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Bat Conservation Management in Exploited European Temperate Forests

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Abstract

Forests offer important refuge to bats by providing attractive roosting and foraging habitats. Their conservation is a major responsibility of forest managers. The use of tree cavities by bats in forests depends on the specific demands of each species, with a large range of different types of microhabitats utilised, from degraded cavities such as peeling bark to healthy hollows in live trees ensuring the temporal stability of the habitat. The conservation of tree-dwelling bats should not be dissociated from their fission-fusion behaviour which involves the use of many different roosts. Conservation measures must therefore take into account forest habitats suitable for feeding and in particular, forest parameters such as structure, composition, vegetation and foliage, among other elements such as deadwood, all upon which the forest manager can intervene. Acting in favour of bats requires close consideration of their complex individual responses concerning roost selection and foraging habitat selection, which is largely dictated by the reproductive status of individuals. Thereafter it is possible to evaluate the impact of wood harvesting on bats and to infer silvicultural conservation measures. The implementation of recommendations must then subsequently be based on a strong involvement on the part of the forest manager.

Keywords: Chiroptera, tree cavities, roost network, foraging habitat, deadwood, forest management

1. Introduction

In Europe, forests cover an area of approximately 4.5 million km^2, from the boreal forests of Scandinavia and Russia to the forests of the Mediterranean, including natural forests, plantations and intensive production forest systems [1]. They constitute a habitat particularly attractive to bats by providing the potential for roosting and foraging. Since the 1990s, conservation biologists have considered the forest as one of the most important refuges for biodiversity, in particular for a number of terrestrial mammals and bats [1–3]. Moreover, forests probably represent one of the least altered habitats across the continental landscape. Thus, forest managers must engage in implementing favourable management strategies for these species [2, 4]. Our knowledge about bats was still largely considered fragmentary at the beginning of the twenty-first century, outlined in a review on the relationships between bats and forests in North America [5]. In Europe, studies have multiplied in recent years promoting a greater understanding of the impacts of forest management on bats. This path to knowledge has revealed the relationships between bats, roosting sites, and foraging habitats across a number of settings, from natural forests, to intensive production forests, and to plantations with exotic species [6]. Unsurprisingly, bat species abundance and richness is considerably higher in forests that resemble a natural state [2, 7], which is probably in response to a greater presence of certain habitats related to the abandonment of logging practices, such as deadwood and tree cavities [8–10]. However, provided society's demand for wood products persists, the sometimes intensive exploitation of forests will continue to have a strong impact on biodiversity. In Europe, some sites already have high-quality favourable habitats at the landscape scale, principally in forests, and contribute markedly to the concentration of bats, especially the most specialised species [8]. These sites have consequently been included in the Natura 2000 network and are subject to contractual or regulatory management measures favouring biodiversity at the landscape scale. However, recent studies on certain forest habitats within the Natura 2000 network, notably beech (*Fagus sylvatica*) forests show that the measures implemented are slow to produce significant positive results for bats [9]. This can be explained by the slow evolution of forests with tree microhabitats taking considerable time to form, particularly in beech stands [10]. Hence, the integration of biodiversity issues should not wait until results are convincing before engaging in concrete conservation management actions as, in any case, they are typically slow at being implemented without strong regulatory measures. In forests primarily destined for logging, two key questions arise: towards which conservation strategy it is necessary to direct managers? And, is the setting aside of certain areas a sufficient response for bats? Thus, reconciling the issues related to both the exploitation of wood and the conservation of bats, accounting as much for roosts as for their foraging habitats is a true challenge for society [11].

2. Bat use of tree cavities

2.1. Types of roosts

In forests exploited for timber production, the number of available trees with cavities that can be used by bats are generally low, as young vigorous trees are favoured for wood production

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[12, 13]. The formation of cavities is very slow. Less than 1% of *Quercus robur* trees of 100 years old or less formed a cavity, compared to 50% of trees aged between 200 and 300 years old and all trees older than 400 years [14]. In forests, time is therefore an essential component to consider. Among cavities, only 9% were used by bats in a lowland temperate forest [15], corresponding to only 1% of trees sufficient in size to possess a cavity [16]. Because bats are incapable of creating their own roosts, they must rely on cavities created by wind, frost, the natural degradation of wood [17, 18], or by other organisms such as saproxylic insects and birds [19, 20]. The selected cavities must provide effective protection against predators and adverse weather conditions (wind, rain, and extreme temperatures) while also supporting social exchanges between individuals [17, 21, 22]. Cavities are generally more numerous on broadleaved trees than on conifers, and are not only favoured by the vitality and diameter of trees but also by the time elapsed since the last harvest at the forest stand level [23, 24]. In Mediterranean hardwoods such as *Quercus ilex*, tree diameter is the best predictor for the formation of microhabitats such as woodpecker hollows, insect holes and peeling bark [24]. Given that cavity-bearing trees are generally scarce in timber production forests, microhabitat density including bat-usable cavities is thus favoured in exclusion areas/set-asides, irrespective of the silviculture stage [23–26].

Bat colonies use tree cavities. As a result, their reproduction is all the more favoured if the forest area they occupy has a high density of potential roosting sites [27]. However, the majority of European forests are subject to the effects of timber harvest, presenting a considerable constraint to the biodiversity associated with tree microhabitats. This therefore constitutes the first major pressure facing bats in forests [2, 12, 13]. Any conservation strategy at the regional scale must therefore take into account the bat species present and the available cavities. Furthermore, the type of cavity selected indeed varies according to the species, *Barbastella barbastellus* preferentially selects cavities such as peeling bark on deadwood, in particular snags [13, 28], that are well exposed to sunlight. This prerequisite contributes to maintaining the necessary heat inside the roost especially when rearing young, consequently reducing the physiological demands linked to thermoregulation [27]. Other species, notably *Nyctalus leisleri* and *Myotis brandtii*, also show preferences for relatively degraded cavities, rather ephemeral and sometimes even distinctly exposed, despite the potential risk of predation [29, 30]. However, most tree-dwelling bat species across different genera select roost types other than defoliating bark, principally woodpecker hollows and narrow fissures/cracks which represent more sustainable cavities, and which are generally protected from terrestrial predators. Maternity colonies target a large available volume in the cavity, situated on a healthy part of the tree and as high as possible; over time a preference for live trees is evident since they ensure better thermal regulation within the roost during periods of extreme weather [15]. Most bat species, for instance, *Myotis bechsteinii*, *M. brandtii*, *Plecotus auritus*, *Vespertilio murinus* and *Pipistrellus* sp. select healthy large diameter trees [16, 30, 31]. Furthermore, whatever the selected roost, the closure of the forest environment allows individuals to take advantage of the foliage and the decline in luminosity to begin foraging earlier and return later all the while sheltered from potential predators [32]. This emergence behaviour has been demonstrated notably for *Barbastella barbastellus* [33], *Myotis nattereri* and *Plecotus auritus* [31]. In contrast, *Nyctalus noctula* and *N. leisleri* have a less manoeuvrable flight not allowing for cluttered areas at the entrance/exit of roosts. They seek out a compromise between the need to avoid predators and the need to take maximum advantage of available solar radiation during the day to minimise energy expenditure concerning the warming of breeding roosts. The cavities selected are thus situated high in trees in order to limit the predation risk where the canopy foliage is sparser favouring the insulation of roosts [34].

