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Population size, trend, and predictors of abundance of the Middle Spotted Woodpecker *Dendrocoptes medius* in the Natura 2000 Special Protection Area Krotoszyn Oak Forest in 2010–2020

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Abstract: Analysis of population size and trends is an important step for the conservation and management of species of conservation concern in the Natura 2000 Special Protection Areas (SPA). In this study, we examined the population dynamics of the Middle Spotted Woodpecker *Dendrocoptes medius* and analyzed its trend in SPA Krotoszyn Oak Forest (KOF) (34,245 ha in size, including 14,757 ha of forest area) in 2010–2020. Furthermore, we attempted to identify which factors related to the area of different forest stands affect its abundance. We also investigated whether the changes in abundance of Middle Spotted Woodpecker in the whole KOF were similar to those occurring in a smaller part of this area (Łówkowiec Forest), in order to determine the usefulness of double sampling for the calibration of data obtained through periodic censuses. To estimate population size and determine the model describing the abundance of Middle Spotted Woodpecker, we used data from 19 randomly selected 1 km^2 sample plots. Birds were counted most frequently during one or two surveys in each study plot using the call-playback method recommended for the censuses of the Middle Spotted Woodpecker. The estimated population size of the Middle Spotted Woodpecker in KOF varied between 587 pairs in 2010 and 823 pairs in 2015 and 2019. The non-significant trend suggests stable population. The rate of population growth between 2010 and 2020 was 1.338 (95% CI: 0.924–1.714), and the mean annual growth rate (λ) was 1.030 (95% CI: 0.992–1.055). The patterns of abundance index were generally similar in KOF and Łówkowiec Forest, except for the beginning of the study period. The abundance of the studied species was positively affected, with decreasing importance, by the area of three age classes of oak forest – ≥120 years, 80–119 years, and 40–79 years, and area of other deciduous stands; however, the effect of the last variable was very weak. Our data confirm that SPA KOF is the second most important area for the Middle Spotted Woodpecker, after the Białowieża Forest, in Poland. In the long run, the greatest threat for this woodpecker population in KOF could be uneven tree age distribution, with a disproportionate ratio of the old and middle age classes, especially in the Jasne Pole Precinct, fragmentation of old stands, and process of oak dieback which, in turn, can increase the intensity of sanitary felling and salvage logging. Our findings suggest that annual monitoring data from the

Łówkowiec Forest could be useful to calibrate and improve interpretation of data from periodic censuses in KOF. This would reduce time needed for monitoring of birds using large-scale sampling.
Keywords: population size, trend, double sampling, *Dendrocoptes medius*, Natura 2000 Special Protection Area

Wielkość populacji, trend i czynniki warunkujące liczebność dzięcioła średniego *Dendrocoptes medius* w Obszarze Specjalnej Ochrony Natura 2000 Dąbrowy Krotoszyńskie w latach 2010–2020. Abstrakt: Określenie wielkości populacji i trendów jest ważnym krokiem w działaniach mających na celu utrzymanie właściwego stanu ochrony gatunków w Obszarach Specjalnej Ochrony (OSO) Natura 2000. Celem prezentowanych badań było oszacowanie wielkości populacji dzięcioła średniego *Dendrocoptes medius* i jej trendu w OSO Dąbrowy Krotoszyńskie (DK) (powierzchnia 34 245 ha, w tym 14 757 ha lasów) w latach 2010–2020 oraz wskazanie, które typy i stadia wiekowe lasów wpływają na liczebność gatunku. Estymacji wielkości populacji oraz analizy związku liczebności gatunku z wybranymi cechami środowiska dokonano na podstawie danych z 19 losowo wskazanych powierzchni próbnych 1 × 1 km. Porównano również zmiany wskaźnika liczebności populacji na terenie całego OSO DK i na mniejszym obszarze – w uroczysku Łówkowiec (LF). Analiza ta miała na celu sprawdzenie czy zmiany wartości wskaźnika uzyskane na corocznie monitorowanej małej powierzchni mogą służyć do kalibracji danych uzyskanych w trakcie periodycznych cenzusów na powierzchniach próbnych w DK. Ptaki liczono najczęściej w czasie jednej lub dwóch wizyt na każdej powierzchni próbnej wykorzystując metodę stymulacji głosowej rekomendowaną do liczenia dzięcioła średniego. Wielkość populacji dzięcioła średniego w badanym okresie zmieniała się od 587 par w roku 2010 do 823 par w latach 2015 i 2019, a jej trend określono jako stabilny. Wskaźnik wzrostu populacji w latach 2010–2020 wynosił 1,338 (95% PU: 0,924–1,714), a średnie roczne tempo wzrostu (λ) 1.030 (95% PU: 0,992–1,055). Wzorzec zmian wskaźnika liczebności w DK i LF był zbliżony, za wyjątkiem początkowego okresu badań. Liczebność dzięcioła średniego na powierzchniach próbnych była pozytywnie związana z powierzchnią trzech kategorii wiekowych drzewostanów dębowych, w kolejności znaczenia – ≥120, 80–119 i 40–79 lat, oraz z powierzchnią innych drzewostanów liściastych, jednakże wpływ ostatniej zmiennej był bardzo słaby. Wyniki badań potwierdzają, że OSO DK jest drugim co do znaczenia po Puszczy Białowieskiej miejscem występowania dzięcioła średniego w Polsce. Zagrożeniem dla trwałości populacji na obecnym poziomie jest nierównomierna struktura wiekowa drzewostanów dębowych, z wysokim udziałem drzewostanów starych w stosunku do średniowiekowych, fragmentacja starodrzewów oraz zamieranie dębów powodujące intensyfikację cięć sanitarnych i przygodnych. Nasze ustalenia sugerują, że dane z monitoringu w LF mogą służyć do kalibracji i polepszenia interpretacji danych uzyskiwanych w czasie cyklicznych ocen liczebności dzięcioła średniego prowadzonych w OSO DK. Metoda ta może również zmniejszać czas niezbędny do monitoringu ptaków w oparciu o próbkowanie na dużym obszarze.
Słowa kluczowe: wielkość populacji, trend, podwójne próbkowanie, *Dendrocoptes medius*, Obszar Specjalnej Ochrony Natura 2000

The determination of distribution, size, and population trends serve as important steps in the development of conservation strategies for a species of conservation concern. Within Special Protection Areas (SPAs) of regional importance, designated to support endangered species (Wilk et al. 2010, Chylarecki et al. 2016) under the European Union Birds Directive (EPCEU 2009), such assessments allow to effectively manage the target species to reach or maintain their 'favorable conservation status' (CEC 1992).

The size of the breeding population of a species may vary from year to year, which can be due to the influence of both density-dependent and density-independent factors (Royama 1992, Berryman & Turchin 2001). The majority of studies estimating the abundance of target species in SPAs in Poland have been performed only over one year period (e.g. Sikora et al. 2015, 2016, Ławicki et al. 2019), and only a few used long-term monitoring data (Lenkiewicz et al. 2021). In this way, the effect of year-to-year changes in population size on population status in a given area is often missed. For example, a significant decrease in population size due to natural fluctuations found during periodic monitoring, such as every few years, can be interpreted as a deterioration in the status of target species, and as a result, affect decision-making regarding conservation management of their habitats in SPA, and management of the area in general (Ostermann 1998). Avoiding this misinterpretation may be overcome by a long-term monitoring based on survey sampling method or by calibrating data, e.g. population indices, obtained from periodic censuses on a broader geographic scale to the data from a smaller reference area investigated year by year, i.e. with a double sampling (Chylarecki et al. 2015). Originally, this approach involves an initial survey of large number of plots using a rapid method such as area searches, point counts or circular plot counts, and a subsample of those plots on which actual density is determined through intensive methods (Bart & Earnst 2002).

