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Flight activity of bats in habitats with different representation of human settlements

Master's thesis

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Declaration:

I hereby declare that I wrote my diploma thesis ″Flight activity of bats in habitats with different represantation of human settlements″ myself and that I have used only sources cited in text and list of references. I agree that my work will be accessible for future studying purposes in the library of CULS.

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Abstract:

Bats are important part of diversity of mammal fauna and they are used as an indicator of environmental quality. One of the aims of the master thesis was to compare activity of bats in habitats with different representation of human settlements. Study localities were chosen randomly, but with given criteria, throughout the whole territory of the Czech Republic. The influence of presence of human settlements on bat activity and structure of their communities was studied using ultrasound bat detectors. All records were evaluated using Sonochiro and Batsound programs. More than 3,664 call sequences of 17 – 21 bat species on 39 study sites were recorded during two summers 2014, 2015; in two types of forest localities. The first set of sites was located in distance 100 – 300 m from human settlements; the second was more than 1,000 m far from the human settlements. It was recorded almost twice higher total activity of bats at sites closer to human settlements and significantly higher total presence of bat species closer to human settlements was proved using statistical tests. It seems that synanthropization of particular bat species is ongoing process; many bat species are able to use manmade constructions and buildings and seem to prefer less thick forest habitats. Therefore not all human impact on habitats can be interpreted as harmful for animal species. Comparative studies including larger data sets with focus on hardly detectable bat species would be helpful for further understanding of the topic and consequently better bats' conservation.

Key words: bat activity, detectoring, forest bats, habitat preferences, urbanization

Abstrakt:

Netopýři jsou důležitou součástí druhové rozmanitosti savců a jsou považováni za indikátor kvality životního prostředí. Jedním z cílů předkládané diplomové práce bylo srovnání aktivity netopýrů v prostředích s odlišným zastoupením lidských sídel. Studované lokality byly vybrány náhodně, avšak s předem danými kritérii. Pomocí ultrazvukového detektoru byl zjišťován vliv lidských sídel na přítomnost a aktivitu jednotlivých druhů netopýrů a strukturu jejich společenstev. Veškeré nahrávky byly vyhodnoceny s použitím programů Sonochiro a Batsound. Během dvou letních období, v letech 2014 a 2015, bylo nahráno více než 3,664 zvukových sekvencí; 17 - 21 druhů netopýrů na 39 lokalitách; ve dvou typech lesních prostředí. Lokality se lišily zejména ve vzdálenosti od lidských sídel. První typ lokality byl vzdálen jen 100 – 300 m od lidských obydlí, druhý typ lokality byl vzdálen více než 1,000 metrů od nejbližšího lidského obydlí. Po vyhodnocení veškerých výsledků byla zaznamenána téměř dvakrát vyšší aktivita netopýrů v blízkosti u sídel a s využitím statistické analýzy byla spočítána výrazně vyšší přítomnost jednotlivých druhů netopýrů blíže k lidským sídlům. Synantropizace některých netopýřích druhů se zdá být stále probíhajícím procesem, mnoho druhů netopýrů využívá lidské stavby a konstrukce a pravděpodobně preferují rozvolněnější porosty. Z tohoto důvodu by neměly být všechny lidské zásahy do biotopů interpretovány jako pro živočichy škodlivé. Srovnávací studie, zahrnující větší počet dat se zaměřením na hůře detekovatelné druhy netopýrů, by mohly pomoci k dalšímu porozumění danému tématu a následné kvalitnější ochraně netopýrů.

Klíčová slova: aktivita netopýrů, detektoring, lesní netopýři, habitatová preference, urbanizace

1 Content

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List of abbreviations

Bbar – barbastelle (*Barbastella barbastellus*)

Enil – northern bat (*Eptesicus nilssonii*)

Eser – serotine (*Eptesicus serotinus*)

Malc – Alcathoe bat (*Myotis alcathoe*)

Mbech – Bechstein´s bat (*Myotis bechsteinii*)

Mbra – Brandt´s bat (*Myotis brandtii*)

Mdau – Daubenton´s bat (*Myotis daubentonii*)

Mema – Geoffroy´s bat (*Myotis emarginatus*)

Mmyo – greater mouse-eared bat (*Myotis myotis*)

Mmys – whiskered bat (*Myotis mystacinus*)

Mnat – Natterer´s bat (*Myotis nattereri*)

Nlei – Leisler´s bat (*Nyctalus leisleri*)

Nnoc – noctule (*Nyctalus noctula*)

Nlas – Greater noctule (*Nyctalus lasiopterus*)

Paur – common brown long-eared bat (*Plecotus auritus*)

Paus – grey long-eared bat (*Plecotus austriacus*)

Pnat – Nathusius´s pipistrelle (*Pipistrellus nathusii*)

Pkuh – Kuhl´s pipistrelle (*Pipistrellus kuhlii*)

Ppip – Common pipistrelle (*Pipistrellus pipistrellus*)

Ppyg – soprano pipistrelle (*Pipistrellus pygmaeus*)

Vmur – parti-coloured bat (*Vespertilio murinus*)

CS – close to settlements

FS – far from settlements

nat – natural

artif – artificial

hab – habitat

a. s. l. – above sea level

n.s. – not significant

NE - northeast

SW - southwest

1 Introduction and Literature Review

1.1 Introduction

Bats and people can be very beneficial for each other, because living together in harmony can bring lots of advantages. Bats and humans inhabit the same huts, cottages and houses already for thousands of years. These human buildings bring many benefits for bats e. g. hiding places from predators, protection from unpleasant weather conditions, lower ectoparasite loads, warmer microclimate leading to faster raising of new-borns and their increased fitness; earlier births and weaning; or use of buildings and its surroundings as a swarming site as in case of *Pipistrellus pipistrellus* (Schreber, 1774) or *Vespertilio murinus* (Kuhl, 1817), (Lausen, 2005; Lausen et Barcley, 2006; Kaňuch et al., 2010; Šuba et al., 2010; Voigt et al., 2016).

Vice versa bats are important for nature and human. They ensure balance in ecosystem by consuming insects and other arthropods, disperse seeds or pollinate plants (Kunz et al., 2011). As Kurta et al (1989) estimate in their study on *Myotis lucifugus* (LeConte, 1831)*,* this species needs to consume around 9, 9 grams of insects per night, which is more than 100 % of its body weight. It is in whole environment significant amount in consideration to all bats hunting each night. Even though many species of moths changed their mechanism during evolution to defend themselves against bats (Hristov et Conner, 2005); Belton and Kempster (1962) found lower infestation rate in corn field by *Ostrinia nubilalis* (Hübner, 1796), (Lepidoptera: Pyralidae) in plots which were exposed to ultrasound broadcast at the same frequencies as bat calls. This shows another possible advantage coming from coexistence with bats. Last but not least, bat´s faeces ″guano″ is considered a huge benefit for humans, being used as high quality fertilizer (Kunz et al., 2011). However, there are some negatives associated with bats. Some tropical species seem to be an important vector of zoonotic diseases and fruit eating bats cause economic losses to farmers (Srinivasulu et Srinivasulu, 2002; Han et al., 2015).

After many years of declining bat population mainly during second half of the 20th century (O'Connor, 2014), caused by pesticides using (Mitchell-Jones et al., 1989; Bontadina et al., 2000), landscape changes, agriculture intensification (Haysom et al., 2010), decline of insect availability (Wickramasinghe et al., 2003), DDT using (Jefferies, 1972), construction of windmills (Kunz et al., 2007), and disturbance of roosting sites by

human (Hutson et al., 2001); the bat population in Europe started to recover. 9 out of 16 bat species are increasing in their total number in hibernation sites (*Rhinolophus euryale* (Blasius, 1853)*, Rhinolophus ferrumequinum* (Schreber, 1774)*, Rhinolophus hipposideros* (Borkhausen, 1797)*, Myotis myotis/blythii* (Borkhausen, 1797; Tomes 1857), *Myotis daubentonii* (Kuhl, 1817)*, Barbastella barbastellus* (Schreber, 1774), *Myotis nattereri* (Kuhl, 1817), *Myotis brandtii/mystacinus* (Eversmann, 1845; Kuhl, 1817), *Myotis emarginatus* (Geoffroy, 1806)), 6 remains stable or uncertain (*Myotis bechsteinii* (Kuhl, 1817) - uncertain , *Myotis dasycneme* (Boie, 1825) – stable, *Eptesicus nilssonii* (Keyserling et Blasius, 1839) – uncertain, *Eptesicus serotinus* (Schreber, 1774) – stable, *Plecotus auritus* (Linnaeus, 1758) – stable, *Miniopterus schreibersii* (Kuhl, 1817) – stable) and just *P. austriacus* (Fischer, 1829) is declining in its population number (Meij et al., 2015). The abundance in species *M. myotis, M. daubentonii* and *R. hipposideros* increased by about 200 % (Horáček et Uhrin, 2010).

Climate changes (caused among others by people) in past many years affected population of some bat species not just only negatively, but in some cases they help them to spread their geographical range. Ancilotto et al (2016) observed distribution of *Pipistrellus kuhlii* (Kuhl, 1817) from year 1980 till year 2013 and showed its increasing range expansion by about 394 % most probably as a response to climate changes. Similar range expansion was observed in the case of *Hypsugo savii* (Bonaparte, 1837), (Uhrin et al., 2016).

1.2 History of occurrence of bats in Central Europe

The first fossils records of European bats originate from already about 50 million years ago, in the early Eocene. During Eocene proceeded big species separation and adaptation for habitats not just only in bats, but among all mammals. The ecological niches were the most diverse. Until now is recognized twenty-four genera of Eocene bats from which at least nine genera were present in early Eocene; originated from North America, Europe, Africa and Australia (McKenna et Bell, 1997; Simmons et Geisler, 1998; Dietz et al., 2007).

In year 2016 we distinguished more than 1,300 bat species (Fenton et Simmons, 2015), which makes Chiroptera the second most diverse mammalian order. Bats are very diverse group not just in their total amount of species, but also in size of their body. The smallest known species *Craseonycteris thonglongyai* (Hill, 1974) weights just about 2 g (Jones, 1996), on the other hand the largest bat species, *Pteropus vampyrus* (Linnaeus, 1758) weights 600 times more around 1.2 kg with length of forearm 179 – 220mm (Lekagul et McNeely, 1977). 75%-85 % of all bat species are insectivorous (Francis, 1990) the rest are flower pollinators (Dobat, 1985), frugivorous (Simmons et Voss, 1998), few bats are carnivorous - feeding on terrestrial vertebrates (Patterson et al., 2003); piscivore bats are even more specialized - eating fish (Schnitzler et al., 1994) and unique diet can be seen in Vampire bats (genus *Desmodus*), which feed on blood that they lick usually from cattle laying on pasture (Fernandez, 1999).

Until now some of the bat species look morphologically so similar, that larger number of distinguished bat species is expected. Just seven species were recognized in Europe during past twenty years. While some of the records are well preserved, even moth in bat´s stomach could be detected, thus we know that bats in Eocene were insectivorous as current species. By measuring parameters of internal ear of bats using fossils records, researchers from Senkenberg Museum found out that early bats from Eocene epoch already oriented themselves with ultrasound (Dietz et al., 2007).

It was thought that expansion of bat species into the Central Europe such as (*M. myotis*, *M. blythii, P. austriacus*, *E. serotinus*, *Rhinolophus hipposideros* (Bechstein, 1800) or *P. pipistrellus*) was supported by the post-Neolithic anthropogenic landscape conversions and/or climate changes. This opinion was promoted by absence of some bat

species in early Holocene. According to latest findings in Býčí skála cave (Southern Moravia), not only *P.pipistrellus*, *B. barbastellus, Nyctalus noctula* (Schreber, 1774)*, P. auritus, M. nattereri, V. murinus* and *M. bechsteinii* species occurred in Europe already in Pleistocene/Holocene boundary, but surprisingly also *R. hipposideros*, *M. myotis, M. blythii*, *M. schreibersii*, *R. euryale* and *H. savii* (Horáček et al., 2014). Therefore, assumption that bats were distributed under condition of human impact appears erroneous.

1.3 Echolocation

The development of ultrasonic microphones allows people to hear echolocation calls emitted by bats. These calls are usually in range of 20 – 120 kHz which is generally beyond the range of human hearing, while their audible frequency ends around 20 kHz (Racey, 2015) and this ability decrease with increasing age (Dietz et al., 2007). Echolocation calls can be emitted either from nose (Rhinolophidae) or from mouth of the bats (Vespertilionidae), (Dietz et al., 2007) usually in frequency modulated (FM), constant frequency (CF) or quasi-constant frequency pulses (Lacki et al., 2007). FM calls are short around 2-5 ms, CF pulses lasts for 10–50 ms, having FM component at the end of the call (Racey, 2015). Using different frequencies of echolocation calls among bat species (Ahlén, 1981) is one of the strategies to avoid competing for prey (Dietz et al., 2007). Echolocation also affects ability of bats to forage in differently cluttered space (Norberg, 1994) by different harmonic structure, duration, intensity, range of frequencies and absolute frequency (Fenton, 1990). In cluttered areas are better suitable calls at high frequency (Simmons et Stein, 1980) contrary low frequency calls better suit in open sites (Neuweiler, 1983), (Fig. 1).
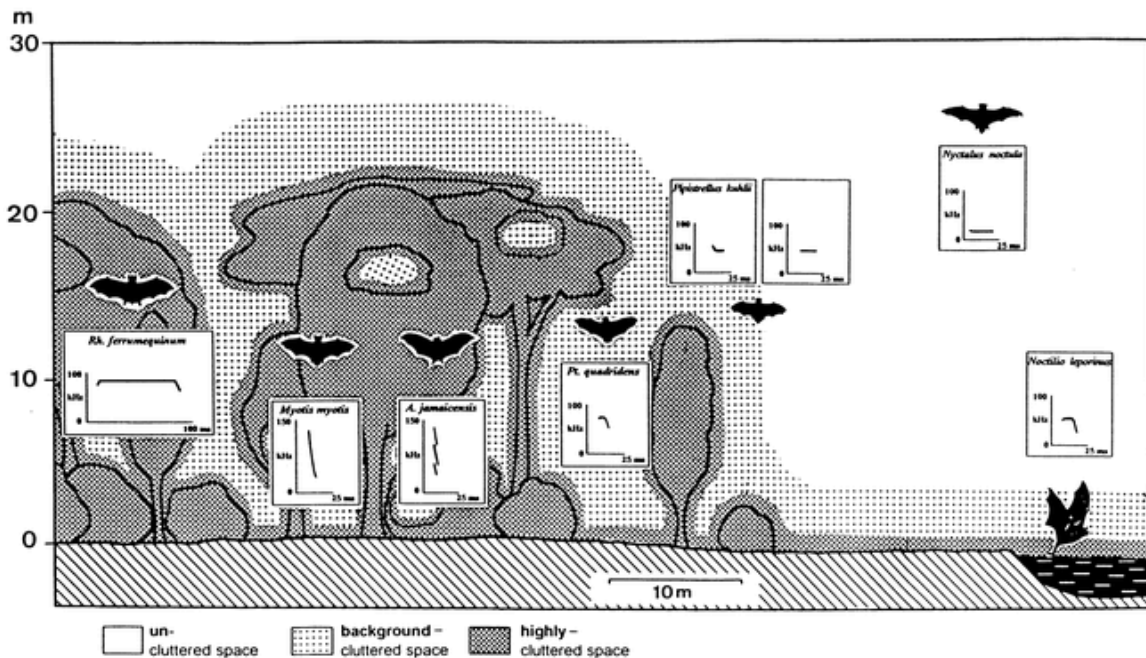
Figure 1. Bats´ foraging habitats according to the clutter situation (Source: Schnitzler et Kalko, 2001).

Echolocation call consists of emitting a sound by bat and listening the echo of reflected wave which comes back from the object. This ability allows bats gain information about the surrounding environment such as the distance from any object, its size, speed, or even texture (Gouge et al., 2015). Closer and closer they are getting to any object, they shorten their signals so the outgoing pulses don´t overlap the returning echoes. By separating pulse and echo in time, they prevent deafening themselves from their own emanated sounds (Racey, 2015), (Fig. 2). Body size and frequency of calls are negatively correlated. Large and fast bats species have usually low frequency of calls. On the other hand, bats with high echolocation frequencies are small and more manoeuvrable (Jones, 1999).
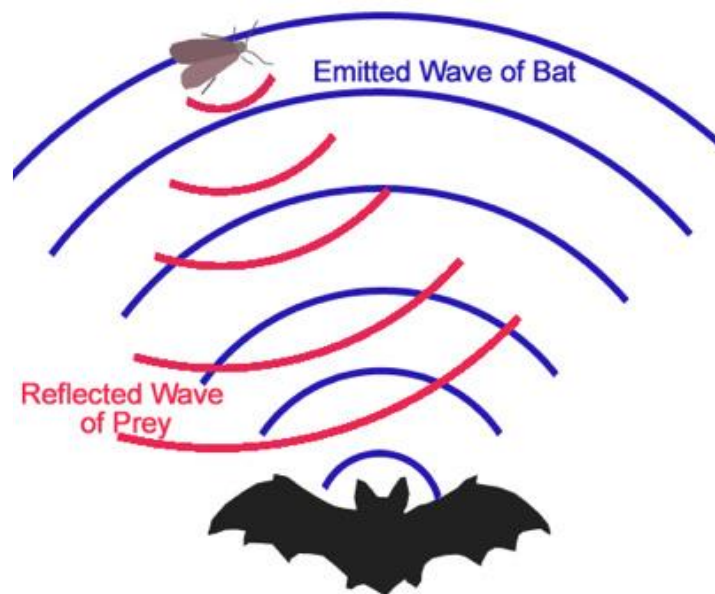
Figure 2. Blue waves represent emitted wave of bat. Pink waves show echo coming from insect (Source: Shung, 2015).

1.4 Flight of bats

Shape of wings differs among bat species and predetermines their hunting strategy, prey selection and habitat selection. Although ability to flight brings many advantages, this kind of move is energetically more costly than terrestrial locomotion (Thomas, 1987). The flight itself requires enough thrust surmount horizontal drag, plus to generate enough lift to overcome gravity (Norberg, 1985). Therefore body mass and wing structure are the most critical attributes.