With increasing pressure for timber products in European forests, tree-dwelling bats must demonstrate sufficient plasticity in their behaviour in order to adapt to the challenge of a fluctuating availability of suitable roosts. *Nyctalus noctula* and *N. leisleri,* which preferentially use old trees of large diameters [29], can adapt to using young trees [12]. *Myotis nattereri* may target woodpecker hollows but is also known to utilise narrow fissures in small diameter trees such as Birch, *Betula* sp. However, this capacity to adapt can have its limits. In New Zealand, certain colonies of *Chalinolobus tuberculatus* appear no longer able to produce enough young to maintain colony numbers when usable cavities are lacking and food resources are reduced following forest exploitation [35]. Hence, management can affect the capacity of forests to produce the required roosts for maternity colonies. As a result roosts clearly become a limiting factor for bats.

2.2. Fission-fusion behaviour

Bat colonies select cavities of which the size and the type govern the structure and the numbers of the group occupying them. Consequently, pregnant females of *Myotis bechsteinii* may target small cavities high in trees limiting the risk of predation, and then select large cavities with a significant volume that can shelter larger groups at lower sites when they are lactating. In contrast, pregnant females of *Plecotus auritus* select a diversity of cavities in order to use smaller roosts after the birth of young (therefore limiting the size of the group) [31]. Most available cavities in forests have a reduced internal volume. Indeed, cavities of large volume take longer to form and are mainly found on old trees of large diameters [36, 37]. In order to respond to such ecological constraints, i.e. the limited number of tree microhabitats of suitable volume, forest-dwelling bat populations split into subgroups, demonstrating an exchange of individuals on a daily basis [38, 39]. Thus, groups divide and disperse each night (fission) then form new groups the following day, reorganised in accordance to the specific rules of each species, often selecting a new roost (fusion) [38].

Fission-fusion may limit the risk of parasitism [38, 40, 41], as tree cavities being confined spaces are conducive to the development of micro-organisms linked to wood degradation [19] and maintain an increase in humidity and heat favouring the development of bat parasites. In mammals, parasite density decreases with the frequent changing of rest sites [42]. For bats, this phenomenon outlines the importance of using a large number and diversity of cavities. The changing of roosts also allows bats to limit the risk of predation, as predators would no longer know which cavity exit to prowl [41]. Though, the frequency in which bats switch roosts is more dependent on meteorological conditions and the individuals' reproductive status [31, 43]. A disadvantage is that over time, these repeated fissions can lead to a loss of familiarity among individuals as life in a fission-fusion society imposes constant regroupings of different individuals [17, 22, 44, 45]. *Myotis bechsteinii* counteracts this problem with the oldest females organising the colonies around a few lineages or familiar groups that have maintained social links for more than 5 years [45]. In every example, fission-fusion behaviour involves the presence of a close network of primary roosts surrounded by "satellite" roosts, with the gradual and regular establishment of new roosts, especially when the oldest ones begin to degrade [46].

2.3. Roost networks

The turnover of roosts in relation to fission-fusion dynamics occurs, on average, every 2 or 3 days (**Table 1**). As a result, a substantial quantity of available cavities within the home range of a given bat colony is essential. The frequency in which bats change roost is largely influenced by the individuals' reproductive status, as outlined above. Females often change roosts when pregnant and tend to stay longer in the same cavity when lactating because maintaining higher temperatures, which is crucial, is energy-intensive for animals [22]. Accordingly, *Nyctalus lasiopterus* changed the cavity every 2.52 ± 0.74 days before the birth of young but stayed 4.88 ± 1.91 days in a cavity after birth [47]. Similarly, pregnant *Barbastella barbastellus* switched roosts every 2.6 ± 1.6 days, whereas lactating females stayed in the same cavity for up to 9.4 ± 1.8 days [27]. Conformably, reproductive females of the species *Myotis bechsteinii*, *M. nattereri* and *Plecotus auritus* stayed longer in their roosts than non-reproductive females [31].

Myotis bechsteinii may exploit more than 300 different cavities in the same year [31] and is able to use more than 15 different zones for roosting purposes [48]. This is in line with other species such as *Myotis nattereri*, *Barbastella barbastellus* and *Plecotus auritus* [13, 28, 31]. In New Zealand a colony of *Chalinolobus tuberculatus* used more than 300 cavities and re-used only 48% over the course of a year [49]. Conversely, *Mystacina tuberculata* selected a small number of roosts but was likely to stay for longer periods of time [50], demonstrating a much higher loyalty to its chosen cavities. Roosts should be voluminous in order to accommodate a large number of individuals (310 ± 88.1 on average) [51]. However, for the majority of species, colonies do not

Species	Duration in number of days	Reference
Chalinolobus tuberculatus (1)	1.7 ± 2.0	[51]
Mystacina tuberculata (1)	5.6 ± 6.9	[52]
Eptesicus fuscus (2)	1.7 ± 0.7	[53]
Myotis septentrionalis(2)	1.6 ± 0.5	[54]
	1.26 ± 0.40 to 1.20 ± 0.49	[55]
Myotis bechsteinii (3)	2.1 ± 1.1	[56]
	1.3 ± 0.8	[31]
Myotis nattereri (3)	1.2 ± 0.6	[31]
Barbastella barbastellus (3)	2.6 ± 1.6	[27]
	2.0 ± 1.8	[28]
Nyctalus lasiopterus (3)	2.68 ± 0.82	[50]
Plecotus auritus (3)	1.4 ± 0.8	[31]