The non-migratory Middle Spotted Woodpecker *Dendrocoptes medius* is distributed over large part of Europe from Northwestern Spain to Western Russia and from the Mediterranean coasts to North Sea and Baltic Sea, in Anatolia, and in an isolated area in the Zagros Mountains of Iran and Iraq (Pasinelli 2003, Kamp et al. 2019, Robles & Pasinelli 2020). This species is mostly associated with mature, rough-barked deciduous stands, primarily oak-dominated forests (Pasinelli 2003); however, it can also be found in mature beech, alder, and other broadleaved tree stands, as well as old orchards (Hertel 2003, Weiss 2003, Winter et al. 2005, Kosiński 2006, Gatter & Mattes 2008, Stachura-Skierczyńska & Kosiński 2014). The Middle Spotted Woodpecker is listed in Annex I of the European Union Birds Directive (EPCEU 2009), and its habitat is subject to special conservation measures in order to ensure survival and reproduction of this species in the area of distribution in EU. Thus, assessing the abundance and population trend of the Middle Spotted Woodpecker is important for its conservation and management in the Natura 2000 SPA, where this species is considered a target species.

SPA Krotoszyn Oak Forest (KOF) PLB300007, created under the European Union Birds Directive in 2007, is the second most important Middle Spotted Woodpecker site in Poland, with an estimated population of 450–460 pairs (SDF 2021) or ca. 480 pairs (Wilk et al. 2010). The abundance, spatial distribution, and habitat characteristics of this species in KOF seem to be well documented. However, most of the data about this species in KOF have been collected in the first decade of the 21st century up to 2010 (Kosiński & Hybsz 2006, Kosiński & Kempa 2007, Żurawlew et al. 2009, Stachura-Skierczyńska & Kosiński 2014).

Recent studies have documented an increase in the population size and range shift of the Middle Spotted Woodpecker in different parts of Europe (Robles and Pasinelli 2020), after a decline in the 20th century (Pasinelli 2003). The Common Breeding Bird Survey also indicated a moderate increase in population abundance in Poland (Chylarecki et al. 2018). Long-term studies on the population dynamics of Middle Spotted Woodpecker in SPAs in Poland are limited, and have only covered a portion of the protected areas (Wesołowski & Tomiałojć 1997, Wesołowski et al. 2015, Kosiński & Walczak 2020). Except for the Łówkowiec Forest, the temporal trend in KOF is unknown (Kosiński & Walczak 2020). The question of whether the increase of the Middle Spotted Woodpecker population in Poland is reflected in KOF remains open.

Earlier studies attributed the abundance of Middle Spotted Woodpeckers in KOF to the area of broadleaved or oak stands >80 years old. However, these studies used the data obtained from sample plots located in smaller part of KOF, a limited number of predictors describing the type and age of forest stands, and employed only simple correlation analysis (Kosiński & Hybsz 2006). The subsequent study, which focused on analyzing the relationship between the number of territories per study plot and different characteristics of forest naturalness, revealed that the share of old and uneven-aged stands determined the abundance of Middle Spotted Woodpecker (Stachura-Skierczyńska & Kosiński 2016). Nevertheless, it is unknown whether these results properly predict the abundance of the species in KOF.

Therefore, in this study, we estimated the population dynamics of Middle Spotted Woodpeckers in 2010–2020, and analyzed the trend of this species in SPA KOF. We also verified whether the pattern of abundance index of Middle Spotted Woodpecker in KOF is similar to that closely followed in a smaller part of this area, in order to determine the usefulness of double sampling for the calibration of data obtained from periodic censuses. Furthermore, we attempted to identify to what extent the area of forest stands with different ecological characteristics affects the abundance of Middle Spotted Woodpecker. We also discussed the threats for this woodpecker species in KOF.

Study area

SPA KOF (34,245 ha in size, central point 17°38'14.28"E, 51°42'52.56"N; Greater Poland voivodeship, Western Poland) is made up of several spatially disjunct larger forest patches with a total area of about 14,757 ha in 2020 (Forest Data Bank 2020). The forest is surrounded by intensively cultivated agricultural areas (Fig. 1). It has been estimated

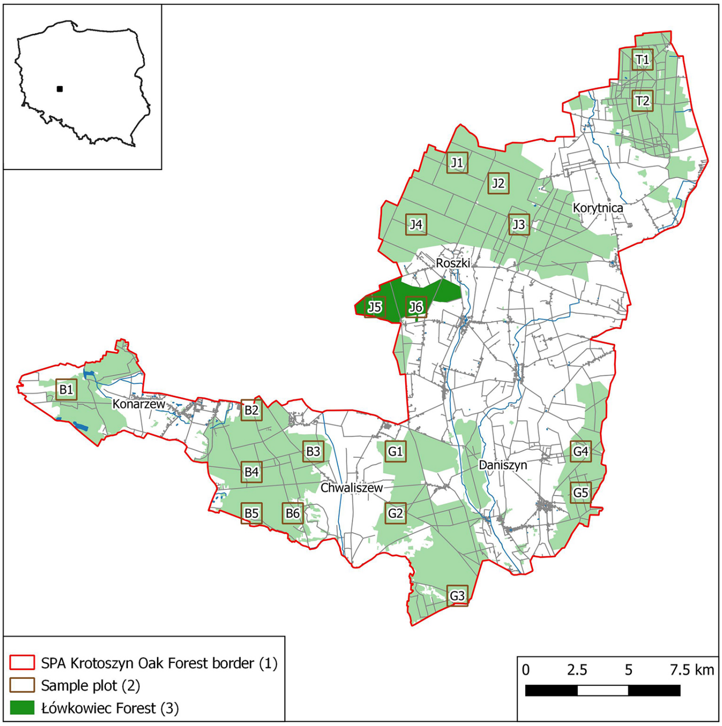


Fig. 1. Map of the Special Protection Area Krotoszyn Oak Forest with distribution of sample plots
Rys. 1. *Mapa Obszaru Specjalnej Ochrony Dąbrowy Krotoszyńskie z lokalizacją powierzchni próbnych. (1) – granica obszaru, (2) – powierzchnie próbne, (3) – uroczysko Łówkowiec*

that pedunculate oak *Quercus robur* stands covered 7,354 ha in 2010 and 7,402 ha in 2020 (51% of the total forest area), which signifies that KOF has one of the highest concentrations of oak forests (mainly *Quercetea-robori petreae*, locally *Calamagrostio arundinaceae–Quercetum petraeae*) in Central Europe (Krahl-Urban 1941, Kasprowicz 2010, Danielewicz ed. 2016). Approximately 49% of oak-dominated stands were >120 years old in 2010. KOF is characterized by two-storey stands and generally low diversity of tree species (up to 2–3 species per stand, e.g. pedunculated oak, hornbeam *Carpinus betulus* and European beech *Fagus sylvatica*, but some forest stands might have more than 3 species) (Brzeg & Kasprowicz 2016, Szmyt 2017). This site has been intensively exploited for high-quality oak wood, and managed since the beginning of the 19th century (Krahl-Urban 1941, Świtała 1948, Macias & Szymczak 2012, Kaźmierczak 2016). Today's silvicultural techniques include mainly clear-cutting and different types of selection cutting methods depending on the forest habitat type and tree species composition (Kaźmierczak 2016). Small elongated clear-cuts, up to ca 3 ha, are the most common type of regeneration in oak-dominated stands. This area is also protected as the Natura 2000 Special Area of Conservation (SAC) Uroczyska Płyty Krotoszyńskiej PLH300002 (CEC 1992). Since the study area is protected both under the Birds and Habitats Directives, there are some special adjustments of forest management to protect the target species and their habitats, e.g. by maintaining sufficient area of suitable habitats for Middle Spotted Woodpeckers, retaining cavity trees when harvesting and stand conversion from coniferous to deciduous species (RDOŚ 2015a, b). Around 0.9% of the total forest area is protected as forest reserves.