1.4.1 Shape of wings determines habitat selection

The shape of the wings is directly connected with habitat use. Bats with greater wingspan (usually heavier species) forage in more open and less cluttered habitats (Kalcounis et Brigham, 1995) than bat species with smaller body size, shorter and broad wings but higher capability of manoeuvrability (Aldridge, 1987; Patriquin et Barclay, 2003; Dietz et al., 2006), (Fig. 3, 4). Bat species such as Nyctaloids forage more likely in open areas (Müller et al., 2013), fly faster and dispose of long and particularly narrow wings (Hayward et Davis, 1964; Dietz et al., 2007, Law et al., 2016). Nevertheless this idea cannot be applied to all bat species. Two Californian bat species *Myotis californicus* (Audubon et Bachman, 1842) and *Myotis ciliolabrum* (Merriam, 1886) forage in the same habitat, but they vary ecologically (Constantine, 1998), in skull morphology and even in echolocations calls (Gannon et al., 2001). Therefore plasticity in foraging strategies may be connected with morphological differences without genetic divergence (Lacki et al., 2007). Analogous case how to avoid competition for prey can be observed in morphologically very similar bat species *P. pipistrellus* and *Pipistrellus pygmaeus* (Leach, 1825). The trophic partitioning is connected with different habitat use. *P. pipistrellus* forage in woodlands with low vegetation layer and in understory layer less intensely than *P. pygmaeus* (Lintott et al., 2015). Andreas et al (2013) show another interesting differentiation of trophic niche overlap. Three studied horseshoe bats (*R. hipposideros, R. ferrumequinum and R. euryale*) having similar echolocation parameters, ecology and preferred habitats vary in body size, thus in the size of individuals consumed in their diet. Their niche overlap is therefore low, despite the fact of using same habitat.

Mobility connected with shape of the wings could be predictor of habitat use of some Neotropical bats. Bader et al (2015) found in their study that species with large-

surfaced, broad wings which are less mobile, decrease their occupancy in anthropogenic and open areas, but are widely distributed in forest areas. Therefore they are more vulnerable to deforestation, urbanization and latter extinction (Jones et al., 2003; Safi et Kerth, 2004). Conversely bats with narrow wings show the opposite trend.

1.4.2 Shape of wings determines hunting strategy

Insectivorous bats evolved different hunting strategies to avoid competition for prey. The largest group of insectivorous bats represent so called aerial hawkers (slow or fast). In this group belongs for example *P. pipistrellus* or *N. noctula* (Norberg et Rayner, 1987). These bat species catch their prey during the flight on the wing and usually hunt in open areas. Kalko et al (1996) divided groups of aerial hawkers into three ´´guilds´´ depending on density of the foraging space: a) bats foraging in uncluttered space with no interfering clutter echoes b) bats foraging in background cluttered –near ground, water or in vegetation gaps c) bats foraging in highly cluttered space within the vegetation.

Second foraging method used by bats is gleaning. These bats fly above substrates and grab the prey (e.g. beetles or bush crickets) from the ground such as *M. myotis*, *M. nattereri*, *M. bechsteinii*, *M. emarginatus* or *Plecotus* sp. (Kunz et Fenton, 2003; Ceľuch et Kaňuch, 2004). Group of bats which does not have flight membrane between the hind feet, called trawling bats glean their prey over water surfaces, such as *M. daubentonii, M. mystacinus bulgaricus* (Heinrich, 1936) or *M. dasycneme*. By their hind feet they catch the prey and swallow it directly (Dietz et al., 2007).

Another technology how to catch a prey is simply to hunt from perch which is widely used by *R. hipposideros* and *R. ferrumequinum*, so called perch hunting (Norberg et Rayner, 1987).

Some of the insects invent many defensive responses to batlike ultrasound including changing speed of the flight, direction or cessation of the flight (Kunz et Fenton, 2003).
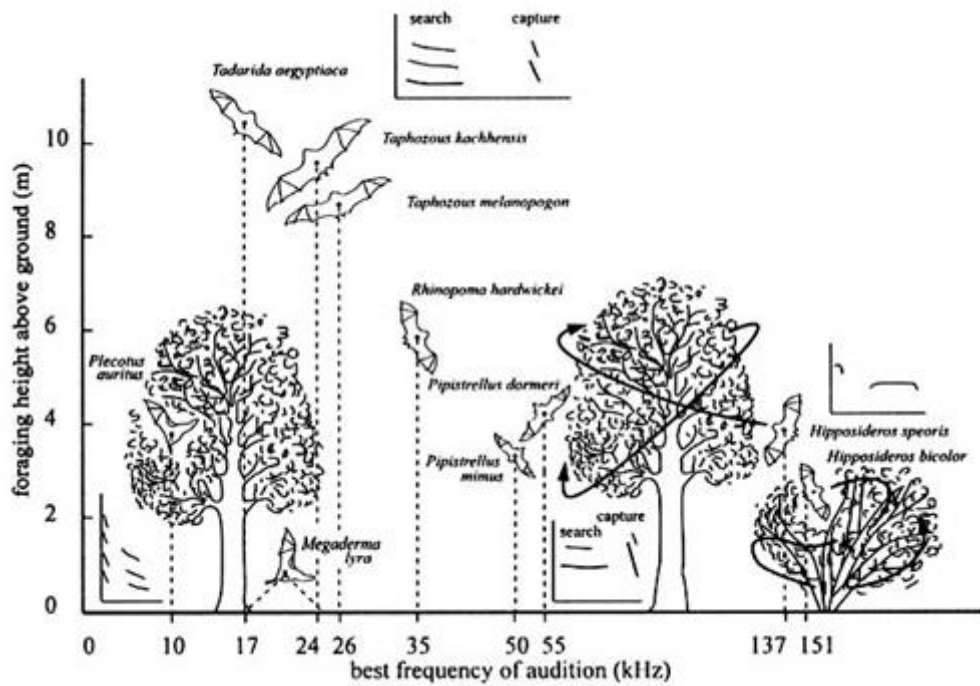
Figure 3. Different bat species show different foraging tactics. Relationship between frequency of audition and foraging height above ground (Source: Neuweiler, 1990).
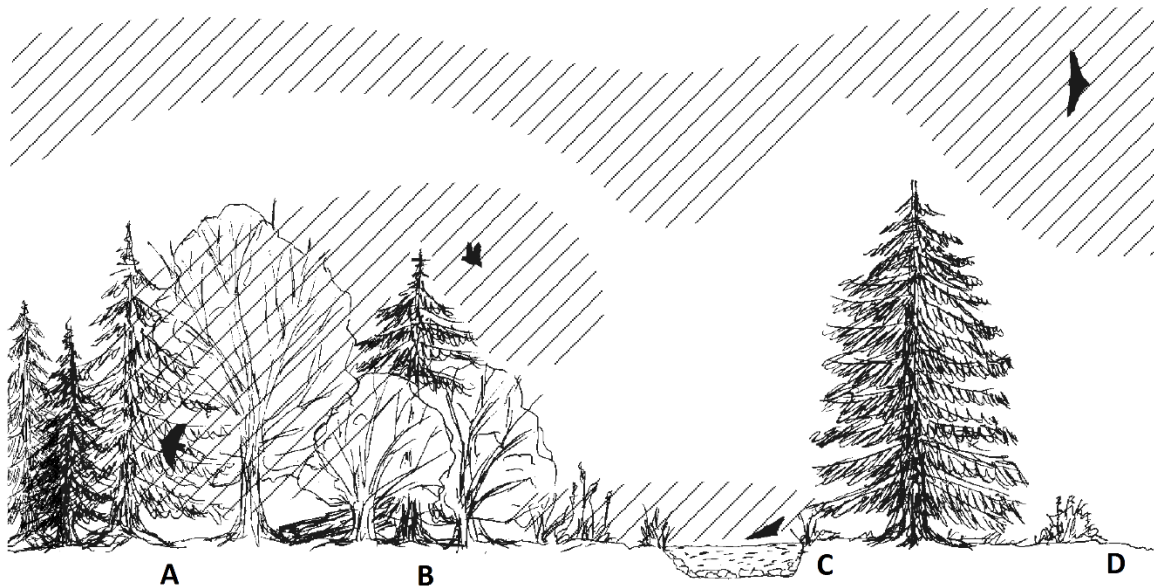
Figure 4. The typical hunting space of selected foraging strategies (A = gleaners, B = slow hawkers, C = trawlers, D = fast hawkers), (Source: Ceľuch et Kaňuch, 2004).

1.4.3 Variables determining flight of bats

There are many aspects determining flight of bats, their foraging strategy, manoeuvrability, speed of the flight or habitat selection (Norberg et Rayner, 1987).

1) <u>Wingspan</u> is a distance between the wingtips of a bat with extended wings.
2) <u>Wing area</u> is combining area of two wings, the entire tail membrane and portion of the body between both wings.
3) <u>Aspect ratio</u> (AR) describes square of the wingspan divided by the wing area. Higher AR corresponds with better aerodynamic efficiency and lower energy losses during the flight.
4) <u>Wing loading</u> (WL) determine speed of the flight and is described as weight of the animal divided by wing area. Bats with narrow wings have always small wing areas and high wing loadings which predicts them to fly fast to obtain sufficient weight support.
5) <u>Tip length ratio</u> is ratio of the length of the hand-wing to the length of the arm-wing which is directly connected to manoeuvrability. For great manoeuvrability the wings of bats should have large wing area, low AR and reduced wingspan.

In case when prediction to response of some species to anthropogenic habitat changes is unclear, it is recommended to use AR and WL indexes (Norberg et Rayner 1987; Bader et al., 2015).

1.4.4 Foraging in cluttered vegetation

The shape and size of the wings indirectly determines foraging habitat of bats (Norberg et Rayner, 1987). Generally, bats with more manoeuvrable but slower flight are able to forage in more cluttered vegetation (*Myotis, Pipistrellus* sp.) than bats (e. g. *Nyctalus* sp.) with faster flight and narrow wings, foraging in more open space (Dietz et al., 2007). Saunders and Barclay (1992) propose that large differences in wing morphology can restrict particular bat species to different foraging areas, but small differences influence just actual type of prey, which is available within the same habitat.

Activity of bats is generally higher in open forests than in cluttered areas (Law et Chidel, 2001), while present physical objects cause reduction of flight efficiency (Jones et Rayner, 1991) and bats foraging closer or within the vegetation have to discriminate

not just echoes of prey, but also echoes coming from unwanted obstacles, so called clutter echoes (Schnitzler et Kalko, 2001). It is generally easier to detect bats in open spaces, because of less amount of cluttered echoes. In study detecting influence of vegetation clutter, Rainho et al (2010) described success in hunting of ground foraging bats. Period of time in which bats catch prey and capture success was decreasing in cluttered vegetation. In dense vegetation bats could detect the prey, but did not strive to capture or if they did, with prolonged delay; the attempts often failed and the vegetation avert them to reach the ground.

Bats foraging near vegetation use broadband FM calls (Neuweiler, 1989) and bats hunting their prey in open areas add longer narrowband component (Kalko et Schnitzler, 1993). Activity is higher on the track, than inside the forest (Krusic et al., 1996; Adams et al., 2009), except bat species which use short-range echolocation calls (*Myotis* sp. and *Plecotus* sp.), (Froidevaux et al., 2016). Adams et al (2009) demonstrate in their study that bats show vertical stratification which varies with respect to echolocation guilds, logging or on/off track location. Bat activity is most noticeable different inside of the forest at the understory/subcanopy level and in old-growth forests. In the strata level the degree of stratification differs mainly in echolocation guild (Froidevaux et al., 2016). In study of Fordiveaux et al (2016) reaserachers showed that despite of high insect presence in the forest understory level, bats activity was low. As expected activity level of ″open space″ bats (frequency range 28 – 34 kHz) was the highest at canopy level of old regrowth forest and bats foraging in high or medium edge space (MES: 39 – 48 kHz, HES: 48 – 54 kHz) were most active at canopy and subcanopy level.

1.5 Habitat preferences of bats

Many studies comparing habitat preferences among European bat species have been already published (Walsh et Harris, 1996a; Zukal et Řehák, 2006; Kaňuch et al., 2008; Ceľuch et Kropil, 2008). Bats generally tend to forage in woodland edges, mixed forests and above many kinds of water bodies (both stagnant and running). Most bats probably select their foraging areas depending on prey availability and habitat structure complexity. Since many species of insects have aquatic larval stage, bats tend to assemblage around water bodies, which becomes important habitat for them (Walsh et Harris, 1996b; Ceľuch et Kropil, 2008; Lesiński et al., 2011). Preferences of bats for woodland sites were described for example by Rachwald (1992) and Clark et al (1993). It is the most biologically diverse system, which offers foraging as well as roosting habitats for bats (Lacki et al., 2007). Vegetation of woodlands and its structure has a great importance in determining habitat quality and availability not just for bats, but for many animal species. There is some evidence for prioritizing stands with domination of certain tree species (Kalcounis et al., 1999). Bats especially try to avoid open and intensively managed areas, roads through coniferous and mixed forests, suburban buildings and arable lands; which can be explained by lower prey availability and restraint of spatial orientation (Ciechanowski, 2015).

1.5.1 Habitat preferences among particular species

There is no any specific habitat which is preferred by all forest-dwelling bats, rather each species select different habitats (Patriquin et Barclay, 2003). For instance bats can prefer one single habitat as in the case of *M. daubentonii* which forages over water bodies; *M. mystacinus/brandtii, E. nilssonii, Nyctalus leisleri* (Kuhl, 1817) and *B. barbastellus* that predominantly forage in forests; *E. serotinus* forages mainly next to villages or even big towns; *P. pygmaeus* dependent mainly on riparian areas (Davidson-Watts et Jones, 2006; Dietz et al., 2007); and *N. noctula* which hunts especially in open areas (Ceľuch et Kropil, 2008).

Some species can use two types of habitats at the same time, for example *M. myotis/oxygnathus* having close affinity to meadows and linear landscape features. Some other bat species don't cling exactly to just one particular habitat, such as *M. emarginatus, V. murinus, P. auritus/austriacus*, *M. nattereri,* and *P. pipistrellus* (using different kinds

of forests, parks, orchards and water bodies), (Bogdanowicz et Ruprecht, 2004; Zukal et Řehák, 2006; Dietz et al., 2007).

M. bechsteinii occurs in high altitudinal range from lowlands up to mountains in deciduous, mixed or even pinewood forests (Albrecht et al., 2002; Dietz et al., 2007). *P. nathusii* prefers forests from lowlands, riparian areas and parks and it is known their occurrence in built-up areas like in case of *P. kuhlii* with even higher synanthropic bound. Nevertheless habitat is not the most important variable affecting bats activity. More valuable seems to be prey availability (Kusch et al., 2004).

1.5.2 Sharing habitat with people

Using same type of habitat as human has its advantages. Higher insect activity around street lamps (Rydell, 1991), over fresh-moved grass areas (Catto et al., 1996) or around garbage bins (Kronwitier, 1988); more woodland edges in urban areas, than in rural areas or higher roosts site availability (Jung et Kalko, 2010). Study of Jung and Kalko (2010) shows that adaptation to anthropogenically altered environments has great potential among aerial insectivorous bats with species specific tolerance. In their study, bats showed the highest presence on a border where mature forest met human settlements. Even though bats prefer diversified landscape habitat their density is lower inside cluttered forests and in opened landscapes (Kusch et al., 2004).

1.5.3 Other variables

Regarding altitude, bats activity in Central Europe is higher in areas with lower altitudinal range (under 300 m a.s.l) such as: thermophilous oak, floodplain and pine-, oak-hornbeam- and lowland beech forest and spruce plantation. Activity in alpine forests, above 700 m a.s.l., show lower bat activity with scarce presence in mountain spruce forest (Řehák et al., 2007).

Moreover, habitat preferences of the same bat species have different patterns within the same continent. Western Europe influenced by oceanic climate, having the highest anthropogenic transformation, shows different habitat preferences among species than result in Central or Eastern Europe (Vaughan et al., 1997; Ciechanowski, 2015).

Ceľuch et Zahn (2008), show in their study how bats use habitat size depending on prey availability or temperature. In many situations bats prefer smaller foraging areas rather than extensive ones, even though they spent more time in larger one.

Response of insectivorous bats to urbanisation in the Americas is showing significant negative effects, otherwise insignificant results are found in the same situations for Europe, Asia and Australia. Globally bats from the family Vespertilionidae show higher association with natural habitats in the Americas, but there is no such interrelation in European, Asian and Australian vespertilonid bats (Jung et Threlfall, 2016).

1.6 Fragmentation

Process of fragmentation is described as an increase number of forest edges towards decreasing area of interior forest. The process itself can have three components. 1) overall habitat loss, 2) reduction of the size of habitat and 3) increasing habitat isolation (Bennet, 2003).

1.6.1 Factors affecting fragmentation

Yet the effect of fragmentation on bat population depends on many factors. Such as: a) ecological capacity to cross deforastated areas and ability of animals to exploit newly incurred habitats, b) constitutions of matrices in affected areas and their possible benefits for the animals c) the origin of the fragmentation process, its characteristics and time horizon (Bernard et Fenton, 2007). Therefore response of bats to fragmentation differs among species and continents. In the Neotropics, response to fragmentation is negative in case of gleaning animalivorous bats (Meyer et al., 2008; Farnenda et al., 2015) and some forest-dependent aerial insectivores (Estrada Villegas et al., 2010), conversely nectarivorous and frugivorous bats increase their abundance in some fragmented landscapes (Delaval et Charles-Dominique, 2006).

1.6.2 Fragmentation in tropical areas

In tropics, fragmentation which is connected with loss of habitat is found everywhere. These interventions in forest habitat is mainly result of human impacts which include logging, increasing agricultural land and plantations, burning of large forest areas, forest clearance or agroforests constructions (Tilman et Lehman 2001; Gardner et al., 2009; Chazdon, 2014). In Asia, Australia and Indo-Pacific region is deforestation the greatest factor in declining of population of megachiropterans (Utzurrum, 1998). In big imminence are especially bats living on islands such as pteropodids facing threat from mangrove forests destruction (Robertson, 1992).

Worldwide the forest systems were harshly affected by loss of habitat and forest cover has been reduced by ca. 50% (Groom et al., 2006), (Fig. 5). In some areas (e.g. Mexico) human interventions resulted in loss of 80 – 90% of forested landscape changed to cattle pastures. Remained land consists of fragmented patches of various size (Estrada et Coates-Estrada, 1988). These patches are strongly vulnerable to edge effects (Ribeiro

et al., 2009), resulting in systematic changes in abiotic and biotic variables. Nevertheless, these created forest edges can exhibit higher activity of bats, than activity in the interior of the forest (Ceľuch et Kaňuch, 2004; Jantzen et Fenton, 2013).

Additionally forest interior species often roosting in trees are more vulnerable to forest fragmentation, than species occupying the edges (Meyer et al., 2008). Incurred forest corridors can be very useful for bats. They provide connection for foraging bats to isolated forest patches (Estrada et Coates-Estrada, 2001) and during high wind speed bats incline to forage closer to tree lines (Verbroom et Spoelstra, 1999).