Table 1. Average duration of presence (± standard deviation) in one roost by a number of forest-dwelling bat species demonstrating a fission-fusion society, in New Zealand (1), North America (2) and in Europe (3).

exceed more than a few dozen individuals in one roost. This pattern was observed in the small European tree-dwelling bat species such as *Myotis bechsteinii, Myotis nattereri, Barbastella barbastellus* and *Plecotus auritus* [31]. On the other hand, *Nyctalus noctula* composes larger groups that occupy large cavities for greater periods of time (unpublished). These diverse behaviours thus imply the need for different conservation strategies. Bat colonies that exploit many cavities are less sensitive to the disappearance of roosts but species that occupy a tree cavity for longer lengths of time are obviously more affected by their disappearance [32, 50]. Thus, the forest manager is faced with the challenge of maintaining a high capacity to accommodate all species throughout his territory. In addition, depending on the forest, the number of cavities can vary considerably. If we consider only woodpecker hollows and fissures on live trees, the number of microhabitats per hectare in a production forest may be greater than 10, while other forests may offer only a very limited or even zero carrying capacity [2, 6, 17, 32]. In the latter, a loss or alteration of roosts constitutes a major limiting factor for bats.

3. Foraging habitats in forests

3.1. The importance of forests as feeding opportunities

The literature is rich in identifying the main forest characteristics utilised by most European bat species [2, 6], as forests undoubtedly remain complex environments offering foraging habitats for these species, even when insect populations fluctuate. Studying forest habitats rather than prey abundance can thus contribute to a greater understanding of foraging behaviours [52, 53]. Regardless of the species, certain forest habitats are more attractive than others, broadleaved forests above all [50, 54–59]. It is therefore difficult for a forest manager to apply bat-friendly practices without a precise description of the factors determining habitat selection. According to the numerous studies, forest management causes changes (in terms of the composition and the structure of a forest stand) that are either acceptable or not for bats, as foraging behaviour may be jeopardised [60]. Logging forests for timber production may therefore reduce a colony's ability to sustain itself due to a lack of feeding resources [60, 61].

3.2. Favourable forest stands

At the bat community level, the silvicultural parameters that best explain the selection of certain forest habitats are that of structure, composition, and the quantity of foliage among other elements beyond the stand itself.

The maximal diameter of trees, different from stand age (but related) generally translates to a forest stand of overmature trees with the presence of microhabitats [10]. Microhabitats can even serve occasionally as refuge for bats that forage several kilometres from their roosting site, when weather conditions dramatically change [31]. Indeed, old forest stands are the most important habitats for bats as they offer a great potential for roosting [31, 60]. In a diverse forest landscape, bats will predominantly select broadleaved tree stands dominated by oaks and tend to avoid conifers [31]. This is in direct response to the entomological richness associated with these tree species [62]. Native *Quercus* spp. have the highest number of dependent insect species including various orders of saproxylics as well as defoliators (*Coleoptera*, *Lepidoptera, Heteroptera*, etc.). They are followed by *Betula* spp. which can sometimes have a greater number of individuals present but have less taxonomic groups associated with *Salix* spp., *Crataegus* spp., *Prunus* spp., and *Populus* spp. The first conifer species is *Pinus sylvestris* before *Fagus* spp. and *Picea abies* [63]. Moreover, the more the forest habitat is diversified, the more the insects' emergence is spread over time. For example, defoliators commonly emerge at different times in accordance with shade-tolerant and shade-intolerant trees [19]. In addition, a diversification of accompanying tree species and a strong presence of forest gaps in mature conifer plantations can have a positive impact on bat activity [64, 65], with bats contributing significantly to the control of insect pests in forests [66]. Furthermore, a higher density of vegetation and a greater heterogeneity from the ground to the canopy appear to increase bat species richness. *Myotis bechsteinii* principally forages within the dense canopy [31, 67] whereas *Myotis myotis* is a specialist of bare ground-dwelling prey [68]. Indeed, a complex structure of the forest with dense foliage, depressions, protuberances, and other ecotones is favourable to the development of different thermal and hygrometric conditions, the source of high entomological production [23, 69]. This can result in a higher activity of hawkers and gleaners [59, 70–72]. The latter forage for prey by gleaning insects from the substrate in dense foliage, while the former requires open spaces, such as forest clearings, paths, corridors, and edges even though they mainly hunt insects dependent on foliage [59, 70, 71]. Hence, the more diverse a forest is in composition, structure, and stratification, the higher bat species abundance and species richness will be [2]. Finally, additional forest environments such as streams and ponds, which present drinking sites for all individuals, also favour the occurrence of forest-dwelling bats [6, 7].

4. The role of deadwood

In Europe few bat species roost in dead trees. *Nyctalus leisleri* and *N. lasiopterus* are known to roost from time to time in cavities found on dead or dying trees [29, 73], and *Barbastella barbastellus* roosts regularly behind peeling bark, especially on snags [27, 28, 74] just like some *Myotis* and *Pipistrellus* species. The use of these ephemeral roosts is usually only part of a network of trees surrounding optimal roosting sites [13].