Materials and methods

Data on the woodpecker population

Monitoring of the Middle Spotted Woodpecker population was performed in 2010–2020 on 19 randomly selected sample plots with an area of 1 km^2 (Fig. 1). The algorithm implemented in ArcGIS software (ESRI, Redlands, CA, USA) assumed that each sample plot includes at least 20 ha of deciduous forest that was potentially suitable for breeding Middle Spotted Woodpeckers (Pasinelli et al. 2001, Stachura-Skierczyńska 2013). The selection of sample plots was primarily made with the aim of developing a landscape-scale predictive model of potential nesting habitats for Middle Spotted Woodpeckers in KOF, reported elsewhere (Stachura-Skierczyńska 2013, Stachura-Skierczyńska & Kosiński 2014), and was further formally implemented for monitoring of this species (RDOŚ 2015b). The total forest area in sample plots in 2010 constituted 1,759.7 ha (92.6%), and the remaining area was made up by clear-cuts, agricultural areas or roads.

To estimate the number and distribution of territories of Middle Spotted Woodpeckers sample plots were surveyed from the second half of March until the end of April, before bud burst of most tree species, a period during which the territorial activity of the species is maximum (Pasinelli et al. 2001, Kosiński & Winiecki 2003). All counts were based on the call-playback method recommended for the censuses of the Middle Spotted Woodpecker (Kosiński & Winiecki 2003, Kosiński et al. 2004, Weggler et al. 2013, Kosiński 2015). Mostly one or two complete censuses were performed each year. It has been found that a single census with audio stimulation coinciding with the peak of territorial activity allows an experienced observer to find almost all the territories during the pre-breeding period (Kosiński et al. 2004). The limitation in the number of surveys in some years (one census per study plot) was mainly due to unfavorable weather conditions in spring, i.e. strong wind and rain, and the inability to find suitable periods for censuses. Moreover, the distribution of territories and detectability of birds in subsequent censuses during the pre-breeding period are highly repeatable because home range centers show no significant shift during spring (Pasinelli et al. 2001, Z. Kosiński – unpubl. data). There was an interval of minimum 6 (exceptionally 4) days between consecutive censuses. We played calls uttered during aggressive territorial interactions (Call-2 according to Węgrzyn & Leniowski 2020) and advertising calls of males (Roché & Chevereau 1993) at selected points to elicit vocal responses from birds. To reduce the probability of some individuals being attracted away from their territories by the playback technique, a minimum distance of 150–200 m between points (corresponding to the mean distance between two neighboring nests of Middle Spotted Woodpeckers in KOF; Kosiński & Kempa 2007), a maximum time of 40 s for stimulation in one bout, and an interval of 1–2 min for listening were used. A second bout of playback was done rarely, mostly when wind gusts exceeded 4–5 m/s and at the end of April, which coincided with the end of territorial activity of Middle Spotted Woodpeckers in Western Poland. The playback was paused after the first woodpecker's response. The bird's initial position, behavior, type of call, direction of movements, and sex (if possible) were recorded and mapped. A special attention was paid to register simultaneously active birds to separate neighboring pairs/territories. The number of pairs was assessed based on at least one observation of pairs, displaying or calling birds in response to vocal stimulation, or registration of spontaneous territorial activity of individuals during the pre-breeding period. The vast majority of territories were identified based on registration of territorial pairs which were well separated in space. To locate the exact position of the birds, we walked mainly along the well-developed and regular network of division lines, stand boundaries, and forest roads. The observations were conducted from morning to late afternoon because the detection of Middle Spotted Woodpeckers during the pre-breeding period is not influenced by the time of day (Z. Kosiński – unpubl. data). Single censuses do not allow for the detection of non-breeding floater birds in estimated populations (Pasinelli et al. 2001, Robles & Ciudad 2012); however, our observations suggested that unpaired males may make up a few percent of the studied population (Kosiński & Kempa 2007; A. Tomczak, Z. Kosiński – unpubl. data). It has been assumed that this count method is acceptable for monitoring purposes (Kosiński 2015, Kosiński & Walczak 2020). All surveys were performed in good weather conditions, when there was no rainfall or strong wind (<5 m/s), but some were conducted when there were tree felling activities inside and outside the boundaries of the study plots. Territories split by the plot boundary were rounded to the nearest half territories and were added to each other, i.e. two fractional territories were treated as one territory; however, each unpaired half territory was rounded up and treated as a whole territory (Pannekoek & van Strien 2005).

Environmental variables

The habitat data were extracted from the official inventory data for Krotoszyn Forest District and Taczanów Forest District consisting of stand-level forest numeric map and attribute tables describing structure and composition of stands in 2007–2009, and data from Forest Data Bank (2020). Private and communal forests (276 ha) were excluded because of lack of the actual data describing age of forest stands; moreover, these forests primarily consisted of coniferous stands (86%), unsuitable for Middle Spotted Woodpeckers.

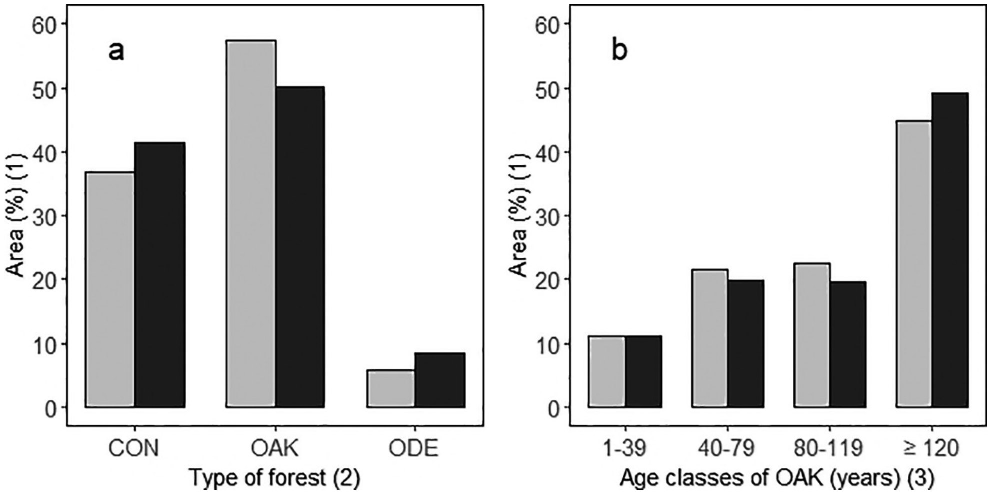


Fig. 2. Proportion of different forest types (a) and age of oak-dominated stands (b) in sample plots (gray bars) and in the whole area of Special Protection Area Krotoszyn Oak Forest (black bars) in 2010. COF – coniferous forest, OAK – oak-dominated forest, ODE – other deciduous forest.
Rys. 2. *Udział typów lasu (a) i klas wieku drzewostanów dębowych (b) na powierzchniach próbnych (szare słupki) i na powierzchni Obszaru Specjalnej Ochrony Dąbrowy Krotoszyńskie (czarne słupki) w roku 2010. COF – lasy iglaste, OAK – lasy dębowe, ODE – inne lasy liściaste. (1) – powierzchnia (%), (2) – typ lasu, (3) – klasy wieku drzewostanów dębowych*

In models describing the abundance of Middle Spotted Woodpecker, several ecologically relevant environmental predictors were used (Kosiński & Winiecki 2005, Kosiński 2006, Kosiński & Hybsz 2006, Stachura-Skierczyńska & Kosiński 2014). For each plot, the area of coniferous stands (CON), oak-dominated stands (OAK), and other deciduous stands (ODE) were estimated. The area of oak-dominated stands was divided into four age classes: early and early-mid successional (1–39 years), mid successional (40–79 years), mid-late successional (80–119 years), and late successional (≥120 years). The other deciduous stands, such as those dominated by beech *Fagus sylvatica*, hornbeam *Carpinus betulus*, alder *Alnus glutinosa*, and birch *Betula* sp., covered only a small area in the study plots (Me = 4.1 ha, interquartile range 2.2–10.2 ha; maximum 21.7 ha) and were therefore combined irrespective of their age (Fig. 2). For each year of the study, the age of forest stands and their area

