations by grey diamonds, Great Spotted Woodpecker locations by circles, and Middle Spotted Woodpecker locations by black dots. The environmental codes are the same as in Table 1.

Figure 3. Decision tree referring to the characteristics of the forest patches occupied by the Syrian woodpecker in an agricultural landscape

Denotations: root node – 62/73 cases classified as "without woodpeckers"; first sub-nodes with classification variable "share of orchards < 2.3%" when "yes" – 43/44 cases classified as "without woodpeckers", and for "no" – 20/29 cases classified as "without woodpeckers"; second sub-nodes with classification variable "share of orchards ≥ 5.6%" when "yes" – 7/7 cases classified as "without woodpeckers", and for "no" – 13/22 cases classified as "without woodpeckers"; third sub-nodes with classification variable "average trees age < 24 years" when "yes" – 6/7 cases classified as "without woodpeckers", and for "no" – 8/15 cases classified as "with woodpeckers".



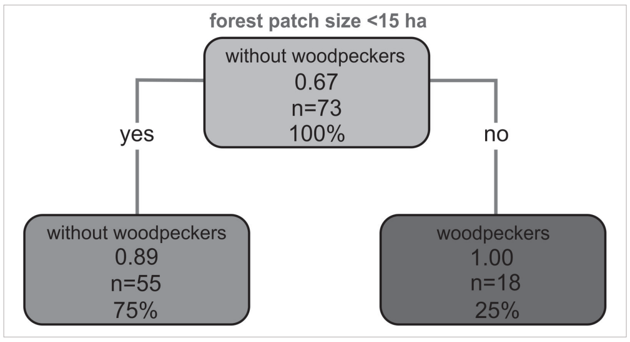


Figure 4. Decision tree referring to the characteristics of the forest patches occupied by the Great Spotted Woodpecker in an agricultural landscape

Denotations: root node – 49/73 cases classified as "without woodpeckers"; first sub-nodes with classification variable "forest patch size < 15 ha" when "yes" – 49/55 cases classified as "without woodpeckers", and for "no" – 18/18 cases classified as "with woodpeckers".

Figure 5. Decision tree referring to the characteristics of the forest patches occupied by the Middle Spotted Woodpecker in an agricultural landscape

Denotations: root node – 62/73 cases classified as "without woodpeckers"; first sub-nodes with the classification variable "forest patch size < 42 ha" when "yes" – 60/60 cases classified as "without woodpeckers", and for "no" – 11/13 cases classified as "with woodpeckers".

found in the forest patches larger than 15 ha (Table 3, Figure 4). The MSW was observed only in the forest patches exceeding 41 ha (Table 4, Figure 5). Generally, the GSW and MSW inhabited much larger forest patches with older tree stands compared to the unoccupied forest patches (Tables 3 and 4). The values of these habitat characteristics were also significantly higher compared to the forest patches inhabited by the SW ($H_{2,45} = 21.69$, $p < 0.001$ with Dunn post-hoc test $p = 0.003$ and $p < 0.001$ and $H_{2,45} = 16.95$, $p < 0.001$ with Dunn post-hoc test $p = 0.016$ and $p < 0.001$, respectively; Table 2). The aforementioned factors were clearly related to the presence of the MSW and less pronounced in the case of the GSW in the forest patches (Figure 2). Both species also inhabited forest patches with a larger area of tree stands over 80 years old (Tables 3 and 4, Figure 2). In the case of the MSW, this value was significantly higher compared to the forest patches inhabited by the SW ($H_{2,45} = 13.37$, $p = 0.002$ with Dunn post-hoc test $p = 0.004$). Forest patches occupied by these two species also included significantly larger areas of oak stands aged over 80 years (Tables 3 and 4, Figure 2).