1.6.3 Species response to fragmentation

Even though high mobility of insectivorous bat species allow them to move between habitats and better tolerate fragmentation and urbanization changes (Avila-Flores et Fenton, 2005; Ethier et Fahrig, 2011), certain species especially in tropical rainforests are sensitive to landscape changes (Meyer et al., 2008). The large distances that bats have to travel between roosts and foraging habitat have direct impact to energetic costs (Jones et al., 1995). This could be a reason why bats with high wing loading, which forage in open areas are capable of travelling larger distances, thus they are less affected by fragmentation than forest species with lower wing loading, lower aspect ratio, higher manoeuvrability and slower flight. These facts make them less capable of long flight and therefore more prone to disappearance, due to fragmentation of the landscape (Estrada-Villegas et al., 2010). Generally vulnerable are especially species that have small geographic ranges, those with specialized food preferences and even bats who have large ranges, but change their foraging and living area quite often and move to places with diffuse or depleted resources (Kunz et Reynolds, 2003).

Frey-Ehrenbold (2013) found out that for bats is more crucial, how is area covered by particular vegetation structures and whether suitable elements are connected - allowing to exploit resources, more than pattern of landscape shape (linear or patchy). Equally, even relatively small fragments of woodland may offer many roosting opportunities, resulting in increased populations of many species. Even more in case of relatively close fragments with high structural diversity (Estrada et Coates-Estrada, 2002; Boughey et al., 2011).

Annual change in forest area (1990-2015)

1000 ha

Net gain
- 50 - 250
- 250 - 500
- >500

Net loss
- >500
- 500 - 250
- 250 - 50

Small change (gain or loss)
- <50
- No data

FAO, 2015. Global Forest Resources Assessment. FAO, Rome

Planted forest area change (1990-2015)

1000 ha

Net gain
- 50 - 500
- 500 - 5000
- 5000 - 10000
- >10000

Net loss
- 500 - 50

Small change (gain or loss)
- <50
- No data

FAO, 2015. Global Forest Resources Assessment. FAO, Rome

Figure 5. Maps show annual change in forest area and newly planted area between years 1990 – 2015. This may indicate inadequate reforestation in the most deforestated regions of the world (Source: FAO, 2015).

1.7 Types of roosts

There are many types of roosts used by bats: caves, trees, mines, crevices, bunkers, buildings etc. Their importance is critical. Roosts are used not just as shelter from elements, but also as refuge from predators, place for hibernation, mating, raising new born young, place to stay when bats are digesting their food during night or as a place for social interaction among individuals (Ormsbee, 1996; Kunz et Lumsden, 2003; Horáček et Jahelková, 2005).

Especially bats in tropical areas exploit many kinds of roosts which provide them crucial benefits for their living, such as bird nests (Schulz, 1977) bamboo culm (Kofron, 1994), roosts in foliage (Tan et al., 1997), in furled leaves (Findley et Wilson, 1974) and in termite and ant nests (Kalko et al., 1999).

Because of high energy costs of flying (Speakman et Thomas, 2004), bats leave their roosts to forage just if it is beneficial for them usually in some threshold level of prey abundance (Avery, 1985; Rydell, 1989). During cooler nights bats tend to leave the roosts later (O'Shea et Vaughan, 1977) and during extreme values of temperature bats do not leave their roosts at all.

1.7.1 Caves and mines

Caves and mines are great shelters not just because of their constant temperature (Sedgeley, 2001), but also because of the dark, which makes it harder for predators to find their prey. In Central Europe caves are usually used during winter time. Bats are mostly found on the walls, ceilings or deep crevices (Roer et Egsbaek, 1966). Especially at the beginning or at the end of hibernation time bats go for a hunt, thus change their positions in such roosts. In summer time caves and mines are not so widely used, because of its cooler temperature (Dietz et al., 2007). In Paleotropics bats that roost in caves are less prone to fragmentation, than bats which roost in tree cavities (Struebig et al., 2008).

1.7.2 Trees

Typical roost for forest bats would probably look like this: tall tree, located in stands with open canopy, close to water resource with high amount of dead trees nearby (Kalcounis-Rüppell et al., 2005). However each bat species have different requirements for roosts and there is not always possibility to find exactly this kind of roost.

Holes in trees usually made by woodpeckers, rotted holes caused by dampness or fungal infection; or cavities as results of lightning strikes, fire or natural damage to branches are widely used by many bat species (Bennet et al., 1994; Dietz et al., 2007; Lučan et al., 2009a). Size of the cavity as well as its shape can determine bats presence, microclimate of the roost and social structure of the community (Kunz, 1982). Bats prefer dying trees (Fig. 6) because of their lower water content (Maeda, 1974), with large diameter at breast height; trees in different stage of decay, in mature or old stands, and comparatively open forest stands (Vonhof, 1996; Crampton et Barclay, 1998; Ruczyński et Bogdanowicz, 2008; Horáček et Uhrin, 2010). Greater selection for higher trees was described by many researches. Higher trees are older, provide more cavities, thus more roosting opportunities (Evelyn et al., 2004), and their stem and bark are thicker so insulation is greater (Rabe et al., 1998). They are accessed and detected easier, because of their higher canopy and they receive higher solar radiation, therefore decrease thermoregulatory costs for reproductive females (Vonhof et Barcley, 1996; Brigham et al., 1997). Generally bats do not discriminate between species of trees, rather choose trees based on cavity characteristics associated with concrete species (Sedgeley et O'Donnell, 1999). Reproducing females who need warmer conditions for lactation and/or pregnancy influence their choice on the fact in which direction is situated the roost entrance (Russo et al., 2004).

In tropical or temperate zone forests basal tree cavities may arise in the interior of the trees after exposed fire in the heartwood. Such cavities provide stable humidity and temperature, protection from weather elements, clear light gradients and large internal space (Gellman et Zielinski, 1996). Bats living in rock or tree crevices usually search for the narrowest cracks just as size of their body, with small cavity openings to mitigate predation risk (Campbell et al., 2005). However in tropical regions or in areas with low predator occurrence size of the cavity openings seems to be not that important since some species roost in large basal openings (Wilkinson, 1985; Fenton et Rautenbach, 1986). Equally, thermal constraints in tropical regions are lower than in temperate zones, where bats choose well-insulated cavities for their thermoregulatory advantages (Kunz et Fenton, 2003).

Figure 6. Dead tree inhabited by Indiana bat (*Myotis sodalis*), (Miller & Allen, 1928). (Source:http://plateauecological.com/services/indiana_and_northern_long-eared_bat_consultation).

1.7.3 Manmade constructions

Due to increasing urbanization, bats use more and more roosts in buildings, stables or other man-made constructions (Gaisler et al., 1998; Voigt et al., 2016). Buildings offer several possible opportunities for roosting (Fig. 7). The expansion of people and their dwellings in last decades allow many bats to enlarge their geographic range as well as increase their abundance (Kunz, 1982). Especially in Western Europe and North America natural habitats are under permanent pressure, such as clearings of forests without sufficient management practices. This leads to tree cavities depletion and removing of bats to manmade structures (Kunz et Reynolds, 2003).

For pregnant and lactating females buildings allow larger aggregations of individuals. This leads to reduction of energetic costs to maintain high body temperature during the day for females and during night for young, while mothers are foraging (Lausen et Barclay, 2006). Females can avoid unnecessary energy expenses such as prolonged gestation (Racey, 1973), reduce the milk production (Wilde et al., 1995) or resorting the torpor (Lausen et Barclay, 2006). Conversely males and non-reproductive females search for roosts at cooler sites in temperature which allows entering torpor, thus saving energy expenditure (Kerth et al., 2000). Finally bats living in buildings exhibit different ectoparasites load than bats living in caves (Lausen, 2005).

Places that bats may use in buildings

1 Barge board
2 Roofing felt
3 Roof joists
4 Ridge tiles
5 Soffit
6 Attic
7 Lead flashing
8 Dormer window
9 Coping stones
10 Gable end
11 Valley
12 Broken tiles
13 Space between downpipe
14 Metal elements on balconies
15 Sash window
16 Loose mortar between bricks
17 Quoins
18 Wood cladding
19 End tiles
20 Fascia board
21 Eaves
22 Guttering
23 Window sill
24 Porch
25 Hanging tiles
26 Cellar

15mm

0   10   20mm

A pipistrelle can use a hole
this size to enter a building

Figure 7. Possible places which bats may use in buildings. (Source: http://www.bats.org.uk/pages/living_with_bats.html).

1.7.4 Roost fidelity

Bats shifts their roosts quite often (Lausen et Barcley, 2006). Especially when we talk about tree roosts. We can divide bats into three groups depending on the roost fidelity. The first group of bats (*M. daubentonii*, *B. barbastellus*, *N. noctula*) shifts their roost every 1 – 2 days. The second group of bats (e. g. *Nyctalus lasiopterus* species (Schreber, 1780) shifts their roost every 3-10 days and the third group of bats includes species that stay in their roosts for more than 10 days (group of Phyllostomidae, species of bats living in Central America), (Kunz et Fenton, 2003; Russo et al., 2007). Different tendency is seen in case of lactating females. They typically shift their roosts less frequently than nonbreeding individuals. This could reflect the energetic costs, which is connected with moving of nonvolant young between the roosts (Menzel et al., 2001). In some cases bats can stay in their roosts for many years until the time, when old cavities become unavailable (Lučan et al., 2009a). Substitute roosts are usually nearby (Dietz et al., 2007) and reasons why bats change their roost are mentioned in study of Lewis (1995). E.g. microclimate advantages, parasites avoiding, social interactions, different gender demands or competition for space. Bats can also switch their roost in response to

unexpected factors such as disturbances by predators (Sparks et al., 2003), destruction of roosts caused by storms or strong wind (Gardner et al., 1991, Willis et al., 2003), high water level blocking the cavity (Hofmann et al., 1999) or undesirable human interventions (Belwood, 2002). The whole bat colony can even disperse from roost when young become volant (Lacki et al., 2007).

1.7.5 Colony size

Number of animals in roosts varies considerably among species. Many species usually form groups of small colonies about 10 individuals, but there are known also colonies about 4 500 animals in single tree (Lloyd et McQueen, 1997). Colony size can reflect the social structure such as monogamous pairs or harem formation (Morrison, 1979; Vehrencamp et al., 1977).

1.8 Natural history of studied species

1.8.1 *Myotis* species:

M. daubentonii is typical trawling bat with broad wings, foraging near water and forest areas. The diet is composed from newly emerged aquatic insects, non-biting midges and other Diptera, larger moths and even small fish (Flavin et al., 2001; Dietz et al., 2007). They usually form nursery colonies in tree holes or manmade bat boxes. Bridges provide possible roosts for nursery colonies as well as for male groups. During winter time *M. daubentonii* hibernate in caves, cellars, bunkers or mines and in tree holes or rock crevices (Dietz et al., 2007; Lučan et al., 2009a). Covering 62. 6 % of the Czech Republic makes it one of the most abundant bat species, with mean altitude of localities from 200 – 800 m a. s. l. (Horáček et Uhrin, 2010).

M. brandtii is strongly linked to forest and water habitats. It is aerial-hawking bat with broad wings and very agile flight. *M. brandtii* usually feeds on moths, spiders and Diptera. They roost during summer in trees, behind raised bards, in roof spaces, bat boxes or trunk cracks. Changing of tree roosts is common (Dense et Rahmel, 2002). Roosts in buildings are often situated near forest edges (Sachanowicz et Ruczynski, 2001). During winter *M. brandtii* roosts mainly in caves or mines (Dietz et al., 2007). Comparing to *M. mystacinus* its occurrence is two times less frequent (25. 8 % of the territory of the Czech Republic), (Horáček et Uhrin, 2010).

One of the most common bat species *M. mystacinus* exhibits its occurrence on 51. 1 % of the area of the Czech Republic. In Central Europe it use to inhabit semi-open landscapes with isolated patches of woodland and is frequently found in villages. *M. mystacinus* has broad wings and dispose with high manoeuvrability. Prey can be caught in air and also collected from surface. The majority of food consists of flying insect, moths or Hymenoptera and lacewings (Rindle et Zahn, 1997; Dietz et al., 2007). Most of monitored localities are in altitude 200 – 1,000 m a. s. l. (Horáček et Uhrin, 2010). Summer roosts of this species are situated in window shutters, hunting towers or different types of cracks or gaps. During winter period bats inhabit mines, mountain cellars, caves or crevices (Dietz et al., 2007).

Myotis alcathoe (von Helversen et Heller, 2001) inhabits deciduous forests, mountain forests or riparian areas. It is aerial hawking bat with broad wings, hunting

usually in dense vegetation; along structured edges or over water areas. Diet is composed from Diptera. This bat species is usually found in protected areas without human intervention (Dietz et al., 2007). They prefer oak-hornbeam forests with trees under decay. Occurrence in Czech Republic constitute around 1. 8 % of the territory (Horáček et Uhrin, 2010).

M. emarginatus conversely to *M. alcathoe* roosts during summer in churches, cattle stables or houses (Richarz et al., 1989). Places are more likely bright (Gaisler, 1971). During hibernation they stay in underground (Dietz et al., 2007). Even though *M. emarginatus* was until now found in 30 % of the Czech Republic recent findings in central Bohemia show gradual spreading over all of the Czech Republic (Horáček et Uhrin, 2010). Foraging areas are multistratified, mostly forest habitats close to meadows, fruit trees, cattle sheds and parks, with avoidance of open areas. *M. emarginatus* hunt within the canopy or close to vegetation and collect insects from the leaves. Such as spiders, lacewings or moths (Brinkmann et al., 2001; Dietz et al., 2007).

M. nattereri is very variable in habitat use. In Central Europe shows affinity to forests, areas along water sides and open woodlands. *M. nattereri* has broad wings, it can fly very slowly, close to vegetation and with high manoeuvrability. It is typical gleaner bat, picking its prey (spiders, harvestmen, flies; seasonally also moths and beetles) from leaves. The most inhabited summer roosts by *M. nattereri* are tree holes, empty bricks of non-plastered buildings or bat boxes. During winter they are hiding in ground rubble, rock crevices, caves or underground corridors (Siemers et al., 1999; Dietz et al., 2007). In total they were so far found in 40. 6 % of the Czech Republic mainly in altitude from 200 – 600 m a. s. l. (Horáček et Uhrin, 2010).

M. bechsteinii lives mainly in deciduous and mixed woodlands. Animals are forage gleaners with broad wings, hunting close to vegetation. They are capable of grabbing their prey from the substrate. Diet is composed of non-flying insects and arthropods (Wolz, 2002; Dietz et al., 2007). *M. bechsteinii* roosts often in bird boxes or trees with height of entrance in 1-5 meters. Selected trees are usually deciduous, large, located farther from human activities, close to water (Napal et al., 2013). During winter they can move to underground roosts or stay in trees; beneath the bark, in branch crevices but mainly use holes made by woodpeckers (Dietz et al., 2007; Napal et al., 2009). It´s occurrence in the Czech Republic is in 135 mapping squares, representing 21. 7 % of the

territory of Czech Republic, with greater abundance in Moravia. Most of the records are from altitude from 200 – 800 m a. s. l. (Horáček et Uhrin, 2010).

M. myotis is typical (ground) gleaner bat with broad wings. The flight is rapid, usually conducted at low height. Since the prey is often grabbed from substrate they cannot detected them by echolocation. Therefore they are dependent in many cases on the rustling sounds emitted by prey (Siemers et Güttinger, 2006). *M. myotis* shows in the diet preference for loudest-rustling species of beetles, arthropods, spiders and larvae of beetles. They show close affinity to different forest types, meadows, pastures and freshly mown fields (Dietz et al., 2007). In Central Europe is *M. myotis* known as typical roof-dwelling species (Güttinger et al., 2001). In case of losing original roost we can find them in bridges or cellars. For winter hibernation they move to caves, bunkers, mountain crevices or mines (Dietz et al., 2007). With 484 mapping squares, representing 77. 1 % of the territory of Czech Republic *M. myotis* is one of the most abundant bat species. Their occurrence covers places from lowlands up to hilly mountains with altitude from 100 – 1,180 m a. s. l. (Horáček et Uhrin, 2010).

1.8.2 *Nyctalus* species:

All *Nyctalus* species have narrow wings, direct and fast flight and they like to forage in open space or on the tree canopy level. The diet consists of Diptera, beetles, moths and bugs. Many years ago were found bird remains in faeces samples of *N. lasiopterus* (Dondini et Vergari, 2000; Dietz et al., 2007). *N. noctula*, *N. lasiopterus* and *N. leisleri* roost in tree holes, in crevices, rotted holes, bat boxes or branch crevices made by lightning. *N. noctula* chooses roosts sites near forest edges, usually in beech forests, and their nursery colonies are often found in buildings. During winter bats stay in tree holes or move to rock crevices, caves or buildings. *N. lasiopterus* is usually found in mixed or deciduous forests, *N. leisleri* in beech or oak forests (Dietz et al., 2007). Ruczyński et Bogdanowicz (2005) compared in their studies roosting preferences of *N. noctula* and *N leisleri*. Both species preferred dry cavities located higher on the tree, in open surroundings, with NE or SW location and with smaller entrances. The main difference is the origin of the roost. *N. leisleri* prefers in 90% natural cavities than those made by woodpeckers, conversely *N. noctula* shows the opposite tendency. *N. noctula* is among *Nyctalus* species the most abundant. Occurrence in 1,000 localities makes it in total 53. 8 % of the territory of the Czech Republic. *N. leisleri* was located in 132 localities

(15 % of the Czech Republic) with preference of lower and middle elevations. The least frequent species *N. lasiopterus* was found only in 3 quadrats; in elevation from 103 – 760 m a. s. l. (Horáček et Uhrin, 2010).

1.8.3 *Eptesicus* species:

E. serotinus is found in Central Europe in almost all kinds of habitats, with just low dependence on forests. *E. serotinus* has rapid and agile flight; and animals often forage close to streetlamps, near human settlements. *E. serotinus* uses as a summer roosts roofs, bat boxes or tree holes. In the buildings they find places such as claddings or gutters, drill holes, places under roof ridges, in ventilation shafts or in wall cracks. During winter majority of bats stay in roof space or move to rock crevices (Dietz et al., 2007). This species was already found in the Czech Republic in almost 1,000 localities, covering 57 % of the total surface area. *E. serotinus* prefers lowlands and hilly landscape showing strong synanthropic linkage. Mean elevation varies between 200 – 600 m a. s. l., up to 1,090 m (Horáček et Uhrin, 2010).

E. nilssonii is typical bat of mountain and boreal forests. Animals catch their prey (Diptera, Nematocera) along vegetation edges and open areas. Flight is agile and rapid. Nursery colonies are found in roofs, often covered by sheet metal or wall linings. (Dietz et al., 2007). *E. nilssonii* frequently roosts with other species of bats (*E. serotinus* or *P. pipistrellus*), (Rydell, 1986). Tree holes and bridges are also used for roosting, frequently by single animals (Van der Kooij, 1999). In winter they stay in buildings or move to caves, bunkers or rock crevices (Dietz et al., 2007). Its occurrence is on 231 quadrats which represents 36. 8% of the Czech Republic (Horáček et Uhrin, 2010).