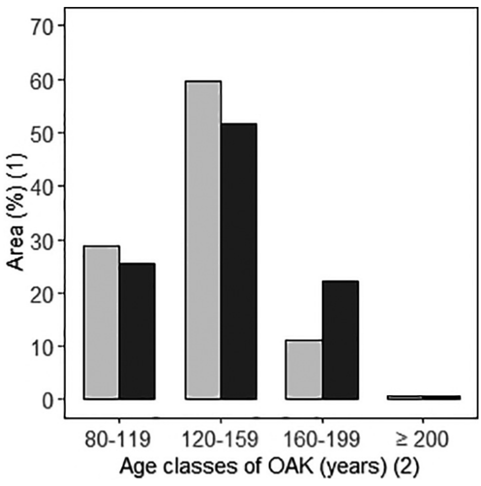


Fig. 3. Proportion of forest age classes of oak-dominated stands ≥80 years in Special Protection Area Krotoszyn Oak Forest in 2010 (gray bars) and 2020 (black bars)
Rys. 3. *Udział klas wieku drzewostanów dębowych ≥80 lat w Obszarze Specjalnej Ochrony Dąbrowy Krotoszyńskie w latach 2010 (szare słupki) i 2020 (czarne słupki). (1) – powierzchnia (%), (2) – klasy wieku*

on sample plots was corrected in relation to values recorded in the previous year (*t*-1). The same predictors were extracted for the total SPA to compare forest structure within the study plots and in KOF. Furthermore, we assessed the proportion of oak stands in KOF in four age classes (80–119, 120–159, 160–199, and ≥200 years) in 2010 and 2020 (Fig. 3).

Statistical analysis

All statistical analyses were carried out using R software version 3.6.3 (R Development Core Team 2020).

An equi-tailed two-sided ordinary nonparametric bootstrap was used to derive unbiased estimates of densities and their 95% confidence intervals (CIs) for the consecutive years based on 1000 resamples in the 'boot' package (Efron & Tibshirani 1993, Canty & Ripley 2020). These values were multiplied by the area of forest stands to determine the total number of pairs of Middle Spotted Woodpecker in KOF. For this purpose, data from the Forest Data Bank on the area of forest stands in 2020 (14,481 ha in size, including 134 ha of clear-cuts) were used (Forest Data Bank 2020).

The temporal trend of Middle Spotted Woodpeckers in KOF was estimated using TRends & Indices for Monitoring data (TRIM) models in the 'rtrim' package (Bogaart et al. 2018). The TRIM analyzes the time series of counts using Poisson regression and produces the estimates of yearly indices and trends (Pannekoek & van Strien 2005). The abundance index reflects changes in abundance in relation to the base year (2010 in our case). In the first step, a model with time effects (model 3 hereafter) which makes no assumptions on how population changes over time, and time effects are strictly independent of each other, was used. In the second step, a linear switching trend model (model 2 hereafter) was applied with a linear (on the log-scale) effect of time (Pannekoek & van Strien 2005). This model implies periodically constant increase in the log expected counts, making it possible to summarize similar, adjacent growth rate estimates into a single coefficient, where model 3 requires coefficients for each pair of adjacent years. This allows to reduce the number of parameters and obtain a more parsimonious model (Bogaart et al. 2018). In model 2, a stepwise procedure of selection of changepoints is used; at changepoints trend becomes sufficiently different from the preceding estimate that a new parameter is introduced. Models 2 and 3 were run with serial correlation and considered overdispersion. However, since serial correlation was very low (rho=0.053) and overdispersion was <1, both parameters were disabled, as suggested by Pannekoek & van Strien (2005). A goodness-of-fit test (likelihood ratio test, LR) was used to assess whether the data fit a model. Site G3 was excluded from the analysis as there was no observation of the studied species. Ultimately, data from 18 sites collected over 11 years (2010–2020) were used. Out of the 198 site-by-year combinations, 189 were positive (with recorded Middle Spotted Woodpecker), 8 were zero (no Middle Spotted Woodpecker recorded), and 1 was missing count (site B1 in 2011); however, the missing count was replaced by an imputed value in the TRIM analyses.

The non-linear relationship of the abundance index with time was fitted using local regression with 'loess' function. To assess whether double sampling can be useful for the calibration of temporal fluctuations of Middle Spotted Woodpeckers, the patterns of abundance index fitted by 'loess' function were visually compared between KOF and the Łówkowiec Forest (LF) located in the central part of the SPA (Fig. 1), which was treated as the reference area (Kosiński & Walczak 2020). Since two plots (J5 and J6) were nested in

LF, the pattern of abundance index in KOF was also assessed excluding both mentioned plots, and compared such calculated index with the pattern in LF.

The effects of habitat variables on the abundance of Middle Spotted Woodpecker were modelled with different types and age of forest stand as fixed factors, and site and year as random factors using the generalized linear mixed effects model (GLMM) with Poisson distribution in the 'lme4' package (Bates et al. 2014). A set of six candidate models were constructed. These included an intercept-only model (model 1), and five models with combinations of variables describing the age of oak-dominated (OAK) stands and the area of other deciduous stands (ODE). Subsequent models were constructed by including the variables with a predicted decreasing role in influencing the abundance of Middle Spotted Woodpecker. The area of coniferous stands (CON) was excluded from the analysis because it highly negatively correlated with all age categories of oak-dominated stands. Values of variation inflation factor (VIF < 1.26 in all cases) indicated lack of severe multicollinearity between other predictor variables in GLMMs. Inspection of residual plots in each model revealed no clear deviations from normality and homoscedasticity. The significance of random factors was tested using the likelihood ratio of the full model with both random effects against the models with one random effect, i.e. year or site. P-values were calculated by likelihood ratio tests using the function anova. In total, we analyzed 208 data points.

The relative support for each model was determined using Akaike's information criterion for a small sample size (AICc). A subset of models with high support (ΔAICc ≤ 2 compared to the best model) was selected, and their parameter estimates and standard errors (SEs) were averaged (Burnham & Anderson 2002) using 'MuMIn' package (Bartoń 2015). Akaike weights were calculated for all models, in order to obtain a quantitative measure of relative support for each competing model, with higher weights indicating better explanatory power. The magnitude of the effect was assessed using 95% CI. To visualise relationship between Middle Spotted Woodpecker abundance and habitat predictors we used results of the best ranked mixed-effect model; prediction and plotting were performed using the 'ggeffects' package (Lüdecke 2018).

Results

The total number of the Middle Spotted Woodpecker territories (hereafter pairs) identified in study plots in consecutive years varied between 77 in 2010 and 108 in 2015 and 2019. The density estimates varied from 4.05 pair/km^2 in 2010 (95% CI: 2.74–5.47) to 5.68 pair/km^2 in 2015 (95% CI: 4.00–7.21) and 2019 (95% CI: 4.10–6.95). The estimated population size in KOF varied between 587 in 2010 and 823 in 2015 and 2019 (Table 1).

In 2010, the contribution of forest types and the age structure of oak-dominated stands (OAK) in the sample plots were similar to that of the whole KOF area (Fig. 2). The maximum difference in the share of forest types in sample plots and in the total area of KOF was found for oak stands (OAK); the share of OAK in study plots was 7% higher than in the entire KOF. The maximum difference in the age classes of OAK stands between sample plots and the total area was 4% (Fig. 2). From 2010 to 2020, the area of oak-dominated stands that were ≥80 years old did not change markedly (5,062 ha in 2010 and 5,156 ha in 2020); however, there were significant differences between the four age classes of forest stands, mainly caused by twofold increase in the area of the oldest stands (≥160 years old), from 589 ha in 2010 to 1,175 ha in 2020 (Fig. 3).