Deadwood constitutes an important support for the development of wood decaying insects with nearly a third of all forest insects directly depending on it [19, 26, 75]. Foraging bats can indeed take advantage of the presence of fresh deadwood by targeting any emerging *Coleoptera* insects. It is often the case with conifer stands that have been cut and stacked which favour the rapid concentrations of bark beetles (*Scolytidae*), subsequently attracting opportunistic species of *Nyctalus*, *Eptesicus* and *Pipistrellus* (**Figure 1**) [76, 77]. More widely, the richness of bat species has been found to be positively correlated to the volume of deadwood, either lying or standing, greatly increasing when deadwood quantity exceeded 25 m^3/ha [78]. This relation can be explained by deadwood-dwelling preys or by changes in the forest structure, due to openings created by dead trees that are favourable for edge-hawkers such as *Pipistrellus* spp., *Eptesicus*

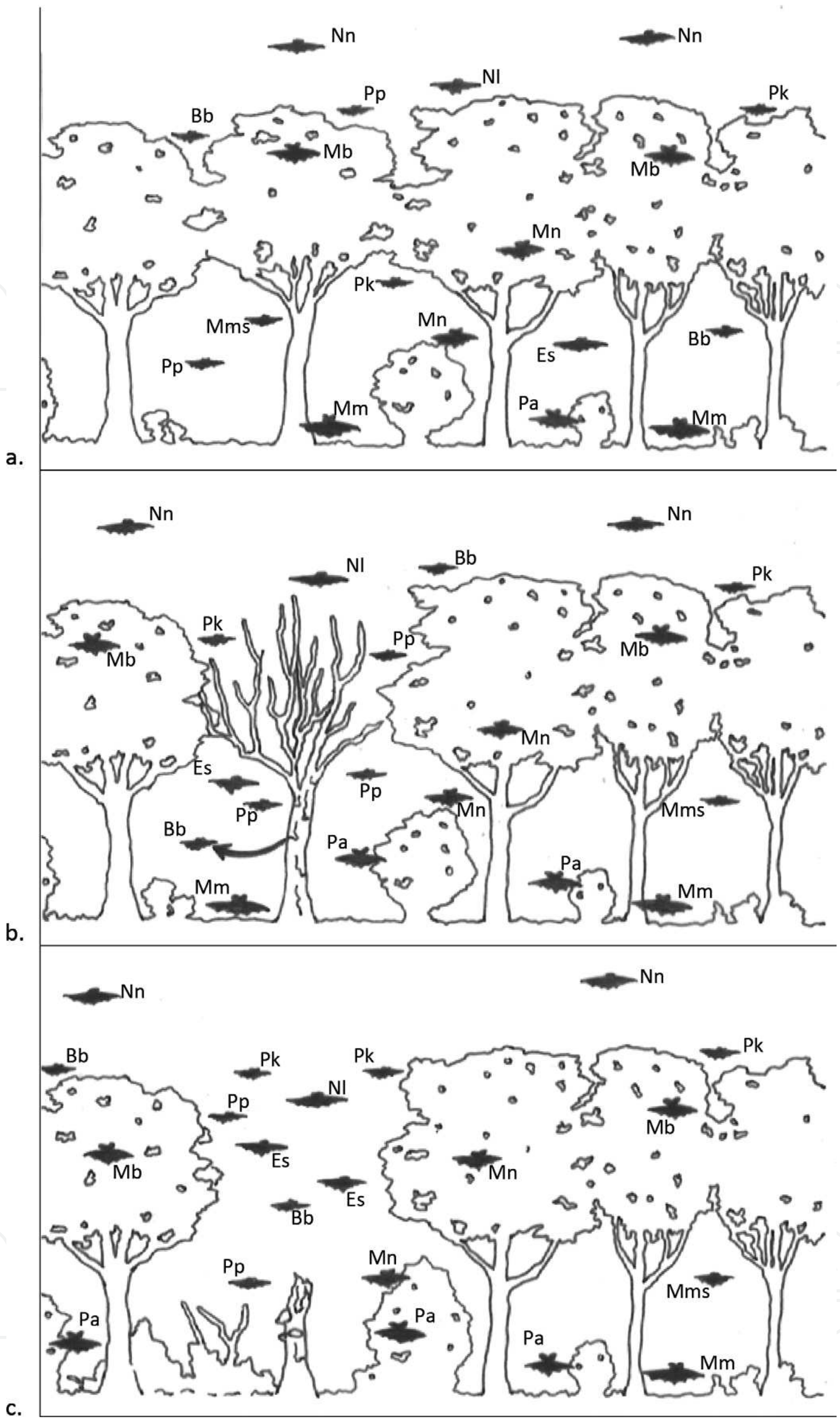

Figure 1. The spatial distribution of foraging bats in a forest stand. Gleaners (*Myotis* and *Plecotus*) forage within the foliage of the trees and around shrubs and bushes in the understory, whereas hawkers (*Nyctalus*, *Eptesicus*, *Barbastella* and *Pipistrellus*) are distributed above and under the canopy (a). When a tree dies, (b) a space free of vegetation forms. This clearing is generally avoided by gleaners and possibly exploited by hawkers where the space is not too cluttered by dead branches. *Barbastella barbastellus* may take advantage of any peeling bark for potential diurnal roosts. Once the dead tree has fallen, (c) hawkers distribute at the top of the clearing. The forest gap allows light to penetrate to the ground level, favouring the development of low vegetation. Certain gleaners (*Myotis nattereri* and *Plecotus auritus*) take advantage of this opportunity by foraging in the understory while others (*Myotis myotis*) require bare ground, and *Myotis bechsteinii* continues to exploit the foliage of the canopy. Bb: *Barbastella barbastellus*; Es: *Eptesicus serotinus*; Mb: *Myotis bechsteinii*, mm: *Myotis myotis*; Mms: *Myotis mystacinus*; Mn; *Myotis nattereri*; Nl: *Nyctalus leisleri*; Nn: *Nyctalus noctula*; Pa: *Plecotus auritus*; Pk: *Pipistrellus kuhlii*; Pp: *Pipistrellus pipistrellus*.

serotinus and *Nyctalus leisleri*. On the other hand, gleaners that pick up insects from the substrate e.g. leaves (most of *Myotis* and *Plecotus*) prefer to forage within the foliage [59, 70, 79–81] and do not dwell in areas with large quantities of deadwood, selecting above all forest habitats that are cluttered by vegetation [78].