1.8.4 *Plecotus* species:

P. auritus is typical forest bat. Two foraging tactics are observed in both *Plecotus* sp. (aerial-hawking and gleaning). The broad wings with short broad hand-wing membranes allow animals to fly slowly and hover above the ground. The diet consists mainly from moths and additionally from Diptera, bugs and grasshoppers. In summer *P. auritus* uses roosts in buildings such as battens, behind claddings, mortises and timberwork places or stay in any kind of tree spaces such as rotten holes, holes made by woodpeckers or in bat boxes. During winter bats stay in rock crevices, caves or tree holes (Dietz et al., 2007). *P. auritus* is distributed all over Czech Republic. Findings cover

around 67. 5 % of the territory. Its absence is in agriculture lands of south Moravia and along Labe river in Bohemian tableland same as *P. austriacus* (Horáček et Uhrin, 2010).

P. austriacus does not show such close affinity to forest sides as *P. auritus*, but is observed also near villages, gardens or warm valleys. In the diet we can find more flying insects, than in case of *P. auritus*. *P. austriacus* use the same summer roosts as *P. auritus*, but changes them more often. During the summer they are contrariwise found in roofs, which they occupied also during summer (Dietz et al., 2007). *P. austriacus* is less ecological tolerant than *P. auritus,* but its occurrence is even though 62. 9 % of the Czech Republic. Altitudinal distribution range is from 200 – 600 m a. s. l. (Horáček et Uhrin, 2010).

1.8.5 *Pipistrellus* species:

P. pipistrellus is synanthropic species which is often found during summer in crevices of buildings, under roof covering or in tree barks. During winter animals hibernate in buildings or they are found in rock crevices. They have narrow wings and their flight is agile and erratic. Majority of the food are Diptera and other flying insect, which animals hunt in wide range of habitats (Dietz et al., 2007). *P. pipistrellus* was found in 309 localities which is about 24 % of the Czech Republic (Horáček et Uhrin, 2010).

Even though *P. pygmaeus* is more associated with riparian forests; summer and winter roosts are the same as in case of *P. pipistrellus* (Häussler et al., 1999; Dietz et al., 2007). *P. pygmaeus* has narrow wings and very agile flight. Prey is caught near vegetation or small water bodies. The diet is very similar to diet of *P. Pipistrellus* (Dietz et al., 2007). *P. pygmaeus* occurrence in the Czech Republic is dated from year 2000, when *P. pygmaeus* was morphologically separated from *P. pipistrellus* as a different species. *P. pygmaeus* is documented in 13. 7 % of the territory of the Czech Republic (Horáček et Uhrin, 2010).

Pipistrellus nathusii (Keyserling and Blasius, 1839) is closely associated to many kinds of forests habitats. Their wings are narrow and flight is direct, often along linear structures. Diet is composed mainly from Diptera. *P. nathusii* roosts usually in tree crevices, bird boxes, rock crevices or tree holes. Hibernation take place in trees, buildings or cliffs (Dietz et al., 2007). As a migratory species its occurrence in the Czech Republic

is rather seasonal. Founded in 232 localities, with high altitude range from 140 – 1,000 m a. s. l. (Horáček et Uhrin, 2010).

P. kuhlii is very synanthropic species, often found in cities. The flight is very manoeuvrable and agile. Typical is foraging in circles around streetlamps. Diet is very similar to all mentioned *Pipistrellus* species (Hymenoptera and Diptera). As other above described *Pipistrellus* species, *P. kuhlii* is aerial-hawking bat. Primary roosts for *P. kuhlii* are cliffs, building´s gaps, window blinds or roofs. In winter time we can find them in buildings, expansion joints or rock crevices (Dietz et al., 2007). Findings in the Czech Republic shows just 5 mapping squares in altitudinal range 102 – 160 m a. s. l. (Horáček et Uhrin, 2010).

1.8.6   Other species

B. barbastellus inhabits wide range of forests, gardens close to forests or hedges. They have broad wings and very fast and agile flight. *B. barbastellus* catches the prey near vegetation, close to the tree canopy (Sierro et Arlettaz, 1997). The diet is composed of moths, beetles, flying insects and Diptera (Sierro, 2003). Animals roost during summer in tree cracks, bat boxes and behind loose barks (Fig. 8), but can be found also in buildings or timber claddings. During winter they hibernate behind the bark or move to caves, mines, ruins or railway tunnels (Dietz et al., 2007). This bat species was already found in 700 localities with majority altitude range from 200 – 600 m a. s. l. (Horáček et Uhrin, 2010).

Figure 8. Suitable roosting site for *B. barbastellus* and other tree-dwelling species. (Source: http://www.bedsbatgroup.org.uk/wordpress/?page_id=1450).

V. murinus has very rapid flight and narrow wings, same as *Nyctalus* species. It is aerial hawker, foraging in height 10 – 40m. Preferred habitats are water bodies, meadows or areas close to human settlements. *V. murinus* roosts usually in manmade buildings such as barns, low-rise houses, in roof crevices, in window shutter boxes as well as in rock crevices or mountain refuges (Baagøe, 2001; Hermanns et al., 2001). During hibernation bats stay in buildings (Dietz et al., 2007). The overall occurrence in the Czech Republic is in 178 mapping squares which is around 28. 7 % of the territory (Horáček et Uhrin, 2010).

1.9 Conservation of bats

Besides many, lack of information and knowledges regarding bat conservation has resulted in declining bat population in the past. Conservationists, same as other people, should understand that every conservation strategy step has to be done with considering the seasonal and geographical variation (Racey, 1998). For good management plans and conservation policies are crucial information such as current status of bat population, its distribution, structure and population trends; identification and preclusion of potential threats; determining factors which are essential for continuing of persistence of species e.g. home range size or roost requirements (Kunz et Fenton, 2003). Effective and appropriate conservation should be done with respect to all species inhabiting particular area, not to target only one species and ignore others (Kunz et Fenton, 2003). Many temperate zone bats change their roosting sites in accordance to season (for details see chapter Roosts). Thus there has to be protection of summer roosts as well as winter roosts. Bats can be used as an example applicable to conservation of other animal taxa due to facts that bats are migratory species; we know their habitat and roosts preferences as well as their foraging strategy and thanks to many recent studies about bat conservation and protection.

1.9.1 Habitat and roosts protection

Some bat species are strongly selective for roosts which they inhabit. Observation of *Chalinolobus tuberculatus* (Forster, 1844) showed that just 1. 3 % of trees is suitable for bats as a roost (Sedgeley et O'Donnell, 1999). Since bats change their roosting sites quite often, higher number of suitable trees is required (Kerth et al., 2000; Lausen et Barcley, 2006). Thus not just habitat, but in many cases even single trees are important for bat survival and overall bat conservation. Unfortunately management of forest landscape in past many years is hard to schedule with harvesting plans. Bats living in temperate zones show their preference for old-growth forest stands than young or logged forest areas. Nevertheless bat activity can be higher in thinned forests which offer open-air areas and gaps (Humes et al., 1999). Thus logging and overall tree clearance has to be done with proper management which follow requirements of animals (Voigt et Kingston et al., 2016).

Other good step in conservation of bats is to increase potential roosting sites if the precedent roosts are no more tenable or irretrievably destroyed. Construction of bat boxes (Fig. 9) or providing roosting sites in buildings can be solution (Swift, 1998). Boyd et Stebbings (1989) published study on population of *P. auritus*. In 10 years long study they showed importance of bat boxes mainly in establishment of population. Immigration accounted just small part of the results, but overall population increased almost twice, from 73 animals to 140.

Figure 9. Ideal bat boxes exploited by *Nyctalus* sp. (Source: https://www.gardenature.co.uk/bat-box-1ff).

1.9.2   Human interventions

Changes in habitat structure, which is affected mainly by human interventions, led to worldwide shifts in use of land. Lands under cultivation are strongly avoided by vespertilionid bats (Walsh et Harris, 1996b). Bat population near intensively farmed areas result in declining numbers, lower body mass and higher burdens of organochloride and cadmium in their bodies (Gerrell et Lundberg, 1993). Replacing intensive farming/agriculture for organic farming might lead to an increasing of bat activity in the area as a consequence of the reduction on the use of agrochemicals, which have proved to decline their populations (Wickramasinghe et al., 2003). Urbanization as a result of habitat degradation yet offers many roosting sites in buildings for house-dwelling bats or roosts in trees in adjacent parks and gardens (Sazima et al., 1994).

1.9.3 Wind power plants

Incoming new trend in the field of alternative energy brings new threat for bats. Deaths of bats in turbines recorded in 18 European countries during years 2003–2013 involved in total 5,626 bats of 27 species (Rodrigues et al., 2014). With increasing number of wind turbines increase also number of bat fatalities. Bats are in even greater risk than birds because the death is caused not just from injuries, but also by barotrauma (Baerwald et al., 2008), which is described as ″tissue damage to air-containing structures caused by rapid or excessive pressure change; pulmonary barotrauma is lung damage due to expansion of air in the lungs that is not accommodated by exhalation″ (Baerwald et al., 2008). The major fatalities occur in late summer and autumn time of the year, when lots of bats migrate (Arnett et al., 2008). Bats response towards dangerous situations vary depending on the species wing shape, foraging strategy and behaviour (Rydell et al., 2010). At the highest risk are species *N. noctula*, *Pipistrellus* sp., or *V. murinus*, in medium risk are *Eptesicus* sp. and *B. barbastellus* and lowest impact seems to be in *Myotis* sp., *Plecotus* sp., and *Rhinolophus* sp.

The reason why some species are more vulnerable than others is the fact that those species forage in open habitats and migrate for long distances which increases the chance of collisions, unlike in case of gleaning bats, which forage near vegetation (Bas et al., 2014; Rodrigues et al., 2014). To avoid mortality caused by wing turbines EUROBATS published guideline how to build new turbines and reduce the number of deaths (Rodrigues et al., 2014).

1.9.4 International help

Fortunately, recent studies involve problem of bat conservation (Cooper – Bohannon, 2015; Maslo et al., 2015; Yanzhen et al., 2015; Voigt et al., 2016). To protect bat population also legislatively during past many years were invented laws and created many organization. Namely: Convention on International Trade in Endangered Species of Wild Fauna and Flora 1973 (CITES), Eurobats – Agreement on the Conservation of Populations of European Bats, Convention on the Conservation of Migratory Species of Wild Animals, Convention on the Conservation of European Wildlife and Natural Habitats, which protects not just bat species but also roosts their inhabit, Convention on

Biological Diversity, Program for the Conservation of Migratory Bats of Mexico and the United States (PCMM) etc.

1.9.5   EUROBATS

EUROBATS is based on Agreement which is acceded by 36 out of 63 states. The Agreement was set up in year 1994, under the Convention on the Conservation of Migratory Species of Wild Animals. This convention recognizes endangered species to help in their proper protection. The Agreement protect 53 European bat species through legislation, education, conservation and international cooperation even with countries which did not join the Agreement yet. One of the important tasks of EUROBATS is monitoring and the identification of bat population and prevention of any possible threats.

2 Aims of the Thesis

The Master thesis goal was:

1) Record echolocation calls of flying bats using bat detector.
2) Analyse ultrasound signals using special software tools and identify particular species.
3) Determine flight activity of different bat species in habitats with different representation of human settlements.
4) Discuss obtained results with the previously published studies.
5) Evaluate influence of human settlements on bat fauna.

3 Material and Methods

3.1 Study area

Observations were carried out in forests throughout the whole territory of the Czech Republic. Data were collected in flight corridors above water streams and other small water bodies mainly in mixed or deciduous forests. The minimum forest area was 50 ha. The sampling point was at least 100 m inside the forest. Water resources had to have always length at least 10 m. The bat echolocation was recorded in two different distances from human settlements. 1. close to settlements (100-300 m) and 2. far from settlements (1,000-1,500 m). The research was conducted in 10 out of 16 regions of the Czech Republic. The maps were created using web portal www.mapy.cz.

The location of studied sites in the territory of the Czech Republic can be seen in map in Fig. 10. The list of localities is in Table 1. The example of location of points, where echolocation calls were recorded can be seen in Figs. 22 – 23 (chapter Annexes). The photos of some typical sampling points, where recordings of bat echolocation calls were collected are in Figs. 24 – 25 (chapter Annexes). The exact coordinates of all localities can be seen in Tab. 9 (chapter Annexes).
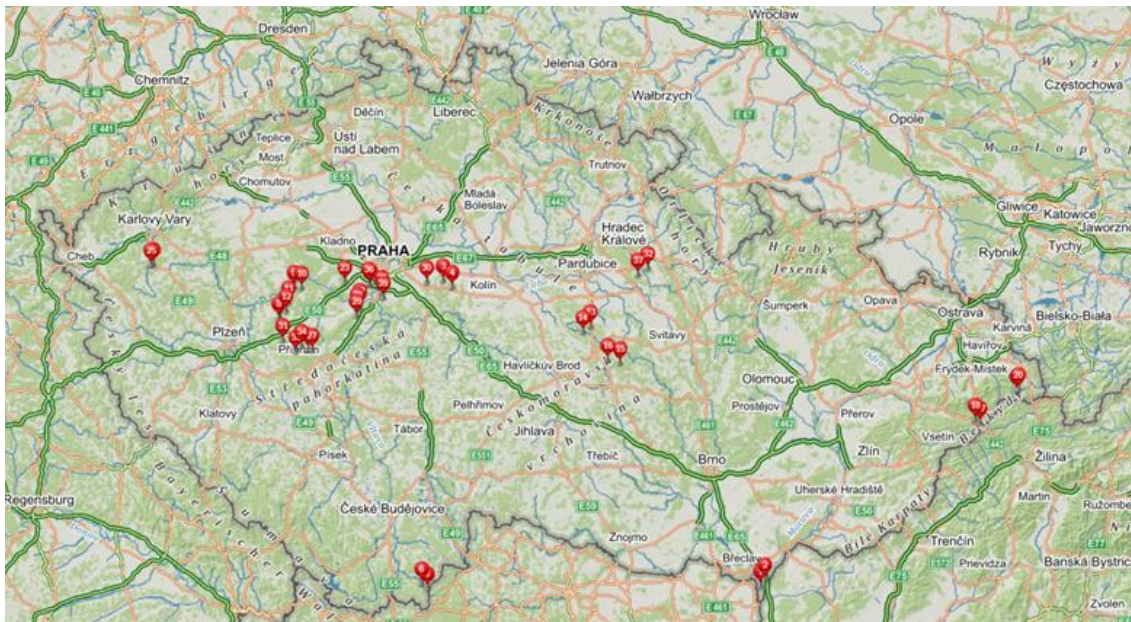
Figure 10. Map of the Czech Republic showing all studied localities (www.mapy.cz).

Table 1. List of all studied localities.

Point No.	Name of the locality	Point No.	Name of the locality	Point No.	Name of the locality	Point No.	Name of the locality
1.	NNR Ranšpurk (FS)	11.	Kouhoutov (FS)	21.	Řevnice (FS)	31.	Číčová (FS)
2.	Lanžhot (CS)	12.	Přehrada Jablečno (CS)	22.	Řevnice (CS)	32.	Brdy (Rezerva) (FS)
3.	U Šembery (FS)	13.	NR Polom (FS)	23.	Bečov (FS)	33.	Brdy (Mourový stream) (FS)
4.	Svatbín (CS)	14.	NR Polom (CS)	24.	Bečov (CS)	34.	Na Cikánce (CS)
5.	NNR Žofín (FS)	15.	Žákova hora (FS)	25.	Obenice (FS)	35.	Zadní Kopanina (CS)
6.	Černé údolí (CS)	16.	Žákova hora (CS)	26.	Obecnice (CS)	36.	Rousínov (FS)
7.	Chotětín (FS)	17.	Bumbálka (Salajka) (FS)	27.	Mníšek p. Brdy (FS)	37.	Břežany (CS)
8.	Chotětín (CS)	18.	Horní Bečva (CS)	28.	Mníšek p. Brdy (CS)	38.	Jarov (CS)
9.	NNR Velká Pleš (FS)	19.	Mionší (FS)	29.	Březí (CS)	39.	Chrustenice (CS)
10.	Karlova Ves (CS)	20.	Horní Lomná (CS)	30.	Medový Újezd (FS)		

3.2 Data collection

The recording of bats' echolocation calls was carried out during June and July 2014 and 2015. Bats were recorded from sunset time for exactly 180 minutes. There were used two types of bat detectors during the study. Bat detector Pettersson D240x (Pettersson Elektronik AB, Uppsala, Sweden), (Fig. 11) together with digital stereo recorder Sony PCM-D50, (Fig. 12) and stereo cable was used in 2014. The switches and buttons of device were set as the follows: normal, time expansion, high, auto trigger, memory size: 1.7 seconds, trigger level: low, source: HET, volume maximum. Frequency was set on 40 kHz during all monitoring time. In year 2015 it was used multi-purpose, terrestrial recording system Song Meter SM2+ batcorder (Wildlife Acoustics, Maynard, Massachusetts, USA), (Fig. 13). Recordings were 16-bit full-spectrum files in standard uncompressed .WAV format. The device was set as follows: Gain +0dB, High pass filter 16 kHz, Trigger 18 SNR, Monitoring was realized only when temperature was higher than 12°C, without strong wind and rain.

Figure 11. Bat detector Pettersson D240x (Source: www.apodemus.eu).

Figure 12. Stereo recorder Sony PCM-D50 (Source: www.bhphotovideo.com).

Figure 13. Song Meter SM2+ batcorder (Source: www.fivethirtyeight.com)

3.3 Sound analysis

All records were evaluated in Sonochiro Program with settings for exact type of recorder, region Northern/Southern temperate, time expansion 1x, minimum call duration 0, 5 ms, sensitivity 8. Records had to be cut in WavePad Sound Editor with settings 44 100 kHz, 16 mono. For better evaluation of unclear results with low validity, evaluated by Sonochiro Program, it was used BatSound Pro Program (version 3.31 b) being set as followed: FFT size 512 samples, FFT window: Hamming, FFT overlap: 87. Sound format: 44 100, time expansion 10x. Measured parameters were: call duration, peak frequency, start and end frequency and interpulse interval (Ahlén, 1990; Jahelková, 2003; Skiba, 2003; Dietz et von Helversen, 2004). Results were evaluated using the table of call parameters (Tab. 5, Chapter Annexes), (www.ceson.org). All records were evaluated as call sequences. One sequence represents 10 seconds of each species recorded, with maximum one record per minute for each species.

3.4 Statistical analysis

To compare overall activity of bats closer/further from human settlements and activity of particular groups of bats it was used Mann-Whitney U test. This test compare two population means, coming from the same population. Mann-Whitney U test is nonparametric alternative to t-test for independent samples. I classified bats on the base of thorough literary review (Norberg et Rayner, 1987; Kunz et Fenton, 2003; Dietz et al., 2007; Lacki et al., 2007; Kunz et Parsons, 2009; Krapp, 2011 and many others) and

divided them into particular groups according to foraging strategy (gleaners vs hawkers), according to wing morphology (broad winged vs narrow winged), according to roost preference (artificial vs natural roost inhabitants) and according to preferred foraging habitat (natural habitats vs antropogenically altered habitats). The species with intermediate characteristics were omitted.