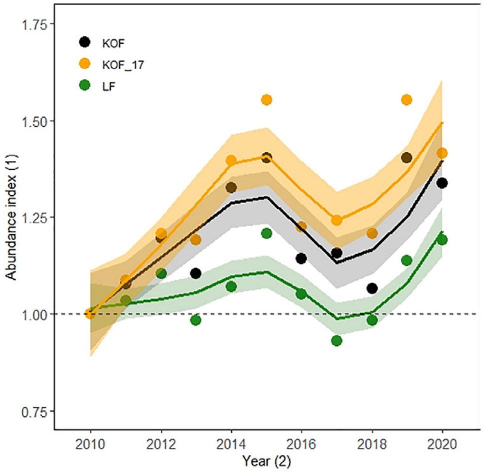
Table 1. Number of pairs, densities and estimated population size, with their 95% confidence intervals, of the Middle Spotted Woodpecker in Special Protection Area Krotoszyn Oak Forest in 2010–2020. Number of pairs and densities based on data from 19 study plots (1 × 1 km)
Tabela 1. *Liczba par, zagęszczenie i szacowana wielkość populacji dzięcioła średniego, wraz z ich 95% przedziałami ufności, w Obszarze Specjalnej Ochrony Ptaków Dąbrowy Krotoszyńskie w latach 2010–2020. Oszacowania na podstawie danych z 19 powierzchni próbnych 1 × 1 km. (1) – rok, (2) – łączna liczba par na powierzchniach próbnych, (3) – zagęszczenie/1 km^2, (4) – średnia, (5) – 95% przedział ufności, (6) – szacowana liczebność, (7) – liczba par, * – wartość skorygowana, ** – w oparciu o dane z 18 powierzchni próbnych*

Year (1)	Total number of pairs on sample plots (2)	Density/1 km^2 (3)		Abundance estimation (6)	
		Mean (4)	95% CI (5)	Number of pairs (7)	95% CI (5)
2010	77*	4.05	2.75–5.42	587	398–785
2011	81**	4.50	3.11–5.51	652	451–797
2012	92	4.84	3.21–6.69	701	465–969
2013	85	4.47	3.25–5.79	648	471–838
2014	102	5.37	3.68–6.74	777	533–976
2015	108	5.68	3.76–7.10	823	545–1029
2016	88	4.63	3.16–6.10	671	457–884
2017	89	4.68	3.21–6.10	678	465–884
2018	82	4.32	3.05–5.73	625	442–830
2019	108	5.68	4.05–7.05	823	587–1021
2020	103	5.42	3.77–7.16	785	546–1037

* Corrected; previous estimation was 75 pairs (Gawroński et al. 2010)
** Based on data from 18 study plots

The TRIM model with site and time effects (model 3) did not differ significantly from a linear trend model (model 2) (Wald test=9.29; df=9; P=0.411). Moreover, models 2 and 3 had similar goodness-of-fit statistic (LR=69.63; df=175; P=1.0 and LR=67.78; df=169; P=1.0, respectively), and fitted well to the data. Model 2 identified so-called changepoints. The test for the significance of changes in slopes in model 2 revealed that slope between 2010 and 2015 was different from zero (Wald test=5.87; df=1; P=0.015), slope between 2015 and 2018 was different from the slope between 2010 and 2015 (Wald test=6.14; df=1; P=0.013), and slope between 2018 and 2019 was different from the slope between 2015 and 2018 (Wald test=5.69; df=1; P=0.017) (Fig. 4). The multiplicative slope coefficient of the linear model across all changepoints suggested that the population of Middle Spotted Woodpeckers was stable in KOF during 2010–2020 (slope ± SE: 1.019 ± 0.010; P=0.091; 95% CI of the slope: 0.999–1.039). The rate of population growth between 2010 and 2020 was 1.338 (95% CI: 0.924–1.714), and the mean annual growth rate (λ) was 1.030 (95% CI: 0.992–1.055) (Fig. 4). The annual growth rate in Łówkowiec Forest for the same period was 1.018. The patterns of abundance index of the Middle Spotted Woodpecker populations in KOF and Łówkowiec Forest were similar, except for the beginning of the study period (Fig. 4). The growth rate in LF in 2010–2011 was smaller than in sample plots both outside this area and in all plots in KOF.

The number of pairs of Middle Spotted Woodpecker varied across sample plots from none in plot G3 throughout the study period to the highest abundance in plot B3 (Fig.



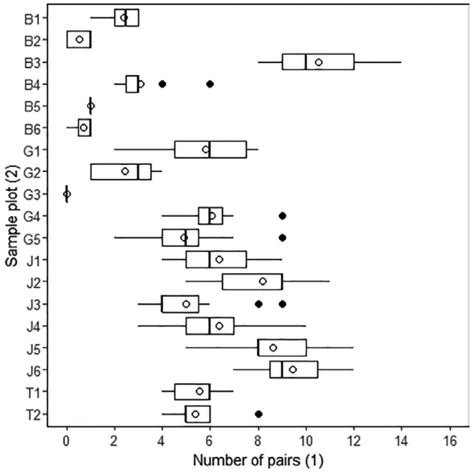


Fig. 4. Abundance index of the Middle Spotted Woodpecker in Special Protection Area Krotoszyn Oak Forest (KOF) and Łówkowiec Forest (LF) in 2010–2020. Trends (black, orange and green solid lines) and standard errors (orange, gray and green areas) were predicted using local regression (loess). KOF_17 – abundance index assessed without sample plots placed in LF

Rys. 4. *Wskaźnik liczebności dzięcioła średniego (1) w Obszarze Specjalnej Ochrony Dąbrowy Krotoszyńskie (KOF) i w uroczysku Łówkowiec (LF) w latach 2010–2020 (2). Trendy (czarna, pomarańczowa i zielona linia) i ich błędy standardowe (pomarańczowy, szary i zielony obszar) określono wykorzystując lokalną regresję wielomianową (loess). KOF_17 – wskaźnik liczebności wyliczony z pominięciem powierzchni położonych w LF*

Fig. 5. Number of pairs of the Middle Spotted Woodpecker in 19 sample plots in Special Protection Area Krotoszyn Oak Forest in 2010–2020. Median (*bolded line*), mean (*circle*), interquartile range (IQR) (*box*), range (maximum, Q_3 + 1.5*IQR) (*whiskers*), and outliers (*dots*) are shown

Rys. 5. *Liczba par dzięcioła średniego na 19 powierzchniach próbnych w Obszarze Specjalnej Ochrony Dąbrowy Krotoszyńskie w latach 2010–2020. Podano medianę (pogrubiona linia), średnią (koło), rozstęp międzykwartylowy Q_1-Q_3 (pudełko), zakres (maksimum, Q_3 + 1,5× rozstęp kwartylowy) (wąsy), wartości odstające (kropki). (1) – liczba par, (2) – powierzchnia próbna*

5). Out of the six models examining the effect of the area of different forest stands in sample plots on the abundance of Middle Spotted Woodpecker, two (models 6 and 5) were well supported by the data, as indicated by the ΔAICc values (Table 2). These two models included all variables considered for the analysis. The parameters based on model-averaging indicated that the abundance of Middle Spotted Woodpecker was positively influenced, with decreasing importance, by the area of late successional (≥120 years), mid-late successional (80–119 years), and mid successional (40–79 years) oak stands (OAK), as well as by the area of other deciduous stands (ODE), due to the fact that these variables had effect sizes larger than their SEs, and the 95% CIs did not include zero; however, the effect of ODE appeared to be very weak as CI was wide and its lower limit was close to zero (Table 3; Fig. 6). The full model (model 6) with random effects of site and year had the highest power in explaining the abundance of Middle Spotted Woodpecker compared to the model without the year effect (LR test; P < 0.0001) or the one without the site effect (LR test; P=0.003).

