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Use of coniferous plantations by bats in western Poland during summer months

GRZEGORZ APOZNAŃSKI [1]*, TOMASZ KOKUREWICZ [1], JUSTYNA BŁESZNOWSKA [1], EWA KWASIBORSKA [2], TOMASZ MARSZAŁEK [2] AND MONIKA GÓRSKA [3]

[1] *Wrocław University of Environmental and Life Sciences, Institute of Biology, Department of Vertebrate Ecology and Paleontology, Kożuchowska 5b, 51-631 Wrocław, Poland; e-mails: tomasz.kokurewicz@upwr.edu.pl; justyna.blesznowska@gmail.com*
[2] *ANSEE Consulting, Św. Antoniego Str. 2/4, 50-073 Wrocław, Poland; e-mail: t.marszalek@ansee.pl*
[3] *ZOO Wrocław, Wróblewskiego 1-5, 51-618 Wrocław, Poland*

* *Corresponding author: apoznanski.grzegorz@gmail.com*

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Abstract

Mixed commercial plantation forests often receive little or no attention in terms of conservation of protected habitats and species. This study was aimed at assessing the value of such habitats for bats. In July 2015 we used standardised mist netting in 11 locations within and near the Natura 2000 sites "Nietoperek" and "Buczyny Łagowsko-Sulęcińskie" in western Poland. Particular attention was paid to mixed plantation forest, usually dominated by Scots pine (*Pinus sylvestris*). Natural and protected habitats, i.e. riparian woodlands and beech forest were also investigated for comparison. In total 96 bats of 12 species were caught. The highest number of bats (15.0 individuals caught per night) and the highest biodiversity index (H′) was recorded in localities situated in mixed plantation forest. Contrary to common evaluation of this type of habitat, mixed plantation forest may serve important role for local bat populations by providing commuting corridors and possibly also foraging areas.

Keywords: *Barbastella barbastellus*, bat conservation, coniferous plantations, *Myotis myotis*

Introduction

Many bat populations suffer from the consequences of deforestation and fragmentation of habitats. In Europe, most species rely on forest habitat for some or all of their life cycle (Altringham et al. 1996). A prominent example is the western barbastelle *Barbastella barbastellus*, a woodland specialist, currently considered as one of the rarest bat species in Western Europe (Temple and Terry 2007). To prevent further loss of important forest habitats a sustainable source of wood for manufacturing industries is necessary (Carnus et al. 2003). This has resulted in huge areas of plantation forest, e.g. covering 54.3 million hectares within the temperate zone. Areas such as the Oceania, Europe, USA and Japan account for more than 50% of plantation areas and further development is predicted, as the increase in current timber requirements is unlikely to be reversed (Honnay 2004, FSC 2012). Województwo Lubuskie (western Poland), where this research took place, is not an exception from this trend. With over 49% of its land covered with forest it is the most forested province of Poland. However, 90% of its forest cover consists of conifer plantations under 60 years old (Jermaczek and Maciantowicz 2005).

In spite of ranging over a large area Central Europe, mixed beech *Fagus silvatica*, Scots pine *Pinus sylvestris,* ash *Fraxinus excelsior* or single species plantation forests, with Scots pine or Norway spruce *Picea abies* as dominant species, often receive little or no attention in terms of research and conservation. Due to low age and species diversity as well lack of undergrowth as a result of intensive management, such forests are often considered as "green deserts" (Bremer and Farley 2010, Gardner 2012) although there is also evidence that they may play an important role in harbouring biodiversity (Humphrey et al. 2003). There is an urgent need for closer investigation of the role of plantation forest in the maintenance of biodiversity, including its importance for bats.

Our study sites were located around the Central Sector of the Międzyrzecz Fortified Front in Lubuskie Province in Western Poland. The area is protected as the Natura 2000 site "Nietoperek", which is one of the most important hibernation sites for bats within the EU. More than 34,000 individuals from twelve species are regularly found hibernating in the underground tunnels during the winter months, including western barbastelle and greater mouse-eared bat *Myotis myotis* (Kokurewicz et al. 2019). These two species are forest-dependent in terms of roosting and foraging. Also barbastelle and several other species found in the tunnels are believed to be non-migratory (Hutterer et al. 2005), which implies that summer breeding colonies may possibly occur in the vicinity of the winter roosts, but there is no evidence so far that this is always the case.

Knowledge of about distribution and habitat selection of e.g. the barbastelle and greater mouse-eared bat within the sites mentioned above is important, because both species are listed in Annex II of EU Habitat Directive (92/43/EEC) and therefore are targets of protection of Natura 2000 sites all over the European Union. Previous studies have found that eleven species are present in the study area in summer, but the range and scope of the study was probably insufficient to document the entire species diversity (Łupicki and Cichocki 2008, Andrzejczak et al. 2009, Kiczyńska et al. 2010). As a result, the current forest management within and near the protected sites may be inadequate.

The aims of our study were the following:

(1) to reassess the use of mixed coniferous forest by bats, as it is often neglected in local conservation plans despite being the most common type of habitat in the area;

(2) to supplement the current state of knowledge regarding the species composition of bats in the Natura 2000 sites "Nietoperek" and "Buczyny Łagowsko-Sulęcińskie", which will be useful for future management plans.

Materials and methods

Study area

We focused on the above ground part of the Natura 2000 site "Nietoperek", large bat hibernation site located in the WWII fortification line known as the "Międzyrzecz Fortified Front" (Rogowska and Kokurewicz 2007, Kokurewicz et al. 2014, 2016, 2019, Cichocki et al. 2015, Pikula et al. 2017). The landscape above the tunnels mostly consists of young monocultures of pines mixed with isolated patches of riparian woodlands with ash and alder *Alnus* spp. remaining mostly in depressions and along shorelines of lakes and rivers areas with restricted access for heavy timber harvesting machinery.