For calculation of presence of particular species closer/further from human settlements it was used Chi-square test. To compare total presence closer/further from human settlements it was used student T-test.

All these tests were computed using STATISTICA for Windows. For more details, see the software manual (StatSoft, 2001).

To compare environmental characteristics of the area and occurrence of bats it was used canonical correspondence analysis (CCA). CCA is a unimodal method of direct ordination that directly expresses the relation between occurrence of bats at paticular sites and independent variables (environmental characteristics). This analysis is a multivariate method to elucidate the relationships between biological assemblages of species and their environment. The method is designed to extract synthetic environmental gradients from ecological data-sets. Calculations were performed using CANOCO for Windows, Version 5.1. Input data were logarithmically transformed. Significance was tested by a Monte Carlo permutation test. Results are presented as a biplot produced by the CanoDraw program. For more details see ter Braak et Šmilauer (2002).

Using geographical information systems (GIS), program ArcView, the proportion of particular landscape parameters was calculated (settlements (%), water area (%), deciduous and mixed forests (%), edge density (m/ha), coniferous forest (%), waterway length (m/ha), altitude (m a.s.l.); and total forest area (%)). Buffer zone was set on 2 km. These parameteres were used as a covariates in CCA.

4 Results

4.1 Comparison of CS × FS sites according to the total activity and presence of bats

Over two summers I recorded in total 3,664 call sequences representing ca. 612 minutes (11. 7 % of all minutes sampled) at 39 study sites. There were altogether recorded 17 – 21 bat species (hardly recognizable species were put together in one group: *M. brandtii/ M. mystacinus, M. alcathoe/M. emarginatus, P. auritus/austriacus, P. nathusii/kuhlii*). 1,956 records belong to *Myotis* sp.; 850 to *Pipistrellus* sp.; 606 to group containing *Eptesicus* sp., *Nyctalus* sp. and *Vespertilio* sp.; 168 to *Barbastella barbastellus* and 83 to *Plecotus* sp.

The difference between activities of particular bat species (expressed as number of recorded 10 sec sequences) at the sites close and far from human settlement was compared (Fig. 14) and significance of observed results was tested using Mann-Whitney U test. The total activity of bats was higher closer to the populated places. It supports my hypothesis that human-dominated areas support bat species diversity and abundance. Observed differences for total activity were almost significant, but unfortunately not fully significant (p=0.084), (Tab. 2). The variability of collected data was higher than expected during preparatory phases of presented study. Due to aforementioned high variability in activity among particular studied sites I did not receive fully significant results. A bigger sample size with more monitored points would be needed for more conclusive results. For that reason there was used another method to test significance of differences between CS and FS sites. I tested difference between CS and FS sites according to total presence of bats. Using T-test I confirmed, that total presence of bat species was significantly higher closer to human settlements (p≤0,001), (see Tab. 3; and Tab. 7 in chapter Annexes).
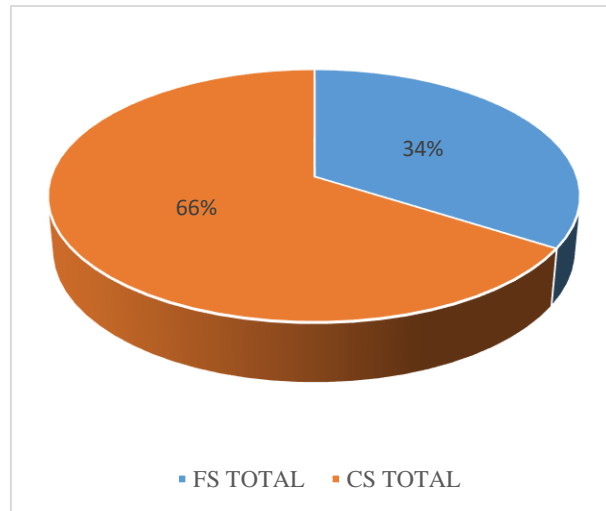
Figure 14. Comparison of total activity (call sequences) of bats far and close to human settlements.

Table 2. Statistical results of Mann-Whitney U test showing differences in activity further and closer to human settlements.

	Rank Sum	Rank Sum	U	Z	p-value	Z	p-value	Valid N	2*1sided
Bbar	580,5000	694,5000	255,5000	-1,09626	0,272965	-1,24152	0,214415	25	0,271363
Enil	558,5000	716,5000	233,5000	-1,52312	0,127729	-1,92555	0,054161	25	0,126084
Eser	549,0000	726,0000	224,0000	-1,70745	0,087739	-2,21417	0,026818	25	0,087822
Malc/ema	597,5000	677,5000	272,5000	-0,76641	0,443431	-0,82154	0,411340	25	0,441038
Mbra/mys	585,5000	689,5000	260,5000	-0,99925	0,317676	-1,01373	0,310710	25	0,315946
Mbech	645,5000	629,5000	304,5000	0,14552	0,884299	0,15241	0,878864	25	0,877749
Mdau	523,5000	751,5000	198,5000	-2,20222	0,027650	-2,27967	0,022628	25	0,026057
Mmyo	621,5000	653,5000	296,5000	-0,30074	0,763610	-0,35830	0,720120	25	0,758301
Mnat	672,0000	603,0000	278,0000	0,65970	0,509449	0,79932	0,424104	25	0,512758
Nlas	625,0000	650,0000	300,0000	-0,23283	0,815890	-0,96000	0,337056	25	0,817504
Nlei	552,5000	722,5000	227,5000	-1,63954	0,101102	-1,85348	0,063815	25	0,099393
Nnoc	565,0000	710,0000	240,0000	-1,39701	0,162413	-1,62920	0,103272	25	0,163779
Pnat/kuh	530,0000	745,0000	205,0000	-2,07610	0,037885	-2,62464	0,008674	25	0,037090
Ppip	513,5000	761,5000	188,5000	-2,39625	0,016564	-2,61229	0,008994	25	0,015194
Ppyg	594,5000	680,5000	269,5000	-0,82462	0,409587	-1,06930	0,284936	25	0,407412
Paur/aus	595,5000	679,5000	270,5000	-0,80522	0,420694	-0,97331	0,330398	25	0,418450
Vmur	575,5000	699,5000	250,5000	-1,19328	0,232762	-1,78238	0,074689	25	0,231218
Total activity	548,0000	727,0000	223,0000	-1,72685	0,084195	-1,73613	0,082541	25	0,084211

4.2 Activity and presence of particular species at CS and FS sites

I tried to grasp differences in presence of particular species. Higher activity was recorded closer to human settlements in following species: *E. nilssonii, E. serotinus, M. alcathoe/emarginatus, Myotis brandtii/mystacinus, M. daubentonii, M. myotis, N. leisleri, N. noctula, N. lasiopterus, P. pipistrellus, P. pygmaeus, P. nathusii/kuhlii, P. auritus/austriacus* and *V. murinus*. Significantly (p≤0.05) higher activity was recorded in case of *E. serotinus*, *M. daubentonii*, *P. nathusii/kuhlii*, and *P. pipistrellus*. Almost significantly higher activity closer to settlements was recorded in species *E. nilssonii*, *N. leisleri* and *V. murinus* (p=0.052-0.072).

Conversely, higher activity at the sites located further from human settlements were recorded in the case of *B. barbastellus, M. bechsteinii* and *M. nattereri*. Nevertheless, the observed differences were not statistically significant (Fig. 15).

The differences in presence of particular species were expressed by presence/absence of species on observed points. The higher presence closer to human settlements was recorded in species: *B. barbastellus, E. nilssonii, E. serotinus, M. alcathoe/emarginatus, Myotis bechsteinii, Myotis brandtii/mystacinus, M. daubentonii, M. myotis, N. leisleri, N. noctula, N. lasiopterus, P. pipistrellus, P. pygmaeus, P. nathusii/kuhlii, P. auritus/austriacus, V. murinus*. Significantly higher presence CS was observed (calculated by Chi square test) in following species: *E. serotinus, P. nathusii/ kuhlii, P. pipistrellus* and *V. murinus*. (For further details see Tab. 4, Fig. 16; and Tab. 6 in chapter Annexes). *M. nattereri* was the only species showing higher presence FS.

Table 3. Statistical results of T-test showing significantly higher amount of positive presence closer to human settlements.

Mean	Std.Dv.	N	Diff.	Std.Dv.	t	df	p
30,19565	16,74665	16	17,30435	11,69854	5,916752	15	0,000028
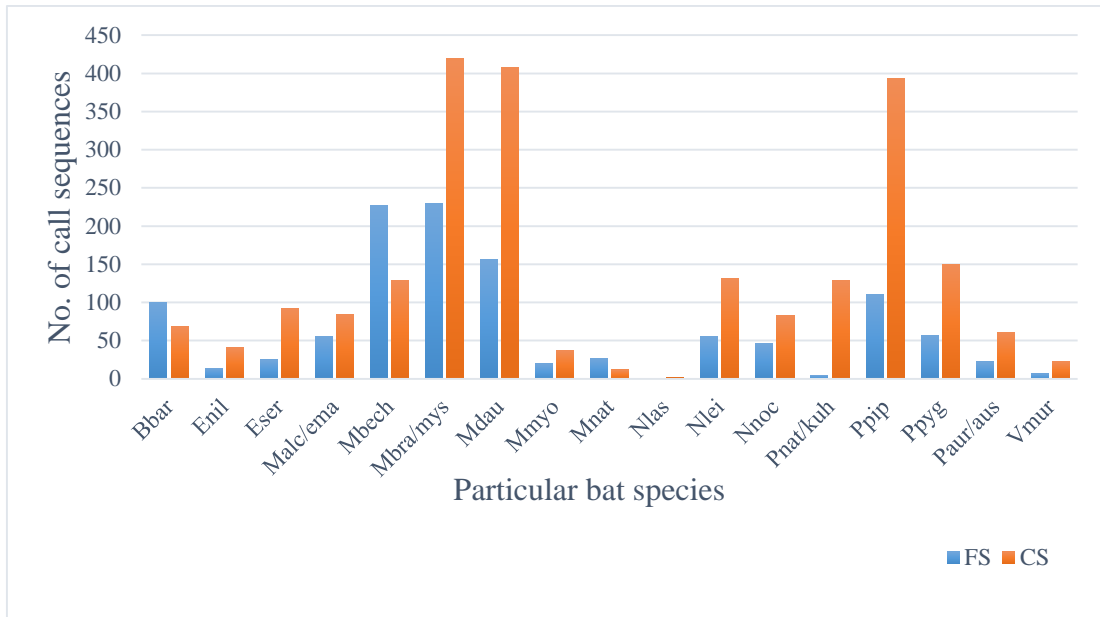
Figure 15. Number of total call sequences of particular bat species FS×CS.
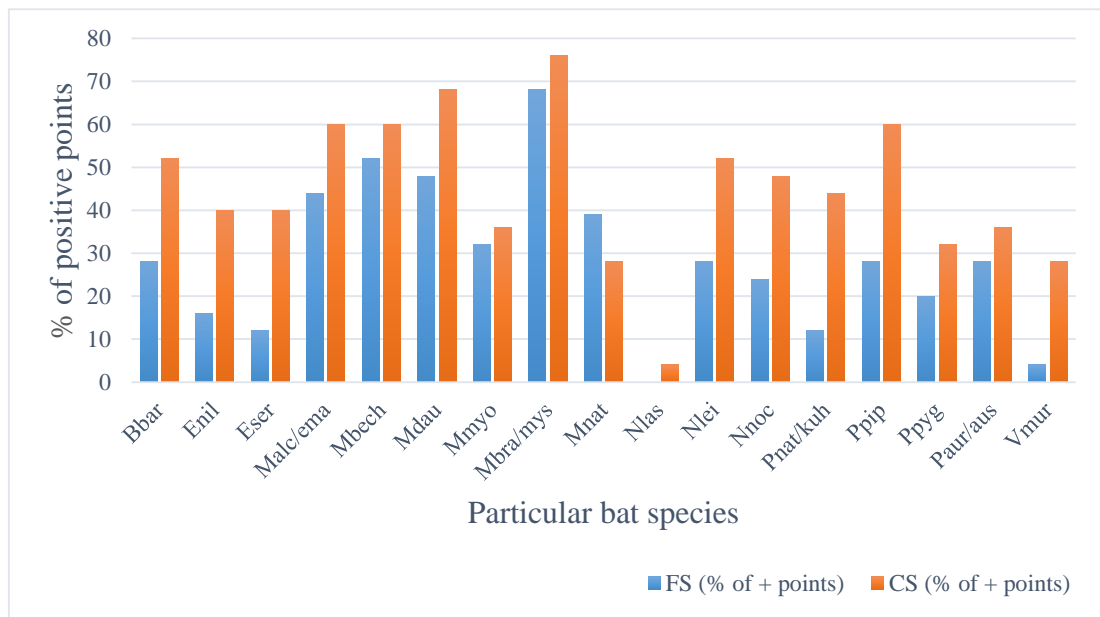
Figure 16. Percentage of positive points (presence) of particular species in points FS×CS.

Table 4. Results of statistical analysis of chi-square test.

	Z	p-value	Valid N
Bbar	-1,24152	0,214415	25
Enil	-1,92555	0,054161	25
Eser	-2,21417	0,026818	25
Malc/ema	-0,82154	0,411340	25
Mbra/mys	-1,01373	0,310710	25
Mbech	0,15241	0,878864	25
Mdau	-2,27967	0,022628	25
Mmyo	-0,35830	0,720120	25
Mnat	0,79932	0,424104	25
Nlas	-0,96000	0,337056	25
Nlei	-1,85348	0,063815	25
Nnoc	-1,62920	0,103272	25
Pnat/kuh	-2,62464	0,008674	25
Ppip	-2,61229	0,008994	25
Ppyg	-1,06930	0,284936	25
Paur/aus	-0,97331	0,330398	25
Vmur	-1,78238	0,074689	25
Total activity	-1,73613	0,082541	25

4.3 Other variables

4.3.1 Comparison of activity depending on foraging strategy CS×FS

Trying to find other factors determining differences between CS and FS sites, bat community was divided according to literary data (see chapter 3.4.) into two groups depending on their foraging strategy. Gleaners (*M. bechsteinii, M. nattereri, P. auritus/austriacus*) and aerial hawkers (*B. barbastellus, E. nilssonii, E. serotinus, M. brandtii/mystacinus, M. daubentonii, N. leisleri, N. noctula, N. lasiopterus, P. pipistrellus, P. pygmaeus, P. nathusii/kuhlii* and *V. murinus*). The species with intermediate characteristics were omitted (*M. alcathoe/emarginatus, M. myotis*). The results show significantly higher total activity of aerial hawkers closer to human settlements ($P \leq 0, 01$). Conversely gleaners show higher activity further from human settlements, which was not confirmed statistically (Fig. 17).
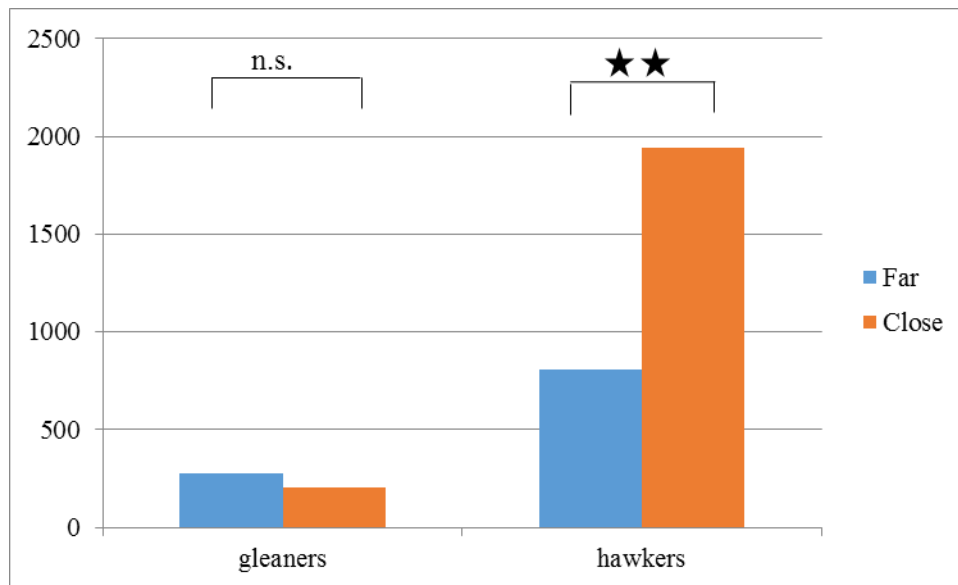
Figure 17. Comparison of activity of gleaners and aerial hawkers on CS×FS sites and its significance. Gleaners – not significant; hawkers - ** $P \leq 0, 01$.

4.3.2 Comparison of activity depending on shape of wings CS×FS

According to literary data (see chapter 3.4.), bat community was divided into two groups to show comparison of activity CS/FS depending on shape of the wings. Bats with narrow wings (*P. pipistrellus, P. pygmaeus, P. nathusii/kuhlii, N. noctula, N. leisleri, N. lasiopterus* and *V. murinus*) and species with broad wings (*B. barbastellus, M. bechsteinii, M. myotis, M. nattereri* and *P. auritus/austriacus*). The species with intermediate characteristics were omitted (*M. alcathoe/emarginatus, M. brandtii/mystacinus, M. daubentonii, E. nilssonii* and *E. serotinus*). Overall higher activity closer to human settlements of narrow-winged bats was confirmed statistically (P ≤ 0, 05). Conversely broad-winged bats show higher activity further from human settlements, which was not statistically confirmed (Fig. 18).
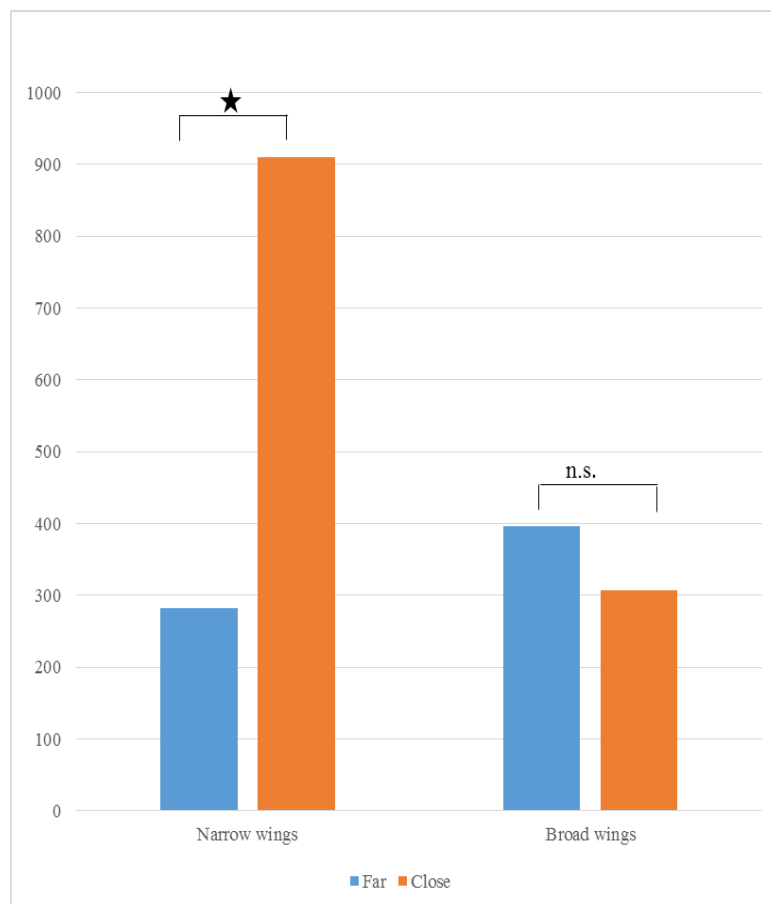
Figure 18. Comparison of activity depending on shape of wings on CS×FS sites and its significance. Broad-winged bats – not significant; narrow-winged bats - * P ≤ 0, 05.