Table 2. Generalized linear mixed-effects models describing the relationship between abundance of the Middle Spotted Woodpecker in 19 sample plots 1 × 1 km and area of different forest stands in Special Protection Area Krotoszyn Oak Forest in 2010–2020. Four age classes of oak stands (OAK) were used in the analysis; ODE – other deciduous stands. The best models (separated by ΔAICc ≤ 2) are highlighted in bold

Tabela 2. *Uogólnione liniowe modele mieszane opisujące zależność między liczebnością dzięcioła średniego na 19 powierzchniach próbnych 1 × 1 km a powierzchnią różnych drzewostanów w Obszarze Specjalne Ochrony Dąbrowy Krotoszyńskie w latach 2010–2020. W analizie uwzględniono cztery kategorie wieku drzewostanów dębowych (OAK) oraz powierzchnię innych drzewostanów liściastych (ODE). (1) – numer modelu, (2) – struktura modelu, (3) – liczba stopni swobody (df), (4) – wartość kryterium informacyjnego Akaike (AICc), (5) – różnica między modelem o najwyższym poparciu (ΔAICc) a danym modelem, (6) – waga modelu (ω AIC), (7) – model bez predyktorów. Modele uszeregowano według malejącego poparcia (ω AICc); pogrubieniem wyróżniono najlepsze modele (ΔAICc ≤ 2)*

Model (1)	Model function (2)	df (3)	AICc (4)	ΔAICc (5)	ω AICc (6)
6	**OAK ≥120 + OAK 80–119 + OAK 40–79 + OAK 1–39 + ODE**	8	781.4	0.00	0.513
5	**OAK ≥120 + OAK 80–119 + OAK 40–79 + ODE**	7	782.6	1.18	0.285
4	OAK ≥120 + OAK 80–119 + OAK 40–79	6	783.6	2.18	0.172
3	OAK ≥120 + OAK 80–119	5	787.1	5.69	0.030
2	OAK ≥120	4	796.8	15.38	0.000
1	Intercept-only model (7)	3	812.5	31.14	0.000

Df – Degrees of freedom.
AICc – Akaike's information criterion.
ΔAICc – Difference in AICc relative to the model with the lowest AICc.
ω AICc – Models are ranked according to their Akaike weight; higher weights indicate more parsimonious models.

Table 3. Model-averaged coefficients of the variables included in the top-ranked generalized linear mixed-effects models explaining the effects of the area of different types of forest stands on the abundance of Middle Spotted Woodpeckers in Special Protection Area Krotoszyn Oak Forest in 2010–2020. See Table 2 for the full list of models fitted to data

Tabela 3. Uśrednione współczynniki zmiennych z najlepszych *uogólnionych liniowych modeli mieszanych wyjaśniających wpływ powierzchni różnych drzewostanów na liczebność dzięcioła średniego w Obszarze Specjalnej Ochrony Dąbrowy Krotoszyńskie w latach 2010–2020.. (1) – zmienna, (2) – oszacowanie, (3) – błąd standardowy oszacowania (SE), (4) – dolna granica przedziału ufności, (5) – górna granica przedziału ufności. Wykaz modeli zawiera tabela 2*

Variable (1)	Estimate (2)	SE (3)	2.5% CL (4)	97.5% CL (5)
Intercept	−0.342	0.261	−0.856	0.172
OAK ≥120 ≥	0.036	0.004	0.028	0.044
OAK 80–119	0.024	0.004	0.015	0.033
OAK 40–79	0.018	0.005	0.007	0.028
ODE	0.027	0.014	<0.001	0.054
OAK 1–39	0.025	0.013	−0.002	0.051

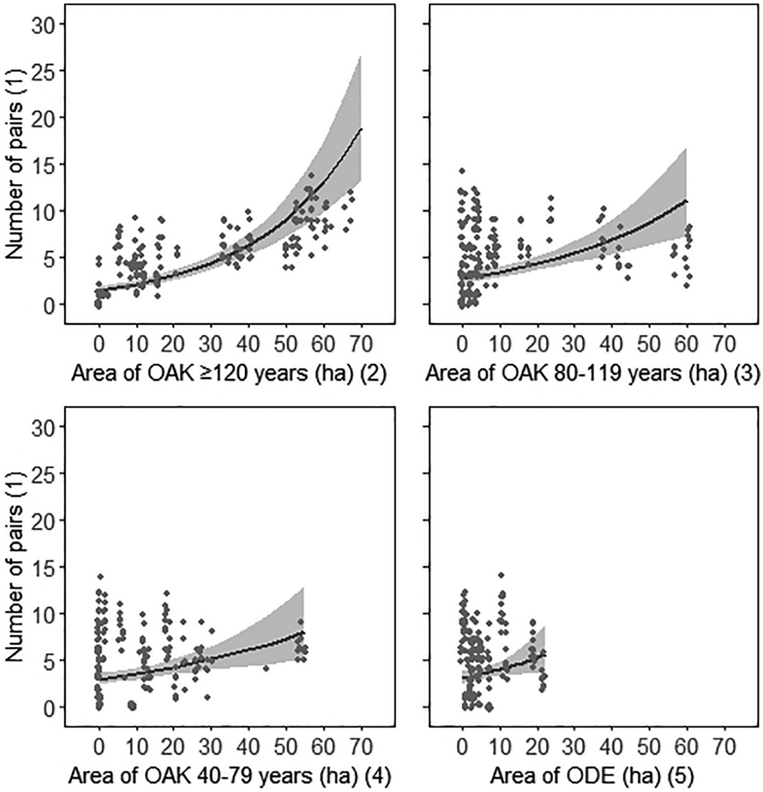


Fig. 6. Relationships between the number of pairs of the Middle Spotted Woodpecker in 1 × 1 km sample plots and area of three age classes of oak-dominated stands (OAK) and other deciduous forest (ODE) in Special Protection Area Krotoszyn Oak Forest in 2010–2020. The curves visualise the relationships predicted from the top-ranked Poisson generalized linear mixed model (see Table 2). Grey area indicates 95% confidence interval for each curve. Each point represents site-by-year combination (N=207). Points were slightly shifted from their original positions to avoid overlap

Rys. 6. *Zależności pomiędzy liczbą par dzięcioła średniego (1) na powierzchniach próbnych 1 × 1 km a powierzchnią drzewostanów dębowych (OAK) w wieku ≥120 lat (2), 80–119 lat (3), 40–79 lat (4) i powierzchnią innych lasów liściastych (ODE) (5) w Obszarze Specjalne Ochrony Dąbrowy Krotoszyńskie w latach 2010–2020. Krzywe wizualizują zależności z uogólnionego modelu mieszanego Poissona o najwyższym poparciu (patrz tabela 2). Szary pas wokół krzywej obrazuje 95% przedział ufności. Każdy punkt reprezentuje kombinację wartości z powierzchni próbnej i roku (N=207). Punkty nieznacznie przesunięto względem oryginalnych pozycji by uniknąć ich nakładania się*

Discussion

The population size of Middle Spotted Woodpecker in SPA KOF varied considerably in 2010–2020, and was estimated on 590–820 pairs in different years. The population size accounted for 2.2–3.0% of the national population (54,000 inds; Wilk et al. 2020). The low precision of the estimates of the Middle Spotted Woodpecker abundance in the consecutive years, as shown by the width of CIs, is most likely due to the sample size and variability in outcome measurements (Fig. 5). The small overrepresentation of oak stands in sample plots as compared to the total forest area could lead to an overestimation of the abundance of Middle Spotted Woodpecker in KOF; however, this effect could be reduced by the smaller area of ≥120-year-old oak stands in sample plots, which are the most important predictors of woodpecker abundance in the study area. Moreover, changes in share of forest types and age structure of oak-dominated stands (OAK) in sample plots in 2010–2020 differed slightly from the structure of forest stands in KOF. This suggests that the abundance of Middle Spotted Woodpecker in KOF estimated for different years was most likely close to the actual population size.

The population abundance estimated for 2010–2020 was higher compared to the value reported for the first decade of the 21st century (480 pairs; Wilk et al. 2010), which was a sum of values from the direct counts obtained on large plots in different parts of KOF (Kosiński & Winiecki 2005, Kosiński & Kempa 2007, Żurawlew et al. 2009), direct counts from sample plots and extrapolation on a larger area (Kosiński & Hybsz 2006), and estimation in an unexplored area (Gliśnica Precinct) based on the state-of-the-art knowledge. The higher estimate for 2010–2020 can be attributed to the better recognition of population as a result of larger spatial sampling, as well as to the limitation of estimates by data from the specific years. For example, the population size in the Gliśnica Precinct estimated by multiplying the mean density of Middle Spotted Woodpecker in the whole KOF in the first decade of the 21st century (0.95 pair/ha) per area of >80-year-old oak stands was ca 90 pairs (Kosiński 2016); however, a complete census performed in 2015 revealed that the population included 138 pairs and 6 unpaired males (A. Tomczak, Z. Kosiński – unpubl. data). The population size in KOF estimated based on the area of habitat predicted by the habitat suitability model for the data from 2010 was 476 territories (Stachura-Skierczyńska & Kosiński 2011). This value was most likely underestimated owing to limited set of habitat variables and number of territories used in the analyses. Although the habitat suitability model has been proven useful for assessing the amount and distribution of appropriate habitats for Middle Spotted Woodpeckers in KOF (Stachura-Skierczyńska & Kosiński 2014), its use for direct assessment of population size is difficult due to lack of possibility to convert different probabilities of species occurrence to variation in density across the study area.