The second study area, "Buczyny Łagowsko-Sulęcińskie", is located approx. 14 km north-west of Nietoperek. It is also protected as Natura 2000 site PLH080008 and represents a well preserved post-glacial hilly landscape with moraines, mesotrophic lakes and peat bogs in the depressions, with well-preserved beech forest.

Netting

Bats were trapped using mist nets for eight consecutive nights (1–8 July 2015) at 11 sites (Figures 1, 2) for one night at each site. Thanks to help from volunteers, between the 1st and 2nd of July we were able to cover two sites per night (sites 1–4, Figure 1, Table 1). At each site we used two 9 m nets and one 6 m monofilament net 2.5 m high (Ecotone, Poland) set across forest roads and in gaps within tree stands. We standardised the setting of the nets between the different sites as much as possible. They were placed either 2.5–5 m above the ground over open roads, or 1.5–2.5 m above the ground in cases where this was restricted by a tree canopy. The nets were set up 30 minutes before sunset and taken down 30 minutes before sunrise. Netting was carried out only in favourable weather conditions (T > 8°C, wind speed < 4 on the Beaufort scale, and no precipitation). The nets were checked every 15 minutes.

Each captured bat was identified to species, sexed and aged as adult or juveniles, based on ossification of the phalangeal epiphyses. Females were classified as lactating

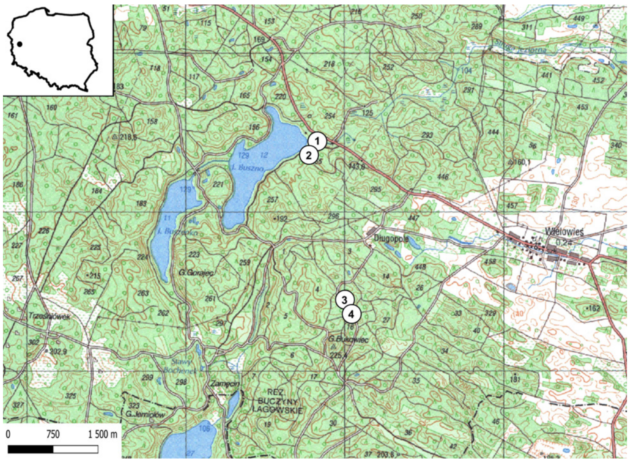

Figure 1. Mist netting locations in Natura 2000 site PLH080008 "Buczyny Łagowsko-Sulęcińskie"

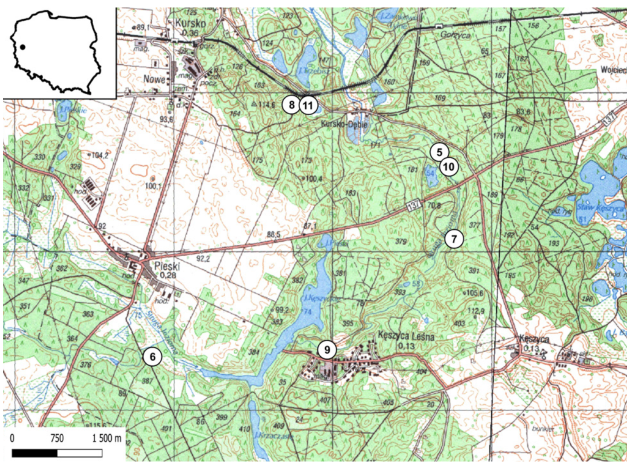

Figure 2. Mist netting locations in Natura 2000 site PLH080003 "Nietoperek"

Table 1. Mist nettings results from 1–8 July 2015 in different habitats located within Natura 2000 sites PLH080008 "Buczyny Łagowsko-Sulęcińskie" and PLH080003 "Nietoperek"