4.3.3 Comparison of activity in CS×FS sites depending on roosts types used by bats and their synanthropy

According to literary data (see chapter 3.4.), bat community was divided into two groups, according to roosting preferences (artificial vs natural roosts) to show their different activity in CS/FS sites. Group of bats using artificial roosts: *M. brandtii/mystacinus*, *E. nilssonii, E. serotinus, M. myotis, P. pipistrellus, P. pygmaeus, P. kuhlii/nathusii, P. auritus/austriacus* and *V. murinus*) and bats using natural roosts (*B. barbastellus, M. bechsteinii, M, daubentonii, M. nattereri, N. leisleri, N. noctula* and *N. lasiopterus*). The species with intermediate characteristics were omitted (*M. alcathoe/emarginatus*). Both groups of bats, using either artificial or natural roosts, show higher activity closer to human settlements. In case of bats using artificial roosts the result is confirmed statistically (P ≤ 0, 01); bats using natural roosts show no significant results (Fig. 19).
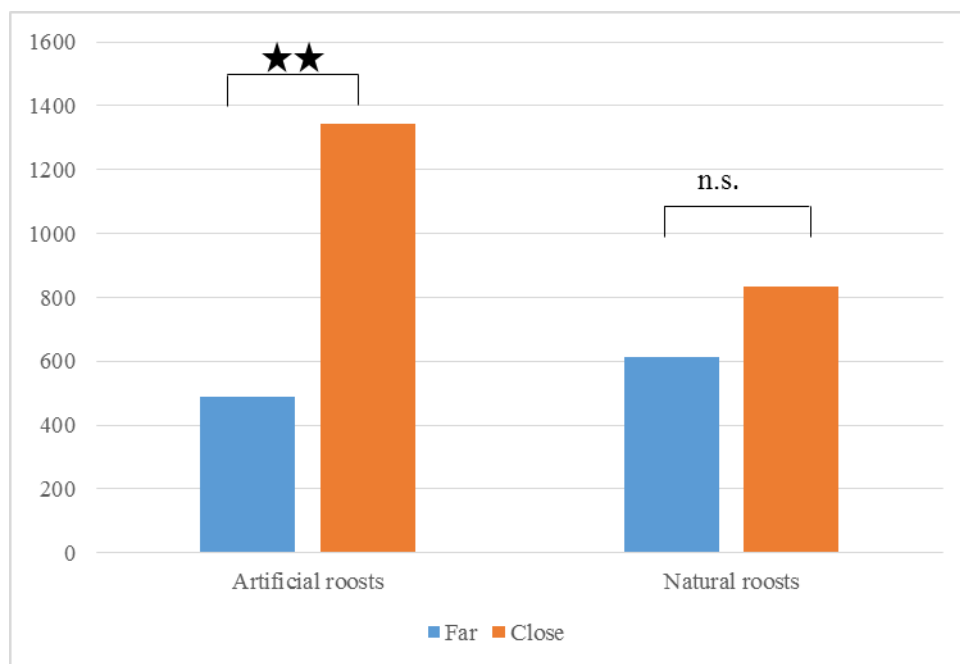
Figure 19. Comparison of activity of species on CS×FS sites, according to their roosting preferences and its significance. Bats using artificial roosts - ** P ≤ 0, 01; bats using natural roosts – not significant.

4.3.4 Comparison of activity in CS×FS sites depending on habitat types used by bats and their synanthropy

According to literary data (see chapter 3.4.), bat community was divided into two groups, to show comparison of activity in CS/FS sites, depending on the type of preferred foraging habitat (antropogenically altered vs natural). Bats using anthropogenically altered habitats (*E. nilssonii, E. serotinus, N. noctula, P. pipistrellus* and *V. murinus*), bats using natural habitats (*B. barbastellus, M.brandtii/mystacinus, M. bechsteinii, M. myotis, M. nattereri, N. leisleri, N. lasiopterus* and *P. pygmaeus*). The species with intermediate characteristics were omitted (*M. alcathoe/emarginatus, M. daubentonii, P. pygmaeus, P. nathusii/kuhlii* and *P. auritus/austriacus*). Both groups of bats using either anthropogenically altered or natural habitat show higher activity closer to human settlements. In case of bats using anthropogenically altered habitats the result is confirmed statistically (P ≤ 0, 01); bats using natural habitats show no significant results (Fig. 20).
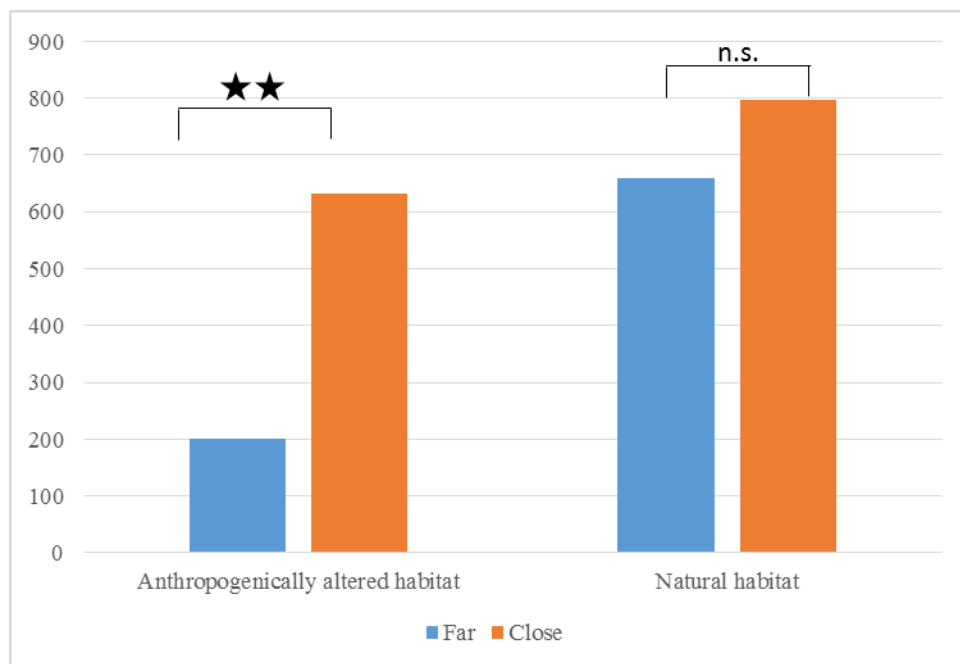
Figure 20. Comparison of activity of species on CS×FS sites, according to preferred foraging habitat and its significance. Bats using anthropogenically altered habitats - ** P ≤ 0, 01; bats using natural habitats – not significant.

Detailed results of statistical analysis of particular groups of bats can be seen in Tab. 8 (chapter Annexes).

4.4 Canonical correspondence analysis

I tried to find the relationship between habitat characteristics and occurrence of particular bat species on studied localities. Landscape and habitat parameters explain 18. 5 % of variability of collected data and their impact on the distribution of bats is not significant (P=0, 472). Generally it can be seen in the Fig. 21 that the highest variability is on horizontal axis being caused by altitudinal gradient and closely related covariates. On the right side of the Fig. 21 we can see, that the altitude correlates with presence of coniferous forests and occurrence of *V. murinus.* On the left side towards present settlements and deciduous forests is visible occurrence of *Pipistrellus* sp.
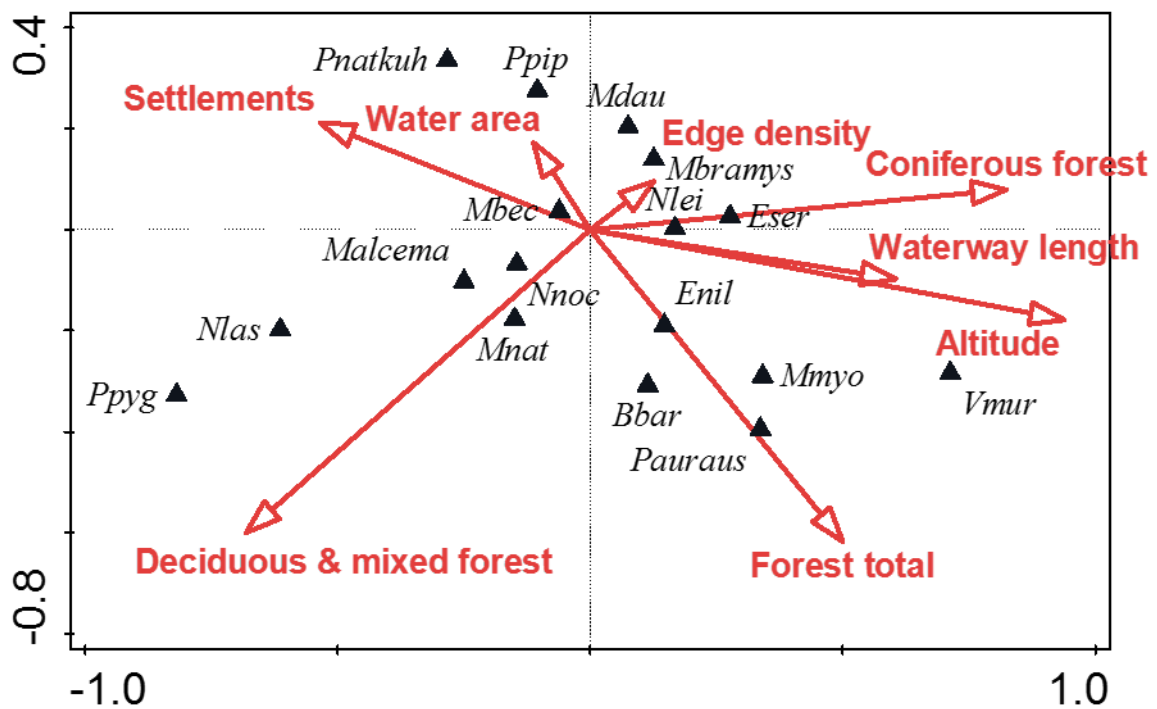
Figure 21. Results of CCA, showing relationship between habitat characteristics and occurrence of bat species.

5 Discussion

5.1 Estimation of the total activity and presence of particular bat species

According to collected data the total bat activity seems to be higher at CS sites. It could denote high importance of urban habitats and human settlements for bats. This was already pointed out in studies of Gaisler et al (1998), Gehrt et Chelsvig (2004) or Avila-Flores et Fenton (2005). However study which would methodically measure activity of bats depending on distance from human settlements in detail has not been published so far.

Avoidance of urban areas inside the city by many of the bat species was already published (Pierson, 1998; Hale et al., 2012; Threlfall et al., 2012a; Ciechanowski, 2015). Nevertheless many studies show importance of suburban landscapes for bats (Lesiński et al., 1999; Threlfall et al., 2011; Threlfall et al., 2012b). Habitats, such as highly urbanized cities, should be put into context with surrounding area, while the influence of urbanization on bats depends on the nature of rural landscape and on the level of urbanization (Fenton, 1997). Successful conservation of bats and higher overall activity could be achieved by connection of productive suburban bushland remnants and riparian areas, together with improvement of the connectivity to the areas with tree cover across the matrix (Threlfall et al., 2012b). Higher activity closer to human settlements may indicate preference of woodland edges by most of the studied species, which was confirmed in studies by Walsch et Harris (1996a) or Lesiński et al (2011). Commonly bats with broad wings, which are less mobile decrease their occupancy in anthropogenically altered habitats and increase their abundance in forests (Bader et al., 2015).

General trend in loss of plant biodiversity in woodlands in past (Barr et al., 1993), could affect prey availability and overall habitat quality in forests. This may be one of the reason causing partial shift in preferred foraging habitats closer to human settlements. Another unexceptionable reason why bats are more and more widely recorded in cities is high amount of possible roosts (Fenton, 1970; Kunz, 1982; Gaisler et al., 1998; Jung et Threlfall, 2016). Areas close and/or in human settlements provide not just natural but also artificial roosts, which is not true for areas in wilderness, which offer ″just″ natural roosts.

Additionally more and more conservation programs are held on all around the world, connected with protection of bats in cities, which support protection of roosts inhabited by bats and create new one so called bat houses (Hutson et al., 2015).

5.2   Possible methodological bias

Presented data could possibly underestimate some bat species because of using ground level detector. This method is biased in favour to bats with low call frequencies (Griffin, 1971) or to bats with intense calls (Waters et Jones, 1995). Thus calls of bats foraging in increased forest height could be reduced. Additionally, bats foraging inside the forest have relatively weak signals (Waters et Jones 1995; Schnitzler et Kalko, 2001), therefore they could be underestimated also (Broders et al., 2003); as well as bats with hardly detectable echolocation calls such as horseshoe bats (Rhinolophidae), (Waters et Jones, 1995).

5.3   Estimation of studied species

While all studied areas were in the vicinity to watersides, it is not surprising that *M. daubentonii* was one of the most recorded bat species in the survey, which is predetermined by hunting strategy of this bat species and its commonly used habitat (Warren et al., 2000). Additionally its diet composition consists mainly from aquatic Diptera (Vaughan, 1997). *M. daubentonii* uses as foraging sites woodland and open water habitats usually in vicinity to their roosts (Parsons et Jones, 2003). The flight activity decreases in the forest interior and highest level of activity is typical for openings and forest edges (Ceľuch et Kaňuch, 2004). *M. daubentonii* is also affected by the water flow and the resulting abundance of the preferred food (Racey et al., 1998; Akasaka et al., 2009; Abbott et al., 2009). Rapid streams are used rather for commuting, than as a foraging sites (Zukal et Řehák, 2006).

Relatively low total number of *M. myotis* could be explained by their wide range of hunting sites, especially in case of females, which often go to forage more than 15 km far from the nursery colonies (Güttinger, 1997), and/or by their preference for few main foraging sites (Bernd-Ulrich et al., 2009). Insignificant activity of *M. myotis*, on either FS or CS sites in the study, may be explained by the fact, that this species shows no preference of foraging habitat in forest, but is more influenced by the spatial distribution

of the forest (Zahn et al., 2005). This idea corresponds with their foraging strategy – ground gleaning. In study of Güttinger (1997), *M. myotis* preferred areas with low underground storey to any other areas. Study of Rainho et al (2010) confirms this pattern. *M. myotis* often ignored insect in the densest grass and their efficiency of locating the prey was higher in sparse grass.

Almost significantly higher activity and presence of *E. nilssonii* closer to human settlements could indicate spreading of the species at sites closer to urbanised areas, which was partly confirmed in my Bachelor thesis and in study of new records of *E. nilssonii* in Prague suburbs and close surroundings (Kovaříková, 2013; Kovaříková et Neckářová, in press). Even though *E. nilssonii* is considered as a habitat generalist, study from Germany shows its seasonal preference (after birth of the young) for urban habitats (Haupt et al., 2006). Relatively low total number of records in the study, comparing to other species, could be caused by studied habitats. *E. nilssonii* is adapted mainly on hemi boreal coniferous forests (De Jong, 1994; Kaňuch et al., 2008), while my studies were mainly conducted in mixed or deciduous forests.

Significantly higher activity and presence of *E. serotinus* CS was not surprising, for already known synanthropy of the species (Racey, 1998; Zukal et Řehák, 2006; Horáček et Uhrin, 2010). Presented results fully confirm conclusions of aforementioned studies. *E. serotinus* as one of a few bats (together with *P. pipistrellus*) is considered as species not avoiding city centres (Gaisler et al., 1998) and often roosting in manmade constructions has also been already described (Horáček et Uhrin, 2010).

Habitat preferences of species *N. noctula* and *N. leisleri* are hard to identify, simply because of their hardly accessible roosts in trees. Yet some evidences of habitat preferences are known. In study from United Kingdom, *N. noctula* shows high selection for particular foraging habitats (e.g. forest edges, open areas, broadleaved woodland and surrounding pastures) and this limitation could have possibly effect on reproductive success (Mackie et Racey, 2007). The opposite trend was observed in study of *N. leisleri* from Ireland, showing activity in many kinds of habitats (including canals, estuary/open waters, roadsides, street lights, orchards, mature trees stands, pastures, farmyards), with just slight preferences of habitats along street lights (Shiel et Fairley, 1998).

During summer mist-nettings (2014) in forest near colony of *N. leisleri*, it was observed high activity of females close to human settlements, but almost no activity inside the forest. (Lučan et al., per obs). This fact is well corresponding with overall activity of *N. leisleri* in my study, which shows significantly higher presence CS and almost significantly higher activity on CS sites. The results of activity of *N. noctula* correspond with study of Rachwald (1992), where higher activity over the rivers and in small woodland villages is shown.

Echolocation of *N. lasiopterus* was recorded only once at site close to settlement. Consequently, there are not enough data to draw any conclusions. In Europe its distribution is recorded mainly in Mediterranean, stretching from the Iberian Peninsula to the Balkans, with just few records to the north (Ibáñez et al., 2004). Study from France observing two breeding populations of *N. lasiopterus*, one roosting in urban areas and other in a nature reserve, show preference for marshland areas which was used by both groups as foraging site (Popa-Lisseanu et al., 2009).

As in other researches (Walsch et Harris, 1996b; Vaughan et al., 1997; Kusch et al., 2004) *P. pipistrellus* was one of the most recorded species, in presented study. The overall activity as well as positive presence was significantly higher closer to human settlements. The high number of recorded calls could be caused by the flexibility of the species regarding foraging sites as a consequence of plasticity of echolocation calls (Kalko et Schnitzler, 1993), which allow them to exploit wide range of habitats (Norberg et Rayner, 1987).