5. Individual responses of bats to habitat selection

Bats respond differently to roosts as well as foraging habitats (or home ranges) according to their reproductive state. The energy needs of reproductive females are such that they become a lot more demanding than the other individuals [82]. *Myotis bechsteinii* and *Plecotus auritus* which are two ecologically and morphologically similar species illustrate this different use of available resources influenced by their reproductive status. Pregnant females of *M. bechsteinii* have smaller home ranges than non-reproductive females, change roost frequently often selecting roosts high in the trees and entering into a torpor when meteorological conditions deteriorate [31, 82]. Then, lactating females and young forage over high-quality habitats while non-reproductive females forage in lower-quality habitats such as conifer or young broadleaved stands. Social exchanges take precedence when selecting roosts, with colonies settling in large cavities without much vegetation clutter at the entrance allowing for several individuals to leave and enter the roost at a time [32]. On the contrary, pregnant females of *P. auritus* use large home ranges and can roost alone in a tree far from the main colony for several days. Lactating females systematically stay within the colony, foraging in good-quality habitats close to the cavity. Non-reproductive females use the same types of habitats but forage further from the colony [31]. Thus, the conservation of a network of cavities is clearly crucial for both species, including the preservation of woodpecker hollows at elevated positions on trees for *M. bechsteinii*. The same advice applies to other species with behavioural differences in the utilisation of tree cavities and habitat selection in Europe such as *Myotis daubentonii* [64] and *Myotis nattereri* [31], and on other continents, such as *Myotis septentrionalis* [65], *Eptesicus fuscus* [74], *Chalinolobus tuberculatus* [70, 83] and *Mystacina tuberculata* [84].

6. Bat conservation in the context of forest management

6.1. The impacts of silviculture

Regardless of the type of silvicultural practice undertaken in forests around the world, biodiversity will be affected. Harvest exclusion areas or setting aside reserves within production forests constitute sites that are richer in terms of species present, whereas timber plantations with more economically profitable methods employed, notably short rotation forestry, are the most impacting of approaches [1, 26, 71]. For bats, silvicultural logging reduces food resources, destroys breeding sites, and can kill individuals or colonies when trees are felled [2, 5, 6, 71]. Females of *Plecotus auritus* have been shown to entirely avoid forests recently logged during lactation periods even if mature trees have been preserved [32]. The same avoidance has also been observed in juveniles of *Myotis bechsteinii* and *Myotis nattereri* probably due to the decrease in the volume of foliage, which is an important source of insect production for these species [31]. More generally, logging forests for timber induces a net loss of prey-bearing mature broadleaves causing an immediate reduction in food resource. Therefore, bats are forced to move to new habitats next to their previous foraging grounds that are already occupied by other individuals, reducing the carrying capacity of the milieu. The silvicultural harvesting of mature trees that possess cavities inevitably leads to a reduction of the total number of roosts available to bats. Even if the natural ageing of trees continues and is accompanied by the gradual formation of new cavities, principally by woodpeckers, the setting aside of areas of unlogged mature forest to protect habitat diversity must still be maintained in order to ensure the temporal and spatial continuity of bat colonies [2, 6, 31]. Indeed, only harvest exclusion areas where the natural forest cycle is allowed to continue without the intervention of man represent truly ideal habitats for bats [80]. However, strict protection obviously remains an unrealistic measure across the European forest scale, implying a need for other forest management strategies.

6.2. Forest management orientations in favour of bats

Given the major differences in the ecological functioning of forest habitats, i.e. different compositions and structures, combined with a diverse range of silvicultural techniques employed to manipulate growth conditions, it becomes difficult for the conservation biologists to propose bat-friendly management measures [2, 81]. The growing literature comparing managed and non-managed forests demonstrates that bats do have the ability to occupy exploited forest systems, which gives hope for improving the conservation status of many species throughout European forests [1]. However, so as to implement effective conservation measures for bats, it is vital to know what habitat parameters to conserve and balance this with appropriate silvicultural treatments that ensure the continuing exploitation of wood while assuring the safety of the loggers themselves and the public who use the forests for recreational purposes. Although it is necessary to further improve knowledge on the relationship between bats and forest management [2], some recommendations can already be put forward. In order to conserve both roosts and foraging habitats, it is imperative that the manager ensures the temporal and spatial continuity of mature broadleaved stands composed of native species by maintaining at least 35% of the surface area of each forest (about 1000 ha). One way of maintaining suitable habitats for bats in forests would be by setting aside a number of small sites of no more than a few hectares in size, leaving the forest within each site to complete its natural cycle. By doing so, this would assure the presence of tree cavities, deadwood, and certain heterogeneity to naturally occur across an entire forest mosaic. In addition, within production forest plots, maintaining a small number of live or dead trees possessing cavities even after felling treatments have been carried out can ensure a minimum continuation of usable roosts. This can be of particular ecological interest: live trees possessing cavities surrounding a dead tree form a group of trees representing a particularly attractive habitat for bats. Also, a tree possessing a large voluminous cavity at a high position can accommodate certain species for an extended period of time such as *Nyctalus noctula*. Because isolated trees are at a greater risk of falling (due to abiotic factors) it is possible and recommended to

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maintain a group of trees, ensuring a forest ambience, around a cavity while, again, limiting the potential risk of injury to forestry workers or public. Maintaining quantities of deadwood, where possible both snags and ground-lying, should target the minimal threshold of $25m^3$/ha. Finally, diversity in tree species, a diversity in the vertical stratification and structure of a forest stand can only further support a diversity and abundance of food resources for the various species of bats.

7. The involvement of forest managers in France

In Europe, the accumulation of knowledge over the last decade on the relationships between bats and forests has orientated programmes geared towards a greater consideration for bats. In addition, the Natura 2000 network has been adopted in the European Community making it possible to designate numerous sites considered as fundamental for these animals [2, 13]. Forests being a key issue for the conservation of bats need to be taken into account as part of regional planning and forest management policies [2]. However, even though the number of appropriate management recommendations has increased in recent years the implementation of concrete conservation strategies is challenging, and unfortunately slow. Furthermore, forest managers must meet society's growing demand for wood products among other objectives such as reducing fossil fuel consumption, curtailing the impacts of climate change.