Site no. coordinates	Date	Habitat	Species sex/age/reproduction status	No. of species	No. of individu-als	$\bar{x}$H'
8. N52 26.293 E15 27.781	05.07.2015	**mixed coniferous forest** (*Fagus sylvatica, Pinus sylvestris, Fraxinus excelsior*)	*M. daubentonii* (F., lact.) – 3 ind. (M., Ad.) – 1 os. (F., juv.) – 2 ind. (M., juv.) – 3 ind. *M. mystacinus* (M., juv.) – 1 ind. *M. nattereri* (M., Ad.) – 1 ind. *P. pipistrellus* (M., Ad.) – 1 ind. *P. nathusii* (M., Ad.) – 3 ind. *P. pygmaeus* (F., lact.) – 1 ind. (M., Ad.) – 2 ind. *N. noctula* (M., Ad.) – 3 ind. *E. serotinus* (F., lact.) – 1 ind. (M., Ad.) – 1 ind. ***B. barbastellus*** (F., lact.) – 1 ind. (M., Ad.) – 4 ind. *P. auritus* (F., lact.) – 1 ind. (F., Ad.) – 1 ind.	10	30	0.84
9. N52 24.561 E15 28.142	06.07.2015		***B. barbastellus*** (M., Ad.) – 1 ind.	1	1	
11. N52 26.289 E15 27.775	08.07.2015		*M. daubentonii* (F., Ad.) – 1 ind. (F., juv.) – 2 ind. (M., juv.) – 3 ind. *P. pipistrellus* (M., Ad.) – 1 ind. *P. pygmaeus* (F., lact.) – 1 ind. *N. noctula* (F., lact.) – 1 ind. (M., Ad.) – 2 ind. ***B. barbastellus*** (M., Ad.) – 3 ind.	5	14	
1. N52 24.377 E15 19.017	01.07.2015	**lowland riparian fraxino-alder forest** (*Fraxino-Alnetum*), code Natura 2000: 91E0-3	*M. daubentonii* (F., lact.) – 2 ind. (F., juv.) – 1 ind. *P. pygmaeus* (F., lact.) – 1 ind. *P. nathusii* (F., lact.) – 2 ind. (M., Ad.) – 2 ind.	3	8	0.75
5. N52 25.942 E15 29.331	03.07.2015		*M. daubentonii* (F., lact.) – 1 ind. (M., Ad.) – 1 ind. *M. nattereri* (M., Ad.) – 1 ind. ***B. barbastellus*** (F., lact.) – 2 ind. (M., Ad.) – 3 ind. *P. pipistrellus* (F., lact.) – 1 ind. *N. noctula* (M., Ad.) – 2 ind.	5	11	
6. N52 24.501 E15 26.153	03.07.2015		*M. daubentonii* (F., juv.) – 2 ind. *P. nathusii* (M., Ad.) – 1 ind. ***B. barbastellus*** (F., lact.) – 2 ind. (M., Ad.) – 1 ind.	3	6	
7. N52 25.398 E15 29.487	04.07.2015		*M. daubentonii* (F., lact.) – 1 ind. (M., Ad.) – 3 ind. (F., juv.) – 1 ind. *M. brandtii* (M., Ad.) – 1 ind. *P. pygmaeus* (F., lact.) – 1 ind. (M., Ad.) – 1 ind. *N. noctula* (M., Ad.) – 1 ind. ***B. barbastellus*** (M., Ad.) – 3 ind.	5	12	
10. N52 25.946 E15 29.340	07.07.2015		*M. nattereri* (M., Ad.) – 2 ind.	1	1	
2. N52 24.319 E15 18.940	01.07.2015	**acid beechwood lowland** (*Luzulo pilosae-Fagetum*), code Natura 2000: 9110-1	*M. daubentonii* (F., lact.) – 1 ind. (M., juv.) – 5 ind. (F., juv.) – 1 ind.	1	7	0.5
3. N52 23.285 E15 19.516	02.07.2015		*P. pygmaeus* (F., lact.) – 1 ind.	1	1	
4. N52 23.252 E15 19.539	02.07.2015		***M. myotis*** (F., lact.) – 1 ind. (M., Ad.) – 2 ind. *P. pipistrellus* (M., Ad.) – 1 ind. *P. pygmaeus* (M., Ad.) – 1 ind.	3	5	

Legend: Bbar – *Barbastella barbastellus*; Eser – *Eptesicus serotinus*; Mbra – *Myotis brandtii*; Mdau – Myotis daubentonii; Mmyo – *Myotis myotis*; Mmys – *Myotis mystacinus*; Mnat – *Myotis nattereri*; Nnoc – *Nyctalus noctula*; Paur – *Plecotus auritus*; Pnat – *Pipistrellus nathusii*; Ppip – *Pipistrellus pipistrellus*; Ppyg – *Pipistrellus pygmaeus*. Reproductive status abbreviations: F. – female; M. – male; Ad. – adult; juv. – juvenile; lact. – lactating, ind. – individual. Species mentioned in Annex II of the EU Habitat Directive were bolded. The netting site numbers used in the table correspond with those on Figures 1 and 2. Coordinates are displayed using World Geodetic System '84.

if the mammary glands were swollen and enlarged nipples surrounded by hairless areas were present. The presence of lactating females and juveniles confirmed reproduction of the species in the study area.

The exact location of mist netting sites was recorded on GPS receiver (Garmin 60 CSx). The netting sites were chosen based on available Natura 2000 site documentation regarding habitat types and subsequently confirmed in the field. For our study the following habitats were selected:

1. Riparian woodlands (*Fraxino-Alnetum*, Natura 2000 code: 91E0-3). This protected habitat occupies 0.77% (56.81 ha) of the total area of Nietoperek Natura 2000 site (7,377.37 ha) and is widely recognised as suitable for bats due to abundance of possible roosts and

high-quality foraging grounds. We surveyed 5 sites within this habitat type.

2. Mixed plantation forest (*Pinus sylvestris, Fagus silvatica*, *Fraxinus excelsior*). Covering 45.42% (3,350.8 ha) of "Nietoperek", it is the largest habitat type present in the area. Mixed coniferous forest is generally not considered as a biodiverse habitat. However, its large extent, and the fact that it is surrounding higher quality habitats makes it important as a commuting corridor and possible foraging area. We surveyed 3 sites within this habitat type.
3. Acid lowland beech forest (*Luzulo pilosae-Fagetum*, Natura 2000 code: 9110-1). This habitat type is of high importance for some vespertilionid species such as *Myotis myotis* which rely on its lack of undergrowth and its ground cover of decomposing leaves for hunting ground-dwelling carabid beetles (Arlettaz 1999). It covers 7.52% (900 ha) of "Buczyny Łagowsko-Sulęcińskie" Natura 2000 area (6,771.02 ha). We surveyed 3 sites within this habitat type.

Data analysis

To examine the diversity of bat species in particular forest types the Shannon-Wiener biodiversity index (H') was calculated for each habitat type. Additionally, for each habitat we calculated the average number of bats per night. Normality of distribution was tested by the Shapiro-Wilk test with $P < 0.05$ confidence. For those features showing a normal distribution, the mean and standard error (*SE*) were calculated. The average biodiversity index was calculated for each habitat type.