Relatively lower overall activity of *P. pygmaeus* as compared to cryptic species *P. pipistrellus* could be explained by their different selection of specific foraging sites (Davidson-Watts et Jones, 2006) e.g. riparian areas (Vaughan et al., 1997; Davidson-Watts et al., 2006). Even though all three *Pipistrellus* species (*P. pipistrellus, P. pygmaeus* and *P. kuhlii*) prefers different habitats, their optimal habitats overlap in relatively large extent. Study models used by Lisón et Calvo (2013) suggest that *P. pygmaeus* has to face strong competition from other two species, which may cause its higher marginality and preferences for aquatic environments, which are easier to defend.

Considered as a synanthropic species, *V. murinus* tend to forage around street lamps and is frequently found hunting in suburban areas, in open areas or newly planted

forests, rather than in the vicinity of high trees (Baagøe, 1986). The summer roosts are found mainly in low buildings, in open areas or along small trees (Baagøe, 1986). Results of presented study show the same pattern - significantly higher affinity CS, than FS. One of the lowest number of call sequnces of *V. murinus*, among all recorded species, could be caused by their lower occurrence in the Czech Republic during this period of time (late June – July). It was demonstrated in study of Hanák et al (2009) in Prague city, where the abundance of this species was lower during particular months, than during winter and autumn overflights.

As echolocation calls of some bat species are very similar (Skiba, 2003), it was not possible to distinguish between some of them. Such as in case of *M. brandtii/mystacinus*, *P. nathusii/kuhlii*, *P. auritus/austriacus* or *M. alcathoe/emarginatus*.

M. mystacinus and *M. brandtii* are hardly distinguishable bat species (using echolocation call analysis). This fact makes it impossible to study these species using bat detectors properly, which causes certain gaps in understanding of their ecology. In continental Europe *M. mystacinus* was described as a forest bat species (Kaňuch et al., 2008) and as a species of open and arable landscapes (Taake, 1984). Conversely in Ireland *M. mystacinus* shows activity in diverse range of habitats, preferring as a foraging sites mixed woodland and riparian areas (Buckley et al., 2013). These differences can be caused by regional differences of habitat use. Since *M. brandtii* is known to forage in forests environments (Ekman et De Jong, 1996), occurrence of *M. mystacinus* in woodland areas may indicate scarcity or absence of *M. brandtii* in such areas, allowing *M. mystacinus* not to face any competition (Boston et al., 2010). Obviously higher activity closer to human settlements in the case of *M.brandtii/mystacinus* in my study may show preference of foraging sites closer to human settlements, while actual positive presence was almost the same in CS and FS sites. Unfortunately I am not able to apply this idea to particular bat species.

Since occurrence of *P. kuhlii* in the Czech Republic is mapped just on 5 mapping squares (*P. nathusii* - 61 mapping squares), (Horáček et Uhrin, 2010), I expect higher proportion of echolocation calls in *P. nathusii*. Study of Flaquer et al (2009) shows preference for natural wetlands and riparian areas in case of *P. nathusii*. Conservation of such areas is crucial in the life cycle of this species. Especially males roosts in same

wetland area, which they uses as a foraging site. Species *P.nathusii/kuhlii* show significantly higher activity and also presence in CS sites and possible records of *P. kuhlii* in the study would correlate with known high synanthropy of this species (Dietz et al., 2007).

In the case of *Plecotus auritus/austriacus*, the most of the echolocation calls recorded in presented localities belong most probably to *P. auritus*, who prefers forest habitats (De Jong, 1995), and forest edges (Ashrafi et al., 2013) unlike *P. austriacus* often observed in villages, gardens (Dietz et al., 2007), orchards and hedgerows (Ashrafi et al., 2013). Additionally, *P. auritus* is more generalist in its diet composition, and uses wider range of foraging sites than *P. austriacus*, who has narrower trophic niche and need to travel longer distances to its hunting ground. This fact makes *P. austriacus* choosier regarding habitat use (Ashrafi et al., 2011).

It is quite complicated to evaluate the data regarding the activity of *M. alcathoe/emarginatus* group, while both species could occur together at many recorded studied sites due to geographic range overlap and relatively similar habitat preferrences.

The geographic distribution of *M. alcathoe* is not still throughly known as this bat was described as a distinct species at the beginning of the 21st century (von Helversen et al., 2001). Occurrence of *M. alcathoe* in the Czech Republic was recorded just in 11 mapping squares, (Horáček et Uhrin, 2010) and quite probably occures in several other parts of the country. Study of Lučan et al (2009b) shows uniform use of the habitat in the case of *M. alcathoe* constisting of old full-grown oak-hornbeam forests, with several large trees in advanced decayed stage, various size of water bodies and/or parts of riparian vegetation bordered by the forest. Their roosts were found inside the forest stands, with predominance for big oaks, birch and lime trees. Conclusions of aforementioned study (Lučan et al., 2009b) do not correspond very well with my results, as the *M. alcathoe/emarginatus* group was recorded more frequently at sites closer to human settlements. Therefore it could be assumed that most of recorded calls belong to *M. emarginatus*, which is also frequently recorded in forest habitats, but likes to use roosts in human settlements (Krull et al., 1991; Benda et Hanák, 2003). But, on the other hand, taking into account current knowledge regarding geographic distribution of *M. emarginatus* in the Czech Republic (Horáček et Uhrin, 2010), the species should be absent

at many sites in Bohemia. There are two possible explanation of observed pattern of activity. The first option is possible fact, that *M. alcathoe* is not so much specific to old full-grown oak-hornbeam forests and exploits also much more anthropogenically altered forest habitats, than it was expected up to now; and/or by their preferences for impure water sources closer to human settlements, where Diptera insect is more common (Vaughan et al., 1997). The second option is possibility that the observed distribution range expansion of *M. emarginatus* in Bohemia (Horáček et Uhrin, 2010) is much more dynamic and advanced process than it was expected and the species is currently much more commonly distributed in Bohemia than it is described in available literature and therefore was relatively often recorded in my study.

Interesting pattern was recorded in the case of *B. barbastellus* and *M. bechsteinii*. Both species showed higher activity FS, but higher positive presence on points CS. This may indicates some affinity to human settlements (probably used as a roosting site), however as a foraging sites bats may prefer areas inside the forest, further from human settlements. *M. nattereri* shows not just higher overall activity on points in FS sites, but as the only species also higher presence in FS sites (although none of these were confirmed statistically). Morphology and echolocation calls of all three species (Ahlén, 1990; Skiba, 2003) indicate that these bat species are adapted to forage in cluttered places close to vegetation. Results of presented study – higher activity inside the forest at sites placed further from human settlements – are fully concordant with these predictions. *M. bechsteinii* is largely restricted to deciduous forests (Mitchell – Jones et al., 1999; Schofield et Morris, 2000; Dietz et Pir, 2009), yet its habitat preferences are still poorly understood. In detailed study of habitat selection of *B. barbastellus* shows clear preference for richly structured forests (Sierro, 1999). *M. nattereri* demonstrate diversity in roost types (e.g. churches, bat boxes), (Mortimer, 2006; Zeale et al., 2016) as well as in habitats around roosts (e.g. woodland, pasture, open-water and arable habitats); with favour to rural rather than urban areas (Parsons et Jones, 2003).

5.4 Canonical correspondence analysis

Results of CCA, showing relationship between habitat parameters and occurrence of particular bat species, are not significant. The most important factor, determining presence of bats and composition of bat communities in various habitats, seems to be

altitudinal gradient and differences among altitudinal vegetation zones. To achieve more consistent results, more sampled localities, more collected data, and evaluation of the results with consideration to elevation zones would be needed.

5.5   Bat activity with respect to variable natural factors

To avoid underestimation of some bat species, each observation/recordings were done in temperatures above 12°C. In study of Gaisler et al (1998) the only bat species, which showed significant correlation in the activity (in Czech urban areas) was *E. serotinus*. This bat species shows one of the highest sensitivity to the air temperature among Central European bat species. The temperature in which *E. serotinus* does not leave the roost is observed somewhere around 10°C, for *Pipistrellus* and *Nyctalus* species threshold temperature is around 3-4 °C, in case of *E. nilssonii* hunting activity is reduced in air temperature below 6°C (Kurtze, 1982; Ciechanowski et al., 2007). Surprisingly *M. daubentonii* shows no significant differences in hunting and flight activity, during lower air temperature (Ciechanowski et al., 2007). The bat activity under different temperature conditions seems to be directly affected mainly by insect availability (Taylor, 1963). Since some bat species (*E. serotinus*, *N. noctula*), (Ciechanowski et al., 2007) avoid rainy weather, my study was held on only under weather conditions without rain.

One of many factors affecting flight activity of bats could be moon phase. Different stage of moon phase varies in level of predation risk. Many studies differs in their results. Bat activity in West African forest is decreasing with increasing visibility of the moon (Meyer et al., 2004), same as activity among bats studied in Northern Poland (Ciechanowski et al., 2007). Contrary general activity of bats observed in Panama did not differ between moon phases (Jung et Kalko, 2010), same as study of bats in the city Brno (Gaisler et al., 1998) or study at 10 habitat types in Mediterranean area (Russo et Jones, 2003). So called lunar phobia was described mainly in tropical forest bat species, such as Neotropical frugivores (Handley et Morrison, 1991) or bats in South Africa (Fenton et al., 1977).

Insectivorous-temperate zone bats living in high altitudes may not face the same level of predation risk as tropical species do (Karlsson et al., 2002). Changes of microhabitats related to moonlight have been noticed just in case of temperate-zone bats,

which move into (higher) canopy level to follow vertical movements of insects (Hecker et Brigham, 1999).

Using different analysis (multivariate regression), which helps to separate other factors that could possibly affect bat activity, Ciechanowski et al (2007) found that species of genera *Pipistrellus*, *Eptesicus*, and *Nyctalus* are not affected by moonlight. The only bat species which showed lower activity is *M. daubentonii* probably because of its different hunting strategy. As a trawling species hunting near water surface in more open spaces, *M. daubentonii* is probably more visible and therefore more vulnerable to predation during moonlight.

All the localities, where the data were collected within the frame of presented study, were placed inside of the forest, thus bats did not face such big effect of moon phase, as in case of open space areas. To complement, not just bats, but also species of insects are differently affected by moonlight. Their activity around street lamps vary and attractiveness toward the light in between full moon and new moon differs (Jung et Kalko, 2010). This could mean that bat activity during full moon is also indirectly affected by insect availability.

6 Conclusions

Activity and presence of bats was compared in localities closer and further from human settlements using automatic bat detectors and special programs for bat echolocation calls analysis. Statistical analysis calculated overall activity and presence of bats, as well as values for particular species. It was collected more than 3,664 call sequences, of 17 – 21 species in 39 study sites all over the territory of the Czech Republic during two summer seasons (2014, 2015). The average number of taxa per site was higher further from human settlements, but overall bat activity was higher closer the human settlements. I determined following:

1) Total activity of bats was almost significantly higher closer to human settlements, than in areas further from human settlements.

2) Total presence of all recorded species was significantly higher at sites closer to the settlements.

3) There were compared activity and presence of particular bat species, thus it can be stated that species *E. serotinus*, *P. nathusii/kuhlii, V. murinus*, *P. pipistrellus*, showed higher affinity to human settlements, which they probably use as a roosting sites. Species *E. serotinus*, *M. daubentonii*, *P. nathusii/kuhlii, P. pipistrellus* showed higher activity in CS sites, which may indicate their preferences of these areas as a foraging sites. This idea could be also applied to species *E. nilssonii* and *N. leisleri,* which showed almost significantly higher activity and presence on CS sites. Species *B. barbastellus* and *M. bechsteinii* displayed interesting pattern: Their presence was higher closer to human settlements (used probably as a roosts), but their overall activity was higher further from settlements (probably used as a foraging site). *M. nattereri* was the only species, which displayed higher activity and also higher presence on FS sites.

4) Activity of different bat groups was analysed on CS/FS sites, dividing bats as gleaners/hawkers; broad/narrow winged; artificial/natural roosts inhabitants and according to preferences of anthropogenically altered/natural habitat. I figured out that: aerial hawkers, narrow winged bats, bats using artificial roosts and bats using anthropogenically altered habitats show higher actvity closer to human settlements, which was confirmed statistically. Conversely gleaners and broad winged bats show higher activity further from the human settlements, which was

not statistically confirmed as well as higher activity on CS sites in case of bats using natural habitats and natural roosts.

5) Results of CCA show, that habitat and landscape parameters explain 18, 5 % of variability of collected data and the impact of landscape parameters on the bat distribution is not significant. Important factor determining occurrence of particular bat species seems to be altitudinal gradient.

6) The large variability between study sites caused less significant results, thus I recommend to collect more data, which would follow criteria set in this study.

7) My results showed higher activity and presence of bats closer to human settlements, which indicates positive ongoing process of synanthropization. With the knowledge of ecology of each bat species, people can provide better and more suitable habitats for bats, preclude inappropriate human interventions in particular habitats and in many cases have a profit from living with bats in symbiosis.

7 References

Abbott IM, Sleeman DP, Harrison S. 2009. Bat activity affected by sewage effluent in Irish rivers. Biological Conservation 142: 2904 – 2914.

Adams MD, Law BS, French KO. 2009. Vegetation structure influences the vertical stratification of open- and edge-space aerial-foraging bats in harvested forests. Forest Ecology and Management 258: 2090 – 2100.

Ahlén I. 1981. The identification of Swedish bats by their sounds. Swedish University Agricultural Science Report 6: 1-56.

Ahlén I. 1990. Identification of bats in flight. Stockholm. Katarina Tryck AB, 50p.

Akasaka T, Nakano D, Nakamura F. 2009. Influence on prey variables, food supply, and river restoration on the foraging activity of Daubenton´s bat (*Myotis daubentonii*) in the Shibetsu River, a large lowland river in Japan. Biological Conservation 142: 1302 – 1310.

Albrecht K, Hammer M, Holzhaider J. 2002. Telemetrische Untersuchungen zum Nahrungshabitatanspruch der Bechsteinfledermaus (*Myotis bechsteinii*) in Nadelwäldern bei Amberg in der Oberpfalz. Schriftenreihe für Landschaftspflege und Naturschutz 71: 109 – 130.

Aldridge HDJN. 1987. Turning flight of bats. Journal of Experimental Biology 128: 419 – 425.

Ancillotto L, Santini L, Ranc N, Maiorano L, Russo D. 2016. Extraordinary range expansion in a common bat: the potential roles of climate change and urbanisation. The Science of Nature 103: 3 - 4.

Anděra M, Hanák V. 2007. Atlas rozšíření savců v České republice, V. letouni (Chiroptera) – část 3. netopýrovití (Vespertilionidae – *Vespertilio, Eptesicus, Nyctalus, Pipistrellus* a *Hypsugo*). Předběžná verze. – Národní muzeum, Praha, 172 p.

Andreas M, Reiter A, Cepáková E, Uhrin M. 2013. Body size as an important factor determining trophic niche partitioning in three syntopic rhinolophid bat species. Biologia 68: 170 – 175.

Arnett EB, Brown WK, Erickson WP, Fiedler JK, Hamilton BL, Henry TH, Jain A, Johnson GD, Kerns J, Koford JRR, Nicholson CP, O´Conell TJ, Piorowski MD, Tankersley RD. 2008. Patterns of bat fatalities at wind energy facilities in North America Journal of Wildlife Management 72: 61 - 78.

Ashrafi S, Beck A, Rutishauser M, Arlettaz R, Bontadina F. 2011. Trophic niche partitioning of cryptic species of long-eared bats in Switzerland: implications for conservation. European Journal of Wildlife Research 57: 843 – 849.

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

Avila-Flores R, Fenton MB. 2005. Use of Spatial Features by Foraging Insectivorous Bats in a Large Urban Landscape. Journal of Mammalogy 86: 1193 – 1204.

Avery MI. 1985. Winter activity of pipistrelle bats. Journal of Animal Ecology 54: 721 – 738.

Baagøe HJ. 1986. Summer Occurrence of *Vespertilio murinus* LINNÉ - 1758 and *Eptesicus serotinus* (SCHREBER - 1780) (Chiroptera, Mammalia) on Zealand, Denmark, based on

records of roosts and registrations with bat detectors. Naturhistorisches Museum Wien 88/89: 281 – 291.

Baagøe HJ. 2001. *Vespetilio murinus*, Linnaeus, 1758 - Zweifarbfledermaus. In: Krapp F (ed). Die Fledermäuse Europas. Wiebelsheim, Aula-Verlag: 473 - 513.

Bader E, Jung K, Kalko EKV, Page RA, Rodriguez R, Sattler T. 2015. Mobility explains the response of aerial insectivorous bats to anthropogenic habitat change in the Neotropics. Biological Conservation 186: 97 – 106.

Baerwald EF, D'Amours GH, Klug BJ, Barclay RMR. 2008. Barotrauma is a significant cause of bat fatalities at wind turbines. Current Biology 18: 695 – 696.

Barr CJ, Bunce RGH, Clarke RT, Fuller RM, Furse MT, Gillespie MK, Groom GB, Hallam CJ, Hornung M, Howard DC, Ness MJ. 1993. Countryside Survey 1990 – Main Report. London. Department of the Enviroment. 180p.

Bas Y, Haquart A, Tranchard J, Lagrange H. 2014. Suivi annuel continu de l'activité des chiroptères sur 10 mâts de mesure: évaluation des facteurs de risque lié à l'éolien. Symbioses, Actes des 14èmes Rencontres Nationales Chauves Souris de la SFEPM. Bourges mars 32: 83 - 87.

Belton P. Kempster R. 1962. A field test on the use of sound to repel the European corn borer. Entomologia Experimentalis et Applicata 5: 281 - 288.

Belwood JJ. 2002. Endangered bats in suburbia: observations and concerns for the future. In: The Indiana bat: biology and management of an endangered species. Kurta A, Kennedy J (eds). Austin: Bat Conservation International, 193 – 198.

Benda P, Hanák V. 2003. Současný stav rozšíření netopýra brvitého (*Myotis emarginatus*) v Čechách. Vespertilio 7: 71 – 86.

Bennet AF, Lumsden LF, Nichols AO. 1994. Tree hollows as a resource for wildlife in remnant woodlands: spatial and temporal patterns across the northern plains of Victoria, Australia. Pacific Conservation Biology 1: 222 – 235.

Bennet AF. 2003. Linkages in the Landscape. In: The Role of Corridors and Connectivity in Wildlife Conservation. IUCN The World Conservation Union, Gland, 254p.

Bernard E, Fenton MB. 2007. Bats in a fragmented landscape: Species composition, diversity and habitat interactions in savannas of Santare´m, Central Amazonia, Brazil. Biological Conservation 134: 332 – 343.

Bernd-Ulrich R, Liegl A, Helversen O. 2009. Habitat selection and Activity Patterns in the Greater Mouse-eared Bat (*Myotis myotis*). Acta Chiropterologica 11: 351 – 361.