In comparison to the uninhabited forest patches, the forest patches inhabited by GSW and MSW possessed a larger proportion of forest cover in their vicinity. The occurrence of these two species was clearly related to the presence of such stands (Figure 2). In addition, the share of forests surrounding those occupied by the GSW and MSW was significantly larger compared to forest cover surrounding the forest patches occupied by the SW ($H_{2,45} = 21.05$, $p < 0.001$ with Dunn post-hoc test $p = 0.002$ and $p < 0.001$, respectively; Tables 2–4, Figure 2). The GSW and MSW inhabited forest patches surrounded by less cover of orchards (Tables 2 and 3). The forest patches inhabited by these two species also included a statistically smaller orchard cover in their vicinity in comparison to the forest patches inhabited by the SW ($H_{2,45} = 13.80$, $p = 0.001$ with Dunn post-hoc test $p = 0.010$ and $p = 0.001$, respectively; Tables 2–4). Only the distance to the nearest forest did not differ between forest patches inhabited and uninhabited by these three species (Tables 2–4). Additionally, the distance to the nearest area with forest or orchard cover did not appear to be essential for the occurrence of the MSW and GSW in the forest patches (Figure 2).

Discussion

The main factor that favoured the occurrence of woodpeckers in the forests of the agricultural landscape of SE Poland was the area of the forest patch. The significant impact of forest patch area on the presence of birds and especially woodpeckers has been shown in many other studies in Europe (Åberg et al. 1995, Mošanský and Mošanský 1999, Salvati et al. 2001, Myczko et al. 2014, Figarski and Kajtoch 2018). Although the presence of large forest areas is mainly conducive to the occurrence of species requiring considerable space as in the case of the Grey-headed Woodpecker *Picus canus*, Black Woodpecker *Dryobates martius*, and White-backed Woodpecker *Dendrocopos leucotos* (Imhof 1984, Rolstad and Rolstad 1995, Bocca et al. 2007, Campion et al. 2020), our study showed that this factor can also determine the occurrence of other specialised species, e.g. the MSW which possesses a smaller home range size, not exceeding 11 ha (Buchmann and Pasinelli 2002). Even the GSW, commonly occurring in Europe, which inhabited small groves of several hectares within the study area (*see* Michalczuk et al. 2018), exhibited a tendency to occupy larger forest patches (*see* Myczko et al. 2014). The results of our study showed that the size of a forest area did not play a significant role only for the SW. Similar results have been presented in other studies conducted in agricultural and even urban landscapes, where sites inhabited by this species were found in parks, gardens and many other non-forest stands (Michalczuk and Michalczuk 2016b, c, 2022, Figarski and Kajtoch 2018, Michalczuk 2020). Because the SW demonstrates the specialisation in inhabiting non-forest woody habitats and is able to find nesting and foraging sites, e.g. in orchards or tree alleys (Michalczuk and Michalczuk 2016a, 2017, 2020a, b), it is able to inhabit small forest patches too.

The occurrence of SW in small patches may also result from its avoidance of competition from the commonly spread GSW (Michalczuk and Michalczuk 2016b), which can also occupy the smallest groves. Competitive relationships between these two species were observed during the expansion of the SW in Europe (Winkler 1973, Mošanský and Mošanský 1999, Michalczuk and Michalczuk 2016c). The SW colonisation of the smallest wooded patches within the research area may indicate a clear niche partition by the two species, probably reducing their mutual competition (Winkler 1973, Michalczuk and Michalczuk 2016b, c, Kajtoch and Figarski 2017, Michalczuk et al. 2018). Such habitat division between these two species is also possible as a result of the different food requirements demonstrated by GSW and SW. The SW diet includes many various invertebrates, and it is more diverse because it contains more plant items in comparison with that of the GSW, which feeds prevalently on invertebrates (Cramp 1985). This is probably the reason why the SW is far less frequent in forests than the GSW (*see* Michalczuk and Michalczuk 2016b, Figarski and Kajtoch 2018, Michalczuk et al. 2018). The conducted studies did not confirm such habitat separation between the GSW and MSW, which in the study area inhabited the same forest patches. Because their niches generally do not overlap, therefore, both species avoid or reduce competition by utilising generally different nest and food resources (Cramp 1985, Pasinelli 2000, Kruszyk 2003, Kosiński and Kempa 2007, Kosiński et al. 2018).