Results

In total, 96 bats belonging to 12 species were caught in 11 localities. The average Shannon biodiversity index showed the highest value in plantation forest (H' = 0.84), middle value in riparian forest (H' = 0.75) and the lowest in the beech woodland (H' = 0.5). Similar pattern was observed in the average number of bats caught per night, the highest number (15.0, *SE* = 2.17) was recorded in plantation forest, followed by riparian forest (7.6, *SE* = 0.71) and beech woodland (4.3, *SE* = 0.86) (Table 1). Reproduction by seven species was confirmed during the netting in the mixed coniferous forest, followed by five species in riparian woodland and only three in beech forest. Out of all the captured bat species breeding was not confirmed for Natterer's and Brandt's bats. Detailed species composition and reproductive status for each site is presented in the table (Table 1).

Discussion

Importance of coniferous plantations

Old mixed broadleaf forests are important habitats for bats, since they support large quantities of insects (Eriksson 2004), while old oak and beech trees have abundant crevices, loose bark and hollows providing roosts for bats (Ruczyński and Bogdanowicz 2005), but the role of coniferous plantations is still poorly understood.

Some studies show avoidance of plantations by individual species (Smith and Racey 2008, Boughey et al. 2011), but on the other hand, more recent publications regarding this topic suggests that bat use of plantations may be more widespread than previously assumed (Cistrone et al. 2015, Charbonnier et al. 2016, Pereira et al. 2016, Kirkpatrick et al. 2017, Węgiel et al. 2019). In case of our work we lean towards the latter as we found that the Shannon diversity index in planted forest was higher than in native, natural forests. Finding the highest abundance and diversity of bats and confirming the presence of lactating barbastelles in these forests suggest that plantation forests may be important for local bat populations. This unexpected result might be explained in the following ways.

Firstly, the landscape surrounding both the Natura 2000 sites investigated during our study mainly consists of conifer plantation with isolated patches of mature native trees usually located in depressions. Most netted bats were caught during the commuting hours, i.e. the early and later parts of the night, and therefore it seems possible that some of bats netted in plantation forest were actually commuting to or from more suitable foraging grounds located in older parts of forest. Unfortunately, distinguishing between foraging and commuting was not possible without use of methods such as radio tracking. Most bat species in their summer habitats prefer to fly along linear landscape elements such as hedgerows, tree lanes, wood edges, canals, etc. instead of crossing open areas (Limpens et al. 1989, Limpens and Kapteyn 1991). According to some studies (Bender et al. 2015, Law et al. 2015) landscapes with a larger proportion of open ground may have a lower proportion of suitable edge habitats and linear features which *P. pygmaeus* may use for commuting to and from the better foraging areas. Therefore, it is possible that plantations serve more as important and safe commuting corridors providing shelter from wind and predators than as feeding habitats.

Secondly, the presence of a large hibernation site near suboptimal habitats in the forests under study may be a cost-benefit strategy for sedentary species such as barbastelles. Our findings were similar to the results of previous study conducted in a plantation forest near Wrocław in SW Poland (Apoznański 2013). During that study four different habitats (beech woodland, oak woodland, riparian forest and conifer plantation) were compared in terms of bat presence and species diversity. It appeared that the second highest total number of bats netted, and activity recorded by use of bat detectors, was found in coniferous plantation. One possible explanation for this could be the presence of a large known barbastelle hibernation site located only 20 km away from that forest. The average length of the barbastelle's seasonal migrations recorded in Germany was 28 km for males and 32 km for females. From 15,000 ringed bats only four travelled over 100 km and the maximum distance was 290 km (Dietz et al. 2006). Therefore, it is likely that barbastelles observed in Nietoperek during hibernation are also present there during breeding season. Despite being observed during the hibernation period in both the main underground system and in free standing ground level bunkers (Łupicki and Kowalcze-Łupicka 1999, Szkudlarek et al. 2001, Kokurewicz et al. 2014, 2019), barbastelles have never been caught there in the summer and their breeding was not confirmed in that area. What is particularly interesting is that barbastelles show unexpected flexibility regarding habitat and roost selection in face of lack of natural alternatives. For example, despite being believed to be dependent on natural roosts in mature old growth deciduous forest (Denzinger et al. 2001, Russo et al. 2004, 2017, Hillen et al. 2009, Kühnert et al. 2016, Carr et al. 2018, Dietz et al. 2018), all 18 breeding colonies of barbastelles recorded in Poland to date were located in man-made structures (Gottfried et al. 2017). A similar pattern is to be found in Sweden there two breeding colonies were discovered in barns during radio tracking study carried out in summer season of 2016 (Apoznański et al. 2018). During the same research barbastelles were observed foraging in coniferous forest, further supporting our assumption regarding their flexibility.

An alternative explanation for such a high biodiversity index in coniferous forest could be that broadleaf forests such as beech forest support the highest insect density only in the spring, when leaves are not fully developed. Bats may change their foraging habitats, as it have been recently recorded for pond bat (*Myotis dasycneme*) in northern Poland (Ciechanowski et al. 2017) in order to exploit temporal food patches with high invertebrate densities (Fukui et al. 2006), which could explain the low biodiversity in beech forest recorded during our study.

Previous lack of information regarding summer spatial distribution is, most likely, a result of insufficient amount of summer research conducted in the region, as well as inappropriate methods used in previous studies. Previous summer observations conducted in the "Nietoperek" area did not detect breeding barbastelles (Łupicki and Cichocki 2008, Andrzejczak et al. 2009). In our opinion an example of inappropriate method used during previous studies is incorrect placement of mist nets where locations were chosen from areas of higher bat activity recorded by use of ultrasonic detectors or by proximity to known bat colonies (Łupicki and Cichocki 2008). None of the sites in these studies were located deep inside woodlands, which we consider an inappropriate method for validating spatial distribution within different habitats. Particularly, we are concerned that habitats were not taken into consideration for comparison between sites. In our research mist netting was conducted in different habitats, and we also put stress on netting in difficult to access riparian parts of the woodland. Nets were also placed at different heights in order to maximize chances of catching a greater variety of species. Another example of a suboptimal method is walking transects with ultrasound detectors, which was carried out as a part of an environmental impact assessment of the A2 motorway route, conducted from March to November 2010. That study recorded barbastelle in only 20 occasions in a zone 3 km from the boundary of "Nietoperek", only 0.39% of all recorded calls (Kiczyńska et al. 2010). Such low numbers can be explained by the fact that the study focused on the area close to the planned motorway route and covered a relatively small area. In our study mist netting was conducted in different habitats to validate their importance for bats. We also put an emphasis on netting in difficult to access riparian parts of the woods.