Although the population size of Middle Spotted Woodpeckers varied considerably during study period, the non-significant trend across time suggests stable population. Long-term monitoring data from the Łówkowiec Forest, located in SPA KOF, revealed that the temporal trend in species abundance in 2001–2019 increased over time but the change was also statistically insignificant (Kosiński & Walczak 2020). These results are contradictory to the documented moderate increase in population size of Middle Spotted Woodpecker in Poland in 2001–2020, especially in the western part of the country; however, the pattern of population change in KOF in 2010–2020 was similar to that observed in Poland, with a maximum value in 2015, and a decline in subsequent 3 years (Chylarecki et al. 2018, Wardecki et al. 2021).

The population increase of Middle Spotted Woodpecker in Europe is related to climate warming and the improvement of habitat quality, e.g. by maintaining old oaks, natural regeneration with multiple native tree species and increasing deadwood abundance (Pasinelli 2000, Lõhmus et al. 2016, Schuck et al. 2018). A long-term study conducted in the Łówkowiec Forest revealed that the Middle Spotted Woodpecker population was influenced by a density-dependent first-order feedback process and a density-independent mechanism, i.e. wind chill equivalent temperature in the previous winter (Kosiński & Walczak 2020). The negative impact of the density-dependent mechanism on Middle Spotted Woodpeckers in KOF can be attributed to the intraspecific competition of the birds for limited resources (Sæther et al. 2016), the most likely food or nest sites, which results in a moderate density of breeding pairs, ca. 1 pair/10 ha in >80-year-old oak stands (Pasinelli 2003, Kosiński & Hybsz 2006, Kosiński & Kempa 2007), compared to more diverse forests (Kosiński & Winiecki 2005, Kosiński & Walczak 2020). On the other hand, this woodpecker species can benefit from warm temperatures due to global climate change by increasing winter survival probability, e.g. as a result of increased accessibility of insects and other arthropods (Pureswaran 2018, Jactel et al. 2019) or decreased heat loss to the surrounding environment as was suggested in some woodpecker species (Saari & Mikusiński 1996, Selås et al. 2008, Kosiński & Walczak 2020), thus mitigating the negative impact of simplified habitat.

We found that the pattern of temporal changes in the population size of Middle Spotted Woodpeckers in the Łówkowiec Forest was similar to that observed in KOF, except for the beginning of the study period; however, the cause of observed discrepancy in this period is unknown. It is reasonable to suspect that abundance of Middle Spotted Woodpeckers in KOF in 2010 and 2011 was slightly underestimated, since in both years most censuses were performed by observers unfamiliar with the study plots, while censuses in the Łówkowiec Forest were done by the same observer since 2001 (Eglington et al. 2010, Kosiński & Walczak 2000). Nevertheless, the observed pattern suggests that the data from the Łówkowiec Forest, as a reference area, can be useful for calibrating and improving interpretation of data from periodic censuses in KOF, which are scheduled every 5 years (RDOŚ 2015b). Moreover, such method may also reduce time needed for monitoring of birds using a large-scale sampling. Because oak stands in the Łówkowiec Forest are predominantly old, they are strongly influenced by forest management practices (Kosiński & Walczak 2020), and can accurately reflect large-scale changes.

Our data confirm the importance of the area of old, oak-dominated forest stands for the abundance of Middle Spotted Woodpecker in KOF. Earlier studies performed in KOF showed that the number of territories positively correlated with the area of broadleaved stands and oak stands >80 years old (Kosiński & Hybsz 2006) or uneven-aged stands, i.e. those at least 80 years old with at least 30-year age difference between trees (Stachura-Skierczyńska & Kosiński 2016). The data of our study also highlight the importance of late successional oak stands (≥120 years old), which have the largest effect size compared to SE across all predictors, as well as mid successional oak stands (40–79 years old), and other deciduous stands on the abundance of Middle Spotted Woodpecker. However, it should be pointed out that models including only late successional and mid-late successional oak stands (GLMMs 1 and 2), were least supported by the data compared with the remaining models, as revealed by Akaike weights. The strong relationship of this woodpecker species with late successional oak stands has also been observed in other SPAs in Poland, i.e. in SPA Borecka Forest (Sikora et al. 2016). Moreover, other studies found the highest breeding density of Middle Spotted Woodpecker in old forests (>140 years), in contrast to young ones (<40 years) without any breeding pairs (Lovaty 1980, Kosiński 2006). Mid successional oak stands or other deciduous stands are used usually by the species if they are adjacent to older oak forest tracts (Walczak & Kosiński 2013, Z. Kosiński – unpubl. data). During the study, we regularly found territorial individuals or pairs in isolated forest patches of >80-year-old oak stands, with an area as small as 1.9–2.4 ha (e.g. plots B2, B5, B6), adjacent to the patches of younger oak stands or other broadleaved stands; the total area of such isolated broadleaved forest patches did not exceed 5 ha. These isolated oak stands were distinctly smaller than the average home range size in oak forests observed in winter, early spring, and even late spring (Pasinelli et al. 2001, Pasinelli 2003). This suggests that Middle Spotted Woodpeckers can inhabit even small isolated forest patches for years despite some negative effects on pairing success and patch-occupancy dynamics (Robles et al. 2008, Robles & Ciudad 2012).

The area of oak-dominated ≥80 years old stands did not change significantly from 2010 to 2020; however, a twofold increase was observed in the area of the oldest stands (≥160 years old). These data suggest that the area of habitats suitable for Middle Spotted Woodpeckers remained stable, and their quality probably improved as forest age increased. Simulations based on forest inventory data, including an increase in forest age, predicted clear-cuts, and thinning treatments between 2008 and 2017, revealed that the total area of optimal and suboptimal habitats of Middle Spotted Woodpeckers in KOF should have increased slightly (ca 4%) during this time; however, these habitats were mostly characterized by a lower probability of species occurrence (Stachura-Skierczyńska 2013). This indicates that planned level of clear-cuts and thinning treatments might deteriorate the habitats of Middle Spotted Woodpeckers even in a short period of time, e.g. by causing an increase in the fragmentation of suitable habitats and a decrease in their quality (Bühlmann & Pasinelli 1996, Müller et al. 2009). However, the predicted detrimental effect of forest management in KOF on the probability of species occurrence was not reflected in the changes in the abundance of Middle Spotted Woodpecker. This could be due to either a smaller area being subject to forestry practices in 2008–2017 (e.g. smaller area of clear-cuts) than planned earlier, as found in the Łówkowiec Forest (Z. Kosiński – unpubl. data), or favorable weather conditions that increased winter survival or improved the amount of food available to Middle Spotted Woodpeckers (Kosiński & Walczak 2020). Moreover, data collected from the Łówkowiec Forest in 2004–2019 did not confirm the hypothesis that the rate of population change of Middle Spotted Woodpecker was negatively affected by the volume of deadwood removed in the previous year (Kosiński & Walczak 2000). Data from 2021 showed a strong decrease (29%) in the abundance of this species (from 69 pairs in 2020 to 49 in 2021) after 2 consecutive years of intensive sanitary felling and salvage logging almost throughout the entire study area; however, the abundance of Middle Spotted Woodpeckers increased again to 68 pairs in 2022 (Z. Kosiński – unpubl. data).