Of the 15 million hectares of forests in France (including overseas territories), 4.5 million hectares are managed by the French Forest Office who are mainly financed by timber production. This management body has integrated key conservation issues for biodiversity at various spatial scales within production forest systems. First, a number of harvest exclusion areas, whereby no silvicultural intervention occurs, have been created, each area ranging in size from ten to hundreds of hectares, totalling nearly 50,000 ha. Second, 3% of managed forests are "habitat islands" (generally ranging from 1 to 10 ha in size) where a true naturalness approach allows the natural cycle of forests to ensue ageing and decomposition of trees. Third, three microhabitat-bearing trees or dead trees are systematically protected per hectare. Fourth, at least one-third of a mature broadleaved forest's area is maintained in each forest canton as often as possible. The exploitation by clearcutting cannot exceed a few dozen hectares for any single block and the natural regeneration of the ecosystem is favoured, which is thus less degrading to biodiversity than plantations. Lastly, a team of 45 conscientious forest engineers, technicians and ecologists set up in 2004 carry out forest inventories and studies to improve knowledge on the relations between bats and forests and to evaluate the impact of forestry in this Office. They convert the collected information into management guidelines that favour bat conservation. These people are trained in forestry and have years of experience in managing forest plots, and can use the technical terminology required when communicating appropriate strategies to silviculture. The internalisation of these issues by teams dedicated to the preservation of bats within forest management organisations is the best assurance of successful bat conservation within exploited forest systems worldwide.

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References

[1] Law B, Park KJ, Lacki MJ. Insectivorous bats and silviculture: Balancing timber production and bat conservation. In: Bats in the Anthropocene: Conservation of Bats in a Changing World. Cham: Springer; 2016. pp. 105-150

[2] Russo D, Billington G, Bontadina F, Dekker J, Dietz M, Gazaryan S, Jones G, Meschede A, Rebelo H, Reiter G, Ruczyński I, Tillon L, Twisk P. Identifying key research objectives to make European forests greener for bats. Conservation. 2016;**4**:1-8

[3] Mayle BA. A biological basis for bat conservation in British woodlands - a review. Mammal Review. 1990;**20**:159-195

[4] Smith TL. A Small Scale Study into the Foraging Habitat Selection of *Myotis* and *Pipistrellus* spp. along the Forth & Clyde Canal. Vol. 3. Scotland: BaTML Publication; 2006. pp. 2-18

[5] Lacki MJ, Hayes JP, Kurta A, editors. Bats in Forests - Conservation and Management. Baltimore: The Johns Hopkins University Press; 2007. p. 329

[6] Meschede A, Heller K-G. Ecologie et protection des chauves-souris en milieu forestier. Le Rhinolophe. 2003;**16**:1-248

[7] Cruz J, Sarmento P, Rydevik G, Rebelo H, White PCL. Bats like vintage: Managing exotic eucalypt plantations for bat conservation in a Mediterranean landscape. Animal Conservation. 2016;**19**:53-64

[8] Kerbiriou C, Azam C, Touroult J, Marmet J, Julien J-F, Pellissier V. Common bats are more abundant within Natura 2000 areas. Biological Conservation. 2018;**217**:66-74

[9] Zehetmair T, Müller J, Runkel V, Stahlschmidt P, Winter S, Zharov A, Gruppe A. Poor effectiveness of Natura 2000 beech forests in protecting forest-dwelling bats. Journal of Nature Conservation. 2015;**23**:53-60

[10] Larrieu L, Cabanettes A, Brin A, Bouget C, Deconchat M. Tree microhabitats at the stand scale in montane beech–fir forests: Practical information for taxa conservation in forestry. European Journal of Forest Research. 2014;**133**:355-367

[11] McCarthy MA, Thompson CJ, Possingham HP. Theory for designing nature reserves for single species. The American Naturalist. 2005;**165**:250-257

[12] Ruczynski I, Nicholls B, MacLeod CD, Racey PA. Selection of roosting habitats by N*yctalus noctula* and *Nyctalus leisleri* in Bialowieza Forest—Adaptive response to forest management? Forest Ecology and Management. 2010;**259**:1633-1641

[13] Russo D, Cistrone L, Garonna AP, Jones G. Reconsidering the importance of harvested forests for the conservation of tree-dwelling bats. Biodiversity and Conservation. 2010;**19**:2501-2515

[14] Ranius T, Niklasson M, Berg N. Development of tree hollows in pedunculate oak (Que*rcus robur*). Forest Ecology and Management. 2009;**257**:303-310

[15] Tillon L, Aulagnier S. Tree cavities used as bat roosts in a European temperate lowland sub-Atlantic forest. Acta Chiropterologica. 2014;**16**:359-368

[16] Tillon L, Bresso K, Aulagnier S. Tree selection by roosting bats in a European temperate lowland sub-Atlantic forest. Mammalia. 2016;**80**:271-279

[17] Kunz TH, Lumsden LF. Ecology of cavity and foliage roosting bats. In: Kunz TH, Fenton MB, editors. Bat Ecology. Chicago and London: The University of Chicago Press; 2003. pp. 3-89

[18] Andrews HL. Bat Tree Habitat Key. Bridgwater: AEcol; 2013 http://battreehabitatkey.co.uk/

[19] Dajoz R. Les insectes et la forêt. Rôle et diversité des insectes dans le milieu forestier. Paris: Tec & Doc Lavoisier; 1998. p. 594

[20] Pasinelli G. Nest site selection in middle and great spotted woodpeckers *Dendrocopos medius* & *D. major*: Implications for forest management and conservation. Biodiversity and Conservation. 2007;**16**:1283-1298

[21] Entwistle AC, Racey PA, Speakman JR. Roost selection by the brown long-eared bat Ple*cotus auritus*. Journal of Applied Ecology. 1997;**34**:399-408

[22] Barclay RMR, Kurta A. Ecology and behavior of bats roosting in tree cavities and under bark. In: Lacki MJ, Hayes JP, Kurta A, editors. Bats in Forests - Conservation and Management. Baltimore: The Johns Hopkins University Press; 2007. pp. 17-59

[23] Larrieu L, Cabanettes A, Delarue A. Impact of silviculture on dead wood and on the distribution and frequency of tree microhabitats in montane beech-fir forests of the Pyrenees. European Journal of Forest Research. 2012;**131**:773-786

[24] Regnery B, Paillet Y, Couvet D, Kerbiriou C. Which factors influence the occurrence and density of tree microhabitats in Mediterranean oak forests? Forest Ecology and Management. 2013;**295**:118-125

[25] Winter S, Möller GC. Microhabitats in lowland beech forests as monitoring tool for nature conservation. Forest Ecology and Management. 2008;**255**:1251-1261