It is not clear how bats are using plantation forest, but our results suggest that further investigation of this habitat type is needed in order to establish their ecological value and perhaps help to develop successful mitigation methods aiming to sustain high biodiversity without negative impact on timber production. It is important to recognise that due to our short study period the species composition found should not be considered as complete. It demonstrates the need for further research involving capture by mist nets, use of bat detectors and telemetry using radio transmitters. The latter method (telemetry) will enable investigation to determine if the coniferous plantations are used as commuting routes or foraging areas.

Consequences for forest management

When developing bat-friendly forest management plans, the habitat requirements of different bat species must be considered. Despite scoring lowest in terms of biodiversity, acid lowland beech forest was the only place where we caught greater mouse-eared bat, another species listed in Annex II of the EU Habitat Directive. Our results confirmed the findings of a radio tracking study conducted in 2008–2010 by the National Foundation for Nature Conservation (Warsaw) during the preparation of the management plan for "Nietoperek" and an environmental impact assessment of A2 motorway, which found foraging areas of female greater mouse-eared bats. The bats were roosting in a breeding colony located in a bunker situated in the southern part of the underground system, and travelled 14 km NW to forage in acid lowland beech forest in "Buczyny Łagowsko-Sulęcińskie" (Andrzejczak et al. 2009). This species uses passive listening to forage on carabid beetles (Insecta: Carabidae) on the woodland floor among dead leaves in beech forests (Arlettaz 1999). Clearly for this species, this type of habitat is crucial for survival.

Managed pine forests are usually harvested using clear-cut felling methods. The other factor to be considered is an impact of this practice on bat numbers and species diversity. In newly harvested forests and in clear-cut areas the reduction in tree density and, consequently, reduction in clutter, increases in bat activity have been recorded (Patriquin and Barclay 2003, Borkin and Parsons 2014). For some "open-habitat foragers" (*Nyctalus* spp., *Eptesicus* spp. and *Pipistrellus nathusii*) and "edge-habitat foragers"

(*Pipistrellus pipistrellus*, *P. pygmaeus*) forest management involving cutting could be beneficial. Węgiel et al. 2019 have found that clear-cut areas and stands of young trees had 2–3 times higher bat activity compared with mid-aged and mature stands. In conclusion, it seems to be possible that for habitat specialists like greater mouse-eared bat, natural habitats such as beech forest are of primary importance, while a mosaic of different habitats, including low quality forests, may suffice for the other species.

High bat activity recorded within coniferous plantations, as well as the high values of the biodiversity index, allows us to view this seemingly uninteresting type of forest from a new perspective. Our study shows that management plans should be carried out with the proper recognition of their potential as bat habitats, e.g. recommending leaving dead trees with loose bark which may serve as roosts (Russo et al. 2004). Bats spend a considerable part of their life in the roost; therefore, roost characteristics have important implications for survival and reproductive success (Kunz 1982). The characteristics of the roosting environment also determine the degree of exposure to predators (Rydell et al. 1996, Vonhof and Barclay 1996). It is also recommended that harvesting large areas of plantation at once is avoided since that reduces connectivity of landscape and hinders the ability of bats to commute between isolated mature parts of woods. Understanding whether there are general patterns that underpin how highly mobile species make use of plantations may be an important strategy for protection against future species declines (Kirkpatrick et al. 2017).

It is also recommended that bat boxes are used as a mitigation strategy following removal of large areas within plantations, since other studies show accelerated uptake of bat boxes adjacent to plantation forests, possibly as a result of the lack of alternative roosting possibilities (Smith and Agnew 2002, Ciechanowski 2005, Russo et al. 2010, López-Baucells et al. 2016). However, mitigation strategies such as installing bat boxes should be followed up with long-term monitoring essential to assess the effectiveness of those installation in plantations and therefore monitoring should be included into any management plan (Russo et al. 2016).

Conclusions

In conclusion, it is important for effective bat conservation to protect all important elements of the landscape used by bats for both summer breeding and winter hibernation, as well as maintaining corridors connecting these elements. Such an approach is especially important in the conservation of light phobic forest dwelling species, such as barbastelle and Bechstein's bat (*Myotis bechsteinii*), which are likely to be heavily influenced by habitat fragmentation.

Our preliminary results await confirmation by bat radio tracking studies to enable assessment of the value of mixed plantation forest for bat abundance and species diversity.

As for the areas already protected, the presence of 12 bat species, and confirmation of breeding for 10 of them, shows the high value of "Nietoperek" and "Buczyny Łagowsko-Sulęcińskie" for chiropterofauna of Central Europe, not only during hibernation but also during the active seasons of the year for bats.

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References

Altringham, J.D., Hammond, L. and McOwat, T. 1996. Bats: biology and behaviour. Oxford University Press, Oxford, UK, 272 pp.

Andrzejczak, W., Batycki, A., Kasprzak, A., Kokurewicz, T., Matraj, M., Rusiński, M., Świerkosz, K., Wylęgała, P., Weigle, A. and Kaim, K. 2009. Dokumentacja Planu Ochrony obszaru Natura 2000 site "Nietoperek" (PLH080003) [Documentation of the Protection Plan for Natura 2000 site "Nietoperek" (PLH080003)]. Narodowa Fundacja Ochrony Środowiska [National Foundation for Nature Conservation], Warszawa, (in Polish).