An important positive factor for the occurrence of the GSW and MSW in the agricultural landscape was the forest cover in the neighbourhood of the forest patch. Such relationship was not confirmed by the results of studies carried out in Spain, where the most important factor for MSW occurrence was habitat quality, in particular, the availability of large oaks (Robles and Ciudad 2012). This may be due to the fact that forest habitats in the study area and on the Iberian Peninsula are different (Bohn et al. 2003, EEA 2007), and for this reason woodpeckers may also show different requirements in the mentioned regions. We assume that probably for this reason, the occurrence of woodpeckers in the studied forest patches was not affected by the distance between them. Only supplementary tree cover near forest patches can improve connectivity between them. According to the metapopulation theory, it can curb extinction of local populations and positively affect the possibility of colonisation of forest patches by new specimens (Hanski 1991). According to the “source-sink” concept, where “source subpopulations” provide individuals to “sink subpopulations” (Pulliam and Danielson 1991), it can also be assumed that occurrence of woodpeckers in forest patches (especially larger ones) surrounded by a large proportion of tree stands may also support inhabitation of the scattered small-size forest patches by the woodpeckers with the most requirements, e.g. the MSW, and even the ubiquitous GSW. However, the proportion of forest canopy in the neighbourhood of the studied forest patches did not affect the occurrence of the SW. This may be because this species is adapted to semi-open landscapes and can nest and forage in diverse treed habitats, which allow it to be present in small forest patches too (Cramp 1985, Michalczuk and Michalczuk 2016b, 2017, Figarski and Kajtoch 2018, Michalczuk 2020). In our study, this process is probably supported by the presence of orchards, which are the basic habitats of this species in the agricultural landscape (Michalczuk and Michalczuk 2016b, Figarski and Kajtoch 2018). Perhaps for this reason in the conducted study, SWs were not recorded in forest patches with a greater share (at minimum 5.6%) of orchards in their vicinity. Such forest patches were probably omitted by the SW, because this species was able to find sufficient resources, e.g. food and nest substrate, outside the forests, i.e. in large orchards adjacent to forest patches (Michalczuk and Michalczuk 2016b, 2017, 2020a, b).

The lack of clear preferences of the SW to any other considered tree stand characteristics associated with its age, confirms that this species has the lowest habitat requirements among this bird group (Cramp 1985). However, the old-growth tree stands were especially important for the presence of GSWs and MSWs in the forest patches. As shown in our and other studies (e.g. Walczak et al. 2013, Wojton and Krasoń 2017), tree stands aged over 80 years are essential for them. Their presence in forests is crucial especially for the MSW, as this species requires old and large trees (Robles and Ciudad 2012) for foraging (Kruszyk 2003) and nesting (e.g. Kosiński and Kempa 2007). Such trees are very often in bad health condition and contain broken or dead branches, which deliver relevant substrate for carving out holes in trees (Pasinelli 2000, Kosiński and Kempa 2007). For this reason, this species prefers old growth forest stands, especially oak stands (Pasinelli 2000, Robles and Ciudad 2012, Walczak et al. 2013, Wojton and Krasoń 2017, Wiesner and Klaus 2018), which was confirmed by this study. The scarcity of such habitats in the study area very probably could have been the factor that negatively affected the number of forest areas inhabited by the MSW there (Michalczuk et al. 2018). It can be expected that the availability of large and dead deciduous trees in forests should be considered as a crucial factor important for the existence of this species as well as other woodpeckers in managed forests (e.g. Pasinelli 2000, Kosiński and Kempa 2007, Robles and Ciudad 2012, Bouvet et al. 2016, Wiesner and Klaus 2018).

Conclusions

Our study showed that in a heavily deforested agricultural landscape, the size of forest patch and the age of forest stand play a crucial role in the occurrence of primary cavity nesters. The specialised MSW had the highest habitat requirements and needed forest patches that exceed 42 ha. However, forest patches greater than 15 ha with older forest stands are also important for the ubiquitous GSW. Therefore, comprehensive protection of woodpecker habitats should also include the preservation of small forest patches. They could be important for the occurrence of the SW, which is also able to inhabit young growth forest patches. The protection of such areas of forest surrounded by non-forest stands, like orchards, should also be considered when developing landscape protection strategies. This could be especially important in the period of degradation of non-forest stands constituting the basic habitats of this species (SW), which is currently observed in the agricultural landscape of SE Poland (Michalczuk and Michalczuk 2015).

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