[26] Paillet Y, Bergès L, Hjältén J, Ódor P, Avon C, Bernhardt-Römermann M, Bijlsma R-J, De Bruyn L, Fuhr M, Grandin U, Kanka R, Lundin L, Luque S, Magura T, Matesanz S, Mészáros I, Sebastià M-T, Schmidt W, Standovár T, Tóthmérész B, Uotila A, Valladares F, Vellak K, Virtanen R. Biodiversity differences between managed and unmanaged forests: Meta-analysis of species richness in Europe. Conservation Biology. 2010;**24**:101-112

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

[28] Hillen J, Kiefer A, Veith M. Interannual fidelity to roosting habitat and flight paths by female western barbastelle bats. Acta Chiropterologica. 2010;**12**:187-195

[29] Ruczynski I, Bogdanowicz W. Roost cavity selection by *Nyctalus noctula* and *N. leisleri* (Vespertilionidae, Chiroptera) in Bialowieza primeval Forest, eastern Poland. Journal of Mammalogy. 2005;**86**:921-930

[30] Sachanowicz K, Ruczynski I. Summer roost sites of *Myotis brandtii* (Evermann, 1845) (Chiroptera, Vespertilionidae) in eastern Poland. Mammalia. 2001;**65**:531-535

[31] Tillon L. Utilisation des gîtes et des terrains de chasse par les Chiroptères forestiers, propositions de gestion conservatoire [thesis]. Toulouse: Université Paul Sabatier; 2015

[32] Thomas AJ, Jacobs DS. Factors influencing the emergence times of sympatric insectivorous bat species. Acta Chiropterologica. 2013;**15**:121-132

[33] Russo D, Cistrone L, Jones G. Emergence time in forest bats: The influence of canopy closure. Acta Oecologica. 2007;**31**:119-126

[34] Ruczynski I. Influence of temperature on maternity roost selection by noctule bats (*Nyctalus noctula*) and Leisler's bats (*N. leisleri*) in Bialowieza primeval Forest, Poland. Canadian Journal of Zoology. 2006;**84**:900-907

[35] O'Donnell CFJ. Timing of breeding, productivity and survival of long-tailed bats *Chalinolobus tuberculatus* (Chiroptera: Vespertilionidae) in cold-temperate rainforest in New Zealand. Journal of Zoology. 2002;**257**:311-323

[36] Regnery B, Couvet D, Kubarek L, Julien J-F, Kerbiriou C. Tree microhabitats as indicators of bird and bat communities in Mediterranean forests. Ecological Indicators. 2013;**34**:221-230

[37] Larrieu L, Cabanettes A, Gonin P, Lachat T, Paillet Y, Winter S, Bouget C, Deconchat M. Deadwood and tree microhabitat dynamics in unharvested temperate mountain mixed forests: A life-cycle approach to biodiversity monitoring. Forest Ecology and Management. 2014;**334**:163-173

[38] Kerth G, König B. Fission, fusion and nonrandom associations in female Bechstein's bats (*Myotis bechsteinii*). Behaviour. 1999;**136**:1187-1202

[39] Metheny JD, Kalcounis-Rüppell MC, Willis CKR, Kolar KA, Brigham RM. Genetic relationships between roost-mates in a fission-fusion society of tree-roosting big brown bats (*Eptesicus fuscus*). Behavioral Ecology and Sociobiology. 2008;**62**:1043-1051

[40] Kashima K, Ohtsuk H, Satake A. Fission-fusion bat behavior as a strategy for balancing the conflicting needs of maximizing information accuracy and minimizing infection risk. Journal of Theoretical Biology. 2013;**318**:101-109

[41] Kerth G. Causes and consequences of sociality in bats. Bioscience. 2008;**58**:737-746

[42] Bordes F, Morand S, Kelt DA, Van Vuren DH. Home range and parasite diversity in mammals. The American Naturalist. 2009;**173**:467-474

[43] Patriquin KJ, Leonard ML, Broders HG, Ford WM, Britzke ER, Silvis A. Weather as a proximate explanation for fission–fusion dynamics in female northern long-eared bats. Animal Behaviour. 2016;**122**:47-57

[44] Kerth G. Animal sociality: Bat colonies are founded by relatives. Current Biology. 2008;**18**:3

[45] Kerth G, Perony N, Schweitzer F. Bats are able to maintain long-term social relationships despite the high fission–fusion dynamics of their groups. Proceedings of the Royal Society B. 2011;**278**:2761-2767

[46] Patriquin KJ, Ratcliffe JM. Should I stay or should I go? Fission–fusion dynamics in bats. In: Sociality in Bats. Cham: Springer; 2016. pp. 65-103

[47] Popa-Lisseanu AG, Bontadina F, Mora O, Ibáñez C. Highly structured fission-fusion societies in an aerial-hawking, carnivorous bat. Animal Behaviour. 2008;**75**:471-482

[48] Kühnert E, Schönbächler C, Arlettaz R, Christe P. Roost selection and switching in two forest-dwelling bats: Implications for forest management. European Journal of Wildlife Research. 2016;**62**:497-500

[49] O'Donnell CFJ, Sedgeley JA. Use of roosts by the long-tailed bat, *Chalinolobus tuberculatus*, in temperate rainforest in New Zealand. Journal of Mammalogy. 1999;**80**:913-923

[50] Mackie IJ, Racey PA. Habitat use varies with reproductive state in noctule bats (*Nyctalus noctula*): Implications for conservation. Biological Conservation. 2007;**140**:70-77

[51] Sedgeley JA. Roost site selection and roosting behaviour in lesser short-tailed bats (*Mystacinus tuberculata*) in comparison with log-tailed bats (*Chalinolobus tuberculatus*) in Nothofagus forest, Fiordland. New Zealand Journal of Zoology. 2003;**30**:227-241

[52] Müller J, Mehr M, Bässler C, Fenton MB, Hothorn T, Pretzsch H, Klemmt H-J, Brandl R. Aggregative response in bats: Prey abundance versus habitat. Oecologia. 2012;**169**:673-684

[53] Pauli BP, Zollner PA, Haulton GS, Shao G, Shao G. The simulated effects of timber harvest on suitable habitat for Indiana and northern long-eared bats. Ecosphere. 2015;**6**:art58

[54] Smith PG, Racey PA. Natterer's bats prefer foraging in broad-leaved woodlands and river corridors. Journal of Zoology. 2008;**275**:314-322