Apoznański, G. 2013. Habitat selection of barbastelle *Barbastella barbastellus* (Schreber 1774) during breeding season. MSc Thesis. University of Wroclaw, Poland, unpublished manuscript.

Apoznański, G., Sánchez-Navarro, S., Kokurewicz, T., Pettersson, S. and Rydell, J. 2018. Barbastelle bats in a wind farm: are they at risk? *European Journal of Wildlife Research* 64: 43. https://doi.org/10.1007/s10344-018-1202-1.

Arlettaz, R. 1999. Habitat selection as a major resource partitioning mechanism between the two sympatric sibling bat species *Myotis myotis* and *Myotis blythii*. *Journal of Animal Ecology* 68(3): 460–471.

Bender, M.J., Castleberry, S.B., Miller, D.A. and Bently Wigley, T. 2015. Site occupancy of for-aging bats on landscapes of managed pine forest. *Forest Ecology and Management* 336: 1–10. https://doi.org/10.1016/j.foreco.2014.10.004.

Borkin, K.M. and Parsons, S. 2014. Effects of clear-fell harvest on bat home range. *PLoS ONE* 9(1): e86163. https://doi.org/10.1371/journal.pone.0086163.

Boughey, K.L., Lake, I.R., Haysom, K.A. and Dolman, P.M. 2011. Effects of landscape-scale broadleaved woodland configuration and extent on roost location for six bat species across the UK. *Biological Conservation* 144: 2300–2310. https://doi:10.1016/j.biocon.2011.06.008.

Bremer, L.L. and Farley, K.A. 2010. Does plantation forestry restore biodiversity or create green deserts? A synthesis of the effects of land-use transitions on plant species richness. *Biodiversity and Conservation* 19: 3893–3915.

Charbonnier, Y., Gaüzère, P., Van Halder, I., Nezan, J., Bar-

nagaud, J.Y., Jactel, H. and Barbaro, L. 2016. Deciduous trees increase bat diversity at stand and landscape scales in mosaic pine plantations. *Landscape Ecology* 31: 291–300. https://doi.org/10.1007/s10980-015-0242-0.

Carr, A., Zeale, M., Weatherall, A., Froidevaux, J. and Jones, G. 2018. Ground-based and LiDAR-derived measurements reveal scale-dependent selection of roost characteristics by the rare tree-dwelling bat *Barbastella barbastellus*. *Forest Ecology and Management* 417: 237–246. https://doi.org/10.1016/j.foreco.2018.02.041.

Carnus, J.-M., Parrotta, J., Brockerhoff, E.G., Arbez, M., Jactel, H., Kremer, A., Lamb, D., O'Hara, K. and Walters, B. 2003. Planted Forests and Biodiversity. In: UNFF Intersessional Experts Meeting on the Role of Planted Forests in Sustainable Forest Management, 24–30 March 2003, New Zealand, Paper 10, p. 24–30.

Cichocki, J., Stopczyński, M., Bator, A., Grzywiński, W., Ignaczak, M., Ignaszak, K., Jaros, R., Kowalski, M., Łochyński, M., Postawa, T., Warchałowski, M., Węgiel, A. and Wojtaszyn, G. 2015. Liczebność nietoperzy zimujących w rezerwacie Nietoperek w roku 2015 [The number of bats hibernating in the Nietoperek reserve in 2015]. In: Streszczenia XXIV Ogólnopolskiej Konferencji Chiropterologicznej, 13–15 listopada 2015, Kazimierz Dolny, p. 36–37 (in Polish).

Ciechanowski, M., 2005. Utilization of artificial shelters by bats (Chiroptera) in three different types of forest. *Folia Zoologica* 54: 31–37.

Ciechanowski, M., Zapart, A., Kokurewicz, T., Rusiński, M. and Lazarus, M. 2017. Habitat selection of the pond bat *Myotis dasycneme* during pregnancy and lactation in Northern *Poland Journal of Mammalogy* 98(1): 232–245.

Cistrone, L., Altea, T., Matteucci, G., Posillico, M., De Cinti, B. and Russo, D. 2015. The effect of thinning on bat activity in Italian high forests: The LIFE+ "ManFor C.BD." experience. *Hystrix* 26: 125–523. https://doi:10.4404/hystrix-26.2-1147.

Denzinger, A., Siemers, M.B., Schaub, A. and Schnitzler, H.U. 2001. Echolocation by the barbastelle bat, *Barbastella barbastellus*. *Journal of Comparative Physiology. A, Sensory, Neural,* and Behavioral Physiology 187: 521–528. https://doi.org/10.1007/s003590100223.

Dietz, C., Von Helversen, O. and Nill, D. 2006. Nietoperze Europy i Afryki północno zachodniej. Biologia, rozpoznawanie, zagrożenia [Bats of Europe and North-West Africa. Biology, recognition, threats]. Multico Oficyna Wydawnicza, Warszawa, 398 pp. (in Polish).

Dietz, M., Brombacher, M., Erasmy, M., Fenchuk, V. and Simon, O. 2018. Bat community and roost site selection of tree-dwelling bats in a well-preserved European Lowland Forest. *Acta Chiropterologica* 20: 117–127. https://doi.org/10.3161/15081109ACC2018.20.1.008.

Eriksson, A. 2004. Habitat selection in a colony of *Barbastella barbastellus* in south Sweden. Examensarbete i ämnet naturvårdsbiologi 20 poäng, Inst. för naturvårdsbiologi, SLU, Uppsala, 125, p. 1–11.