Historical forest inventory data suggest that the current population of Middle Spotted Woodpeckers in KOF is probably the highest, at least since the beginning of the 20th century. According to the data characterizing the age of oak-dominated stands in Gliśnica and Jasne Pole precincts in the 1930s (Fig. 7), the area of stands suitable for Middle Spotted Woodpeckers (oak-dominated stands ≥80 years old) in this period was approximately twofold smaller than the same area in 2020 (1,998 ha vs 4,306 ha of forest stands, respectively); moreover, the area of late successional oak stands (≥120 years old) in 1930s was up to five times smaller than nowadays (615 ha vs 3,166 ha, respectively) (Krahl-Urban 1941, Forest Data Bank 2020). The population abundance in recent decades is most likely linked to the increasing length of forest rotation in the 20th century. The cutting age of oaks in the area managed by the Krotoszyn Forest District was specified to be 140 years between 1928 and 1930, 120 years between 1931 and 1935, 160 years between 1936 and 1978 (and even 200 years between 1973 and 1978 in some oak stands), and 180 years since 1979 (Kaźmierczak 2016, S. Zaradny – pers. inf.). The main reason for increasing cutting age was to maximize the economic value of oak wood (https://www.poznan.lasy.gov.pl/aukcja-cennego-drewna-debowego1, S. Zaradny – pers. inf.).

The strong relationship between the abundance of Middle Spotted Woodpeckers and the area of old oak-dominated forest stands clearly indicates that for the conservation of this species in KOF it is necessary to maintain sufficient area of old forest stands (Pasinelli

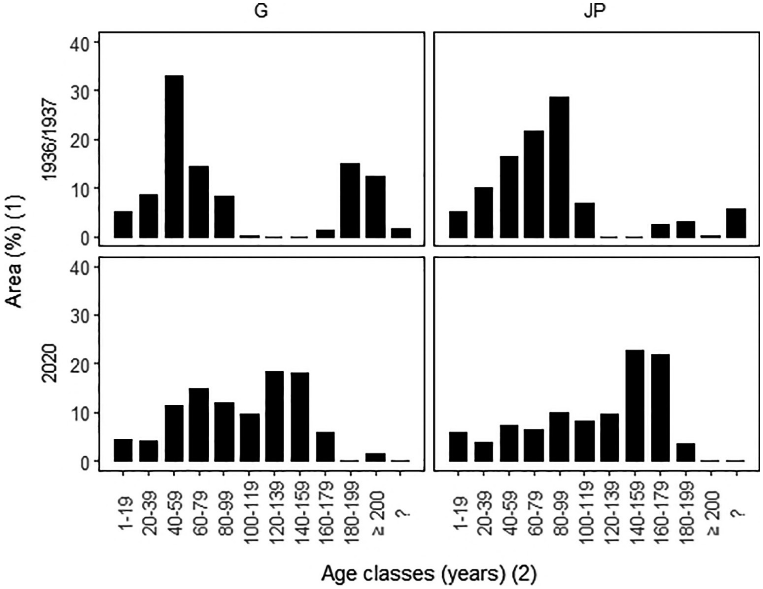


Fig. 7. Age distribution of oak forest stands in the Gliśnica Precinct (G) in 1936 and Jasne Pole Precinct (JP) in 1937 and 2020. Based on data from Krahl-Urban (1941) and Forest Data Bank (2020)
Rys. 7. *Rozkład wieku drzewostanów dębowych w obrębie Gliśnica (G) i Jasne Pole (JP) w latach 1930. (Krahl-Urban 1941) oraz w roku 2020 (Bank Danych o Lasach 2020). (1) – powierzchnia (%), (2) – klasy wieku w latach*

2003, Kosiński & Hybsz 2006, Müller et al. 2009). In the long run, the population of Middle Spotted Woodpeckers could be affected by uneven tree age distribution, with a predominance of old oak-dominated forest stands (Pasinelli 2000), especially in the Jasne Pole Precinct (Fig. 7), fragmentation of old stands (Stachura-Skierczyńska 2013), and oak dieback process (Danielewicz ed. 2016). Of 7,403 ha of oak-dominated stands in KOF, almost 37% is ≥140 years old (Forest Data Bank 2020, Z. Kosiński – unpubl. data), and will likely be cut down in the next decades due to the rotation age of oaks. Because the current silvicultural system in oak stands in KOF is based mainly on complete removal of trees and artificial regeneration, the continuity of key forest habitats for Middle Spotted Woodpeckers will likely be jeopardized over time; however, this process will be probably slow due to the use of small clear-cuttings (up to ca. 3 ha) and 5–7 (minimum 4) years cutting-interval period (Stachura-Skierczyńska 2013, Kaźmierczak 2016). For example, the cumulative area of forest harvested (habitat loss) in the Łówkowiec Forest in 2001–2019 accounted for ca. 10% of the total forest area (65 of 631 ha), and this loss did not affect the abundance of Middle Spotted Woodpeckers (Kosiński & Walczak 2020). The application of other forest management systems, e.g. shelterwood cutting, for creating a new generation of trees is impossible due to ineffective natural regeneration of pedunculate oak in KOF (Kasprowicz 2010, Danielewicz 2016).

Oak dieback, which is primarily caused by drought stress, is a common phenomenon in Europe in recent decades (Thomas et al. 2002, Sallé et al. 2014), and poses a threat to the durability of oak stands in KOF (Kaźmierczak 2016). Despite the fact that the extent and intensity of this process have significantly increased in KOF in recent years, resulting in a considerable increase in sanitary felling and salvage logging (Jabłoński et al. 2016, Kosiński & Walczak 2020, Z. Kosiński – unpubl. data), the breeding population of Middle Spotted Woodpeckers in 2019 and 2020 was among the highest during the study period.

According to the Habitats Directive, EU member states are required to manage natural habitats and species in Natura 2000 sites to reach or maintain their 'favorable conservation status' (CEC 1992). The Krotoszyn Oak Forest is protected both by Birds and Habitats Directives that guarantee the maintenance of the Middle Spotted Woodpecker's population and its habitats (e.g. old acidophilous oak woods; Annex 1 of the Habitat Directive) based on the management plans for Natura 2000 sites (RDOŚ 2015a, b). However, the evaluation of effectiveness of management plans is difficult due to short time passed from their implementation. Long-term data from LF did not show a positive impact of conservation measures on population of the Middle Spotted Woodpecker. A recent study suggests that the effective conservation management of forest birds may depend on the presence and quality of forests also outside of Natura 2000 sites, especially in the case of smaller sites (Orlikowska et al. 2020). Since KOF consists of forest patches surrounded by large, intensively cultivated agricultural areas, the presence, quality and connectivity of forests inside this area are of special importance for conservation of Middle Spotted Woodpeckers, and as such these should be carefully managed (Stachura-Skierczyńska & Kosiński 2014).

Because the condition of forests is expected to deteriorate gradually (Stachura-Skierczyńska 2013), it is unclear whether the high abundance of Middle Spotted Woodpecker will persist in the future, despite the likely positive impact of climate change. Long-term studies are needed to assess the effect of habitat disturbances associated with habitat loss, sanitary felling, and salvage logging of dead trees as well as climate change on the abundance of Middle Spotted Woodpecker (White 2019, Kosiński & Walczak 2020). Moreover, the effect of conservation measures on the population of Middle Spotted Woodpecker should be evaluated and tracked over time.

Conclusions

Population size of Middle Spotted Woodpeckers varied greatly in SPA KOF in 2010–2020, despite the fact that the trend suggests stable population; therefore, the estimation of population abundance assessed during periodic monitoring should be interpreted with caution in the decision-making process for species conservation management. We confirmed that SPA KOF is the second most important area for Middle Spotted Woodpeckers, after the Białowieża Forest, in Poland. We learned that mid successional (40–79 years) oak stands and other deciduous stands, apart from late successional (≥120 years) and mid-late successional oak stands (80–119 years), can play an important role in shaping abundance of Middle Spotted Woodpecker, especially if they are adjacent to older oak forest tracts. We found that the pattern of abundance index obtained on permanently monitored area can be useful for calibrating data from periodic censuses in the Krotoszyn Oak Forest. Although KOF is protected both by Birds and Habitats Directives, the evaluation of effectiveness of the management plans on the population of Middle Spotted Woodpecker is difficult due to the short period of time since its implementation.

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