[55] Dietz M, Pir JB. Distribution and habitat selection of *Myotis bechsteinii* in Luxembourg: Implications for forest management and conservation. Folia Zoologica. 2009;**58**:327-340

[56] Napal M, Garin I, Goiti U, Salsamendi E, Aihartza J. Habitat selection by *Myotis bechsteinii* in the southwestern Iberian peninsula. Annales Zoologici Fennici. 2010;**47**:239-250

[57] Murphy SE, Greenaway F, Hill DA. Patterns of habitat use by female brown long-eared bats presage negative impacts of woodland conservation management. Journal of Zoology. 2012;**288**:177-183

[58] Ashrafi S, Rutishauser M, Ecker K, Obrist MK, Arlettaz R, Bontadina F. Habitat selection of three cryptic *Plecotus* bat species in the European alps reveals contrasting implications for conservation. Biodiversity and Conservation. 2013;**22**:2751-2766

[59] Arrizabalaga-Escudero A, Napal M, Aihartza J, Garin I, Alberdi A, Salsamendi E. Can pinewoods provide habitat for a deciduous forest specialist? A two-scale approach to the habitat selection of Bechstein's bat. Mammalian Biology. 2014;**79**:117-122

[60] Archaux F, Tillon L, Fauvel B, Martin H. Foraging habitat use by bats in a large temperate oak forest: Importance of mature and regeneration stands. Le Rhinolophe. 2013;**19**:47-58

[61] Hayes JP, Loeb SC. The influences of forest management on bats in North America. In: Lacki MJ, Hayes JP, Kurta A, editors. Bats in Forests - Conservation and Management. Baltimore: The Johns Hopkins University Press; 2007. pp. 207-235

[62] Southwood TRE, Moran VC, Kennedy CEJ. The richness, abundance and biomass of arthropod communities on trees. The Journal of Animal Ecology. 1982;**51**:635-649

[63] Southwood TRE. The number of species of insect associated with various trees. The Journal of Animal Ecology. 1961;**30**:1-8

[64] Lučan RK, Radil J. Variability of foraging and roosting activities in adult females of Daubenton's bat (*Myotis daubentonii*) in different seasons. Biologia (Bratislava). 2010;**65**: 1072-1080

[65] Garroway CJ, Broders HG. Day roost characteristics of northern long-eared bats (*Myotis septentrionalis*) in relation to female reproductive status. Ecoscience. 2008;**15**:89-93

[66] Charbonnier Y, Barbaro L, Theillout A, Jactel H. Numerical and functional responses of forest bats to a major insect pest in pine plantations. PLoS One. 2014;**9**:e109488

[67] Plank M, Fiedler K, Reiter G. Use of forest strata by bats in temperate forests. Journal of Zoology. 2012;**286**:154-162

[68] Arlettaz R. Feeding behaviour and foraging strategy of free-living mouse-eared bats, *Myotis myotis* and *Myotis blythii*. Animal Behaviour. 1996;**51**:1-11

[69] Otto H-J. Ecologie forestière. Paris: Institut pour le Développement Forestier; 1998

[70] Borkin KM, Parsons S. Home range and habitat selection by a threatened bat in exotic plantation forest. Forest Ecology and Management. 2011;**262**:845-852

[71] Chaudhary A, Burivalova Z, Koh LP, Hellweg S. Impact of forest management on species richness: Global meta-analysis and economic trade-offs. Scientific Reports. 2016;**6**(23954)

[72] Blakey RV, Law BS, Kingsford RT, Stoklosa J, Tap P, Williamson K. Bat communities respond positively to large-scale thinning of forest regrowth. Journal of Applied Ecology. 2016;**53**:1694-1703

[73] Beuneux G, Courtois J-Y, Rist D. La Grande noctule (*Nyctalus lasiopterus*) en milieu forestier en Corse : bilan des connaissances sur les arbres-gîtes et les territoires de chasse fréquentés. Symbioses. 2010;**25**:1-8

[74] Willis CKR, Voss CM, Brigham RM. Roost selection by forest-living female big brown bats (*Eptesicus fuscus*). Journal of Mammalogy. 2006;**87**:345-350

[75] Good JA, Speight CD. Les invertébrés saproxyliques et leur protection à travers l'Europe. Strasbourg: Conseil de l'Europe; 1996. p. 54

[76] Tillon L. Impact de la tempête du 26 décembre 1999 sur la forêt domaniale de Rambouillet. Exemple des Chiroptères. Revue forestière française. 2001;**53**:83-90

[77] Mehr M, Brandl R, Kneib T, Müller J. The effect of bark beetle infestation and salvage logging on bat activity in a national park. Biodiversity and Conservation. 2012;**21**:2775-2786

[78] Tillon L, Bouget C, Paillet Y, Aulagnier S. How does deadwood structure temperate forest bat assemblages? European Journal of Forest Research. 2016:1-17

[79] Patterson BD, Willig MR, Stevens RD. Trophic strategies, niche partitioning, and patterns of ecological organization. In: Kunz TH, Fenton MB, editors. Bat Ecology. Chicago and London: The University of Chicago Press; 2003. pp. 536-579

[80] Bouvet A, Paillet Y, Archaux F, Tillon L, Denis P, Gilg O, Gosselin F. Effects of forest structure, management and landscape on bird and bat communities. Environmental Conservation. 2016;**43**:148-160

[81] Guldin JM, Emmingham WH, Carter SA, Saugey DA. Silvicultural practices and management of habitat for bats. In: Lacki MJ, Hayes JP, Kurta A, editors. Bats in Forests - Conservation and Management. Baltimore: The Johns Hopkins University Press; 2007. pp. 177-205

[82] Otto MS, Becker NI, Encarnação JA. Cool gleaners: Thermoregulation in sympatric bat species. Mammalian Biology. 2013;**78**:212-215

[83] Borkin KM, Parsons S. Sex-specific roost selection by bats in clearfell harvested plantation forest: Improved knowledge advises management. Acta Chiropterologica. 2011;**13**:373-383

[84] Sedgeley JA. Roost site selection by lesser short-tailed bats (*Mystacinus tuberculata*) in mixed podocarp-hardwood forest, Whenua Hou/Codfish Island, New Zealand. New Zealand Journal of Zoology. 2006;**33**:97-111