FSC. 2012. Strategic Review on the Future of Forest Plantations. Forest Stewardship Council. A12-06869, ID 11914. Indufor, Helsinki, Finland, 11 pp. Available online at: https://ic.fsc.org/download.strategic-review-on-the-future-of-forest-plantations.671.htm.

Fukui, D., Murakami, M., Nakano, S. and Aoi, T. 2006. Effect of emergent aquatic insects on bat foraging in a riparian forest. *Journal of Animal Ecology* 75: 1252–1258.

Gardner, T.A. 2012. Monitoring Forest Biodiversity: Improving Conservation through Ecologically-Responsible Management. Routledge, London, 388 pp.

Gottfried, I., Gottfried, T., Bator, A. 2017. Roost use by colonies of the western barbastelle *Barbastella barbastellus* (Chiroptera) during summer in Poland. *Przegląd Przyrodniczy* 28: 104–115.

Hillen, J., Kiefer, A. and Veith, M. 2009. Foraging site fidelity shapes the spatial organization of population of female western barbastelle bats. *Biological Conservation* 142: 817–823.

Honnay, O. 2004. Forest biodiversity: lessons from history for conservation. CAB International, Wallingford, UK, 320 pp. (IUFRO Research Series, Vol. 10).

Humphrey, J.W., Ferris, R. and Quine, C. 2003. Biodiversity in Britain's planted forests: Results from the Forestry Commission's Biodiversity Assessment Project. Forestry Commission, Edinburgh, p. 51–62.

Hutterer, R., Ivanova, T., Meyer-Cords, C. and Rodrigues, L. 2005. Bat Migrations in Europe. A Review of Banding Data and Literature. Federal Agency for Nature Conservation, Bonn, 162 pp.

Jermaczek, A. and Maciantowicz, M. (Eds.). 2005. Przyroda Ziemi Lubuskiej [Nature of the Lubusz Land]. Wydawnictwo Klubu Przyrodników, Świebodzin, 400 pp. (in Polish).

Kiczyńska, A., Kokurewicz, T., Błaszczyk, M., Horbacz, A., Jaśkiewicz, M., Kieroński, D., Kowalewski, H. and Rusiński, M. 2010. Ekspertyza w zakresie oddziaływania autostrady A2 na obszar Natura 2000 "Nietoperek" na odcinku Świecko–Trzciel (km 1+995 – 92+533) w województwie Lubuskim [Expertise on the impact of the A2 motorway on the Natura 2000 "Nietoperek" area on the Świecko–Trzciel section (km 1+995 – 92+533) in the Lubuskie province]. Opracowanie wykonane przez Narodową Fundację Ochrony Środowiska z Warszawy na zlecenie Generalnej Dyrekcji Dróg Krajowych i Autostrad Oddział w Zielonej Górze (in Polish).

Kirkpatrick, L., Maher, S.J., Lopez, Z., Lintott, P.R., Bailey, S.A., Dent, D. and Park, K. 2017. Bat use of commercial coniferous plantations at multiple spatial scales: Management and conservation implications. *Biological Conservation* 206: 1–10. https://doi.org/10.1016/j.biocon.2016.11.018.

Kokurewicz, T., Bongers, F., Ciechanowski, M., Duvergè, L., Glover, A., Haddow, J., Rachwald, A., Rusiński, M., Schmidt, C., Schofield, H., Wawrocka, K., Willems, W. and Zapart, A. 2014. Bat research and conservation in "Nietoperek" bat reserve (Western Poland). In: Abstracts of the XIII European Bat Research Symposium, 1–5 September 2014, Šibenik, Croatia, p. 93–94.

Kokurewicz, T., Ogórek, R., Pusz, W. and Matkowski, K. 2016. Bats increase the number of cultivable airborne fungi in the "Nietoperek" bat reserve in Western Poland. *Microbial Ecology* 72(1): 36–48.

Kokurewicz, T., Apoznański, G., Gyselings, R., Kirkpatrick, L., De Bruyn, L., Haddow, J., Glover, A., Schofield, H., Schmid, T.C., Bongers, F., Torrent, L. and Rachwald, A. 2019. 45 years of bat study and conservation in Nietoperek bat reserve (Western Poland). *Nyctalus* (N.F.) 19(3): 252–269.

Kunz, T.H. 1982. Roosting ecology. In: Kunz, T.H. (Ed.) Ecology of bats. Plenum Press, New York, p. 1-/55.

Kühnert, E., Schönbächler, C., Arlettaz, R. and Christe, P. 2016. Roost selection and switching in two forest-dwelling bats: implications for forest management. *European Journal of Wildlife* Research 62: 497–500. https://doi.org/10.1007/s10344-016-1021-1.

Law, B., Park, K. and Lacki, M.J. 2015. Insectivorous Bats and Silviculture: Balancing Timber Production and Bat Conservation. In: Voigt, C.C. and Kingston, T. (Eds.) Bats in the Anthropocene: Conservation of Bats in a Changing World. Springer Cham, Heidelberg – New York – Dordrecht – London, p. 105–150. https://doi.org/10.1007/978-3-319-25220-9_5.

López-Baucells, A., Puig-Montserrat, X., Torre, I., Freixas, L., Mas, M., Arrizabalaga, A. and Flaquer, C. 2016. Bat boxes in urban non-native forests: a popular practice that should be reconsidered. *Urban Ecosystems* 20: 217–225. https://doi.org/10.1007/s11252-016-0582-9.

Limpens, H.J.G.A, Windeii, A. van and Mostert, K. 1989. Bats (Chiroptera) and linear landscape elements. *Lutra* 32(1): 1–20.