Bogdanowicz W, Ruprecht AL. 2004. *Nyctalus leisleri* (Kuhl, 1817) – Kleinabendsegler (In: Krapp F (ed). Die Fledermäuse Europas. Wiebelsheim, Aula-Verlag: 717–756.

Bontadina F, Arlettaz R, Fankhauser T, Lutz M, Muhlethaler E, Theiler A, Zingg,P. 2000. The lesser horseshoe bat *Rhinolophus hipposideros* in Switzerland: present status and research recommendations. Le Rhinolophe 14, 69–83.

Boston ESM, Buckley DJ, Bekaert M., Gager Y, Lundy MG, Scott DD, Prodöhl PA, Montgomery WI, Marnell F, Teeling EC. 2010. The status of the cryptic species, *Myotis mystacinus* (Whiskered bat) and *Myotis brandtii* (Brandt's bat) in Ireland. Acta Chiropterologica 12: 457 – 461.

Boughey KL, Lake IR, Haysom KA, Dolman PM. 2011. Effects of landscapescale broadleaved woodland configuration and extent on roost location for six bat species across the UK. Biological Conservation 144: 2300 – 2310.

Boyd IL, Stebbings RE. 1989. Population changes of brown long-eared bats (*Plecotus auritus*) in bat boxes in Thetford Forest. Journal of Applied Ecology 26: 101 – 112.

ter Braak CJF, Šmilauer P. 2002. CANOCO Reference manual and CanoDraw for Windows User's guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca, NY, USA. 352 p.

Brigham RM, Vonhof M, Barclay RMR, Gwilliam JC. 1997. Roosting behaviour and roost-site preferences of forest-dwelling California bats (*Myotis californicus*). Journal of Mammaology 78: 1231 – 1239.

Brinkmann RE. Hensle E, Steck C. 2001. Artenschutzprojekt Wimperfledermaus. Freiburg. Gutachten im Auftrag der Landesanstalt für Umweltschutz 50p.

Broders HG, Quinn GM, Forbers GJ. 2003. Species status and the spatial and temporal patterns of activity of bats in southwest Nova Scotia Canada. Northeastern Naturalist 10: 383 – 398.

Buckley DJ, Lundy MG, Bostona ESM, Scott DD, Gager Y, Prodöhl P, Marnell F, Montgomery WI, Teelinga EC. 2013. The spatial ecology of the whiskered bat (*Myotis mystacinus*) at the western extreme of its range provides evidence of regional adaptation. Mammalian Biology 78: 198 – 204.

Campbell S, Lumsden LF, Kirkwood R, Coulson G. 2005. Day roost selection by female little forest bats (*Vespadelus vulturnus*) within remnant woodland on Philip Island, Victoria. Wildlife Research 32: 183 – 191.

Catto CM, Hutson AM, Racey PA, Stephenson PJ. 1996. Foraging behaviour and habitat use of the serotine bat (*Eptesicus serotinus*) in south-ern England. Journal of Zoology 238: 623-633.

Ceľuch M, Kaňuch P. 2004. Foraging and flight activity of bats in beech-oak forest (Western Carpathians). Folia Oecologica 31: 8 – 16.

Ceľuch M, Kropil R. 2008. Bats in a Carpathian beech-oak forest (Central Europe): habitat use, foraging assemblages and activity patterns. Folia Zoologica 57: 358 – 372.

Ceľuch M, Zahn A. 2008. Foraging habitats preferences of bats: new question in interpretation of bat detector data. Vespertillio 12: 3 - 9.

Ciechanowski M. 2015. Habitat preferences of bats in anthropogenically altered, mosaic landscapes of northern Poland. European Journal of Wildlife Research 61: 415 – 428.

Ciechanowski M, Zając T, Biłas A, Dunajski R. 2007. Spatiotemporal variation in activity of bat species differing in hunting tactics: effects of weather, moonlight, food abundance, and structural clutter. Canadian Journal of Zoology 85: 1249 – 1263.

Chazdon RL. 2014. Second growth. The promise of tropical forest regenaration in an age of deforastation. Chicago. Chicago Press: 472p.

Clark BS, Leslie DM, Carter TS. 1993. Foraging activity of adult female ozark big-eared bats (*Plecotus townsendii ingens*) in summer. Journal of Mammalogy 74: 422 - 427.

Constantine DG. 1998. An overlooked external character to differentiate *Myotis californicus* and *Myotis ciliolabrum* (Vespertilonidae). Journal of Mammalogy 79: 624 – 630.

Cooper–Bohannon R. 2015. Assessing the distribution of bats in southern Africa to highlight conservation priorities. Stirling: University of Stirling. 273p.

Crampton LH, Barclay RMR. 1998. BiologySelection of Roosting and Foraging Habitat by Bats in Different-Aged Aspen Mixedwood Stands. Conservation Biology 12: 1347 – 1358.

Davidson-Watts I, Jones G. 2006. Differences in foraging behaviour between *Pipistrellus pipistrellus* (Schreber, 1774) and *Pipistrellus pygmaeus* (Leach, 1825). Journal of Zoology 2006; 268: 55 – 62.

Davidson-Watts I, Walls S, Jones G. 2006. Differential habitat selection by *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus* identifies distinct conservation needs for cryptic species of echolocating bats. Biological Conservation 133: 118 – 127.

De Jong J. 1994. Habitat use, home-range and activity pattern of the northern bat, *Eptesicus nilssoni*, in a hemiboreal coniferous forest. Mammalia 58: 535 – 548.

DeJong J. 1995. Habitat use and species richness of bats in a patchy landscape. Acta Theriologica 40: 237 – 248.

Delaval M, Charles Dominique P. 2006. Edge effects on frugivorous and nectarivorous bat communities in neotropical primary forest in French Guyana. Revue d'Écologie 61: 343 – 352.

Dense C, Rahmel U. 2002. Untersuchungen zur Habitatnutzung der Großen Bartfledermaus (*Myotis brandtii*) im norwestlichen Niedersachsen. Schriftenreihe für Landschaftspflege und Naturschutz 71: 51 - 68.

Dietz CH, Helversen O. 2004. Illustrated identification key to the bats of Europe [online]. Electronic publication. Version 1.0., 35 str. Available at: http://biocenosi.dipbsf.uninsubria.it/didattica/bat_key1.pdf (25. 1. 2016).

Dietz CH, Dietz I, Siemers BM. 2006. Wing measurement variations in five european horseshoe bat species (Chiroptera: Rhinolopidae). Journal of Mammalogy 87: 1241 – 1251.

Dietz CH, Helversen O, Nill D. 2007. Bats of Britian, Europe and Nortwest Africa. London: A & C Black Publisher Ltd. 400p.

Dietz M, Pir JB. 2009. Distribution and habitat selection of *Myotis bechsteinii* in Luxembourg: implications for forest management and conservation. Folia Zoologica 58: 327 – 340.

Dobat K. 1985. Blüten und Fledermäuse. Rafnkfurt am Main, Waldemar Kramer: 370p.

Dondini G, Vergari S. 2000. Carnivory in the greater noctule bat (*Nyctalus lasiopterus*) in Italy. Journal of Zoology 251: 233 – 236.

Ekman M., De Jong J. 1996. Local patterns of distribution and resource utilisation of four bat species (*Myotis brandtii, Eptesicus nilsonni, Plecotus auritus* and *Pipistrellus pipistrellus*) in patch and continuous environments. Journal of Zoology 238: 571 – 580.

Estrada A, Coates-Estrada R. 1988. Tropical rain forest conversion and perspectives in the conservation of wild primates (Alouatta and Ateles) in Mexico. American Journal of Primatology 14: 315 - 327.

Estrada A, Coates-Estrada R. 2001. Bat species richness in live fences and i corridors of residual rain forest vegetation at Los Tuxtlas, Mexico. Ecography 24: 94 – 102.

Estrada A, Coates-Estrada R. 2002. Bats in continuous forest, forest fragments and in an agricultural mosaic habitat-island at Los Tuxtlas, Mexico. Bilogical Conservation 103: 237 – 245.

Estrada-Villegas S, Meyer CFJ, Kalko EKV. 2010. Effects of tropical forest fragmentation on aerial insectivorous bats in a land-bridge island system. Biological Conservation 143: 597 – 608.

Ethier K, Fahrig L. 2011. Positive effects of forest fragmentation, independent of forest amount, on bat abundance in eastern Ontario, Canada. Landscape Ecology 26: 865 – 876.

Evelyn MJ, Stiles DA, Young RA. 2004. Conservation of bats in suburban landscapes: roost selection by *Myotis yumanensis* in a residental area in California. Biological Conservation 109: 95 – 102.

Farnenda FZ, Rocha R, Lopez-Baucells A, Groenberg M, Silva I, Palmeirim JM, Bobrowiec PE, Meyer CHJ. 2015. Trait-related responses to habitat fragmentation in Amazonian bats. Journal of Applied Ecology 52: 1381 – 1391.

FAO, 2015. Global Forest Resources Assessments 2015. Food and Agriculture Organization of the United Nations, Rome.

Fenton MB. 1970. Population studies of *Myotis lucifugus* (Chiroptera: Vespertilionidae) in Ontario.

Fenton MB. 1990. The foraging behaviour and ekology of animal-eating bats. Canadian Journal of Zoology 68: 411 – 422.

Fenton MB. 1997. Science and the Conservation of Bats. Journal of Mammalogy 78: 1 – 14.

Fenton MB, Boyle NGH, Harrison TM, Oxley DJ. 1977. Activity patterns, habitat use, and prey selection by some African insectivorous bats. Biotropica 9: 73 - 85.

Fenton MB, Rautenbauch IL. 1986. A comparison of the roosting and foraging behaviour of three species of African insectivorous bats (Rhinolopidae, Vespertilonidae and Moossidae). Canadian Journal of Zoology 64: 2860 – 2867.

Fenton MB, Simmons NB. 2015. Bats: A world of Science and Mystery. Chicago. University of Chicago Press. 240p

Fernandez AZ. 1999. Draculin, the anticoagulant factor in vampire bat saliva, is a tight-binding, noncompetitive inhibitor of activated factor X. Biochimica et Biophysica Acta 1434: 135 – 142.

Findley JS, Wilson DE. 1974. Observation of neotropical disk-winged bats, *Thyroptera tricolor*. Spix. Journal of Mammalogy 55: 562 – 571.

Flaquer C, Puig-Montserrat X, Goiti U, Vidal F, Crurcó A, Russo D. 2009. Habitat selection in Nathusius' pipistrelle (*Pipistrellus nathusii*): the importance of wetlands. Acta Chiropterologica 11: 149 – 155.

Flavin DA, Biggane SS, Shiel CB, Smiddy P, Fairley JS. 2001. Analysis of the diet of Daubenton´s bat *Myotis daubentonii* in Ireland. Acta Theriologica 46: 43 – 52.

Francis CM. 1990. Trophic structure of bat communities in the understorey of lowland dipterocarp rain forest in Malaysia. Journal of Tropical Ecology 6: 421 – 431.

Frey-Ehrenbold A, Bontadina F, Arlettaz R, Obrist MK. 2013. Landscape connectivity, habitat structure and activity of bat guilds in farmland-dominated matrices. Journal of Applied Ecology. 50: 252 – 261.

Froidevaux JSP, Zellweger F, Bollmann K, Jones G, Obrist MK. 2016. From field surveys to LiDAR: Shining a light on how bats respond to forest structure. Remote Sensing of Environment. 175: 242 – 250.

Gaisler J. 1971. Zur Ökologie von *Myotis emarginatus* in Mitteleuropa. Decheniana-Beihefte 18: 71 – 82.

Gaisler J, Zukal J, Řehák Z, Homolka M. 1998. Habitat preference and flight activity of bats in a city. Journal of Zoology 244: 439 – 445.

Gannon WL, Sherwin RE, de Carvalho TN, O'Farell MJ. 2001. Pinnae and echolocation call differences between *Myotis californicus* and M. *ciliolabrum* (Chiroptera: Vespertilonidae). Acta Chiropterologica 3: 77 – 91.

Gardner JE, Hofmann JE, Garner JD. 1991. Summer roost selection and roosting behaviour of *Myotis sodalis* (Indiana bat) in Illinois. Unpublished report, Illinois Natural History Survey, Champaign. 66p.

Gardner TA, Barlow J, Chazdon R. Ewers RM, Harvey CA, Peres CA, Sodhi NS. 2009. Prospects for tropical forest biodiversity in a human-modified world. Ecology Letter 12: 561 – 582.

Gehrt SD, Chelsvig JE. 2004. Species-specific patterns of bat activity in an urban landscape. Ecological Applications 14: 625 - 635.

Gellman ST, Zielinski WJ. 1996. Use by bats of old-growth redwood hollows on the north coast of California. Journal of Mammalogy 77: 255 – 265.

Gerrell R, Lundberg K. 1993. Decline of a bat, *Pipistrellus pipistrellus*, population in an industrialised area in southern Sweden. Biological Conservation 65: 153 – 157.

Griffin DR. 1971. The importance of atmospheric attenuation for the echolocation of bats (Chiroptera). Animal Behavioral 19: 55 – 61.

Gouge D, Li S, Nair S. 2015. Bats. The University of Arizona Cooperative Extension. 11p. Available at: https://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1675-2015.pdf (9. 4. 2016)

Groom MJ, Meffe GK, Carroll CR. 2006. Principle of Conversation Biology, 3rd edition. Massachusetts, Sinauer Associates, Inc.: 779p.

Güttinger R. 1997. Jagdhabitate des Groβen Mausohrs (*Myotis myotis*) in der modernen Kulturlandschaft. Buwal-Schriftenreihe Umwelt 288: 1 – 104.

Güttinger R, Zahn A, Krapp F, Schoeber W. 2011. *Myotis myotis*, Groβemausohr. In: Krapp F (ed). Die Fledermäuse Europas. Wiebelsheim, Aula-Verlag: 123 - 207.

Hale JD, Fairbrass AJ, Matthews TJ, Sadler JP. 2012. Habitat Compostition and Connectivity Predicts Bat Presence and Activity at Foraging sites in Large UK Conurbation. PLoSONE 7: 1- 12.

Han H, Wen H, Zhou CH. et al. 2015. Bat**s** as reservoirs of severe emerging infectious diseases. Virus Research 205: 1 – 6.

Hanák V, Neckářová J, Benda P, Hanzal V, Anděra M, Horáček I, Jahelková H, Zieglerová A, Zeiglerová D. 2009. Fauna netopýrů Prahy: přehled nálezů a poznámky k urbánním populacím netopýrů. Praha. Natura Pragensis 19: Studie o přírodě Prahy, 3 - 89.

Handley CO, Morrison DW. 1991. Foraging behavior. In: Demography and natural history of the common fruit bat, *Artibeus jamaicensis*, on Barro Colorado Island, Panama. Handley CO, Wilson DE, Gardner AL (eds). Smithsonian Contributions to Zoology. Washington. Smithsonian Institution Press 511: 137-140

Haupt M, Menzler S, Schmidt S. 2006. Flexibility of habitat use in *Eptesicus nilssonii*: Does the species profit from anthropogenically altered habitat? Journal of Mammalogy 87: 351 – 361.

Häussler U, Nagel A, Braun M, Arnold A. 1999. External characters discriminating sibling species of European pipistrelles, *Pipistrellus pipistrellus* and *P. pygameus*. Myotis 37: 27 – 40.

Haysom KA, Jones G, Merrett D, Racey PA. 2010. Bats. In: Silent Summer. Maclean N (ed.). The State of Wildlife in Britain and Ireland. Cambridge University Press: 259–280.

Hayward BJ, Davis RP. 1964. Flight speed in western bats. Journal of Mammaology 45:236 – 242.

Hecker KR, Brigham MR. 1999. Does moonlight change vertical stratification of activity by forest-dwelling insectivorous bats? Journal of Mammalogy 80: 1196 – 1201.

von Helversen O, Heller KG, Mayer F, Nemeth A, Volleth M, Gombkőtő P. 2001. Cryptic mammalian species: a new species of whiskered bat (*Myotis alcathoe* n. sp.) in Europe. Naturwissenschaften 88: 217 – 223.

Hermanns U, Pommeranz H, Schütt H. 2001. Erste Ergebnisse einer systematischen Erfassung der Zweifarbfledermaus, *Vespertilio murinus*, in Mecklenburg-Vorpommern im Vergleich zu Untersuchungen in Ostpolen. Nyctalus (N.F.) 7: 532 – 554.

Hristov NI, Conner WE. 2005. Sound strategy acoustic aposematism in the bat-tiger moth arms race. *Naturwissenschaften* 92**:** 164 – 169.

Hofmann JE, Gardener JE, Krejca JK. 1999. Summer records and a maternity roost of the southeastern myotis (*Myotis austroriparius*) in Illinois. Transactions of the Illinois State Academy of Science 92: 95 – 107.

Horáček I, Uhrin M. 2010. A tribute to bats. Kostelec nad Černými lesy: The Publishing House Lesnická Práce, s.r.o. 400p.

Horáček I, Knitlová M, Kipson M. 2014. *Hypsugo savii* and other Mediterranean bats colonized Europe already in the earliest Holocene. Conference paper.

Horáček I, Jahelková H. 2005. History of the *Pipistrellus pipistrellus* group in Central Europe in light of its fossil record. Acta Chiropterologica: 7: 189 – 204.

http://plateauecological.com/services/indiana_and_northern_long-eared_bat_consultation (Available 5.3.2016).

http:// www.apodemus.eu (Available 11.4.2016).

http://www.bats.org.uk/pages/living_with_bats.html (Available 5.3.2016).

http://www.bedsbatgroup.org.uk/wordpress/?page_id=1450 (Available 5.3.2016).

http://www.bhphotovideo.com (Available 11. 4. 2016).

http://ceson.org/media/tab1.htm (Available 5.3.2016).

http://fivethirtyeight.com/datalab/big-data-is-saving-this-little-bird/ (Available 11. 4. 2016).

https://www.gardenature.co.uk/bat-box-1ff (Available 5.3.2016).

http://www.mapy.cz

Humes ML, Hayes JP, Collopy MW. 1999. Bat activity in thinned, unthinned and old-growth forests in western Oregon. Journal of Wildlife Management 63: 553 – 561.

Hutson AM, Mickleburgh SP, Racey PA. 2001. Microchiropteran Bats – GlobalStatus Survey and Conservation Action Plan. IUCN, Gland. 272p.

Hutson MA, Marnell F, Tõrv T. 2015. EUROBATS. A guide to the implementation of the Agreement on the Conservation of Populations of European Bats (EUROBATS). Bonn. Online   at: http://www.eurobats.org/sites/default/files/documents/publications/other_available_publ ications/ImplementationGuideFINAL.pdf. (Available 27. 3. 2016).

Ibáñez C. Guillén A, Bogdanowicz W. 2004. *Nyctalus lasiopterus* (Schreber, 1780) Riesenabendsegler. In: Krapp (ed) Handbuch der Säugetiere Europas, Fledertiere (Chiroptera) II. Aula-