Limpens, H.J.G.A. and Kapteyn, K. 1991. Bats, their behaviour and linear landscape elements. *Myotis* 29: 63–71.

Łupicki, D. and Kowalcze-Łupicka, M. 1999. Dominacja gatunków nietoperzy odławianych przy głównym wjeździe do podziemi MRU przed i po zmianach konstrukcji kraty zamykającej w 1995 r. [Domination of bat species caught at the main entrance to the underground MRU before and after changes in the structure of the closing grille in 1995]. In: Dzięciołowski, R. (Ed.) Materiały Konferencyjne, XIII Ogólnopolska Konferencja Chiropterologiczna, Błażejewko, 5–7 November 1999. 31. PTOP "Salamandra", Poznań, Poland, p. 31 (in Polish).

Łupicki, D. and Cichocki, J. 2008. Występowanie nietoperzy na terenie Międzyrzeckiego Rejonu Umocnionego w okresie letnim [Occurrence of bats in the Międzyrzecki Fortified Region area in summer]. *Nietoperze* 9(1): 19–27 (in Polish).

Szkudlarek, R., Paszkiewicz, R., Blohm, T., Nowak, E. and Łupicki, D. 2001. Bunkry Ziemi Lubuskiej jako schronienia nietoperzy [Bunkers of the Lubusz Land as a shelter for bats]. *Nietoperze* 2: 83–92.

Patriquin, K.J. and Barclay, R.M.R. 2003. Foraging by bats in cleared, thinned and unharvested boreal forest. *Journal of Applied Ecology* 40: 646–657. https://doi.org/10.1046/j.1365-2664.2003.00831.x.

Pereira, M.J., Peste, F., Paula, A., Pereira, P., Bernardino, J., Vieira, J., Bastos, C., Mascarenhas, M., Costa, H. and Fonseca, C. 2016. Managing coniferous production forests towards bat conservation. *Wildlife Research* 43(1): 80. https://doi.org/10.1071/WR14256.

Pikula, J., Amelon, S.K., Bandouchova, H., Bartonička, T., Berkova, H., Brichta, J., Hooper, S., Kokurewicz, T., Kolarik, M., Köllner, B., Kovacova, V., Linhart, P., Piacek, V., Turner, G.G., Zukal, J. and Martínková, N. 2017. White-nose syndrome pathology grading in Nearctic and Palearctic bats. *PLoS ONE* 12(8): e0180435. https://doi.org/10.1371/journal.pone.0180435.

Rogowska, K. and Kokurewicz, T. 2007. The longest migrations of three bat species to the "Nietoperek" bat reserve (Western Poland). *Berichte der Naturforschenden Gesellschaft der Oberlausitz, Supplement zu Band* 15: 53–60.

Ruczyński, I. and Bogdanowicz, W. 2005. Roost cavity selection by *Nyctalus noctula* and *N. leisleri* (Vespertilionidae, Chiroptera) in Bialowieza Primeval Forest, eastern Poland. *Journal of Mammalogy* 86: 921–930.

Russo, D., Cistrone, L., Jones, G. and Mazzoleni, S. 2004. Roost selection by barbastelle bats (*Barbastella barbastellus*, Chiroptera: Vespertilionidae) in beech woodlands of central Italy: consequences for conservation. *Biological Conservation* 117: 73–81.

Russo, D., Cistrone, L., Garonna, A.P. and Jones, G. 2010. Reconsidering the importance of harvested forests for the conservation of tree-dwelling bats. *Biodiversity and Conservation* 19: 2501–2515.

Russo, D., Billington, G., Bontadina, F., Dekker, J., Dietz, M., Jones, G., Meschede, A., Rebelo, H. and Reiter, G. 2016. Identifying key research objectives to make European forests greener for bats. *Frontiers in Ecology and Evolution* 4: 87. https://doi.org/10.3389/fevo.2016.00087.

Russo, D., Cistrone, L., Budinski, I., Console, G., Della Corte, M., Milighetti, C., Di Salvo, I., Nardone, V., Brigham, R.M. and Ancillotto, L. 2017. Sociality influences thermoregulation and roost switching in a forest bat using ephemeral roosts. *Ecology and Evolution* 7: 5310–5321. https://doi.org/10.1002/ece3.3111.

Rydell, J., Entwistle, A. and Racey, P.A. 1996. Timing of foraging flights of three species of bats in relations to insect activity and predation risk. *Oikos* 76: 243–252.

Smith, G.C. and Agnew, G. 2002. The value of "bat boxes" for attracting hollow-dependent fauna to farm forestry plantations in southeast Queensland. *Ecological Management & Restoration* 3: 37–46. https://doi.org/10.1046/j.1442-8903.2002.00088.x.

Smith, P.G. and Racey, P.A. 2008. Natterer's bats prefer foraging in broad-leaved woodlands and river corridors. *Journal of Zoology* 275: 314–322. https://doi.org/10.1111/j.1469-7998.2008.00445.x.

Temple, H.J. and Terry, A. 2007. The status and Distribution of European mammals. Office for Official Publications of the European Communities, Luxembourg, pp. 58. Available online at: https://ec.europa.eu/environment/nature/conservation/species/redlist/downloads/European_mammals.pdf.

Vonhof, M.J. and Barclay, R.M.R. 1996. Roost-site selection and roosting ecology of forest-dwelling bats in southern British Columbia. *Canadian Journal of Zoology* 74: 1797–1805.

Węgiel, A., Grzywiński, W., Ciechanowski, M., Jaros, R., Kalcunis-Rüppell, M., Kmiecik, A., Kmiecik, P. and Węgiel, J. 2019. The foraging activity of bats in managed pine forests of different ages. *European Journal of Forest Research* 138(3): 383–396. https://doi.org/10.1007/s10342-019-01174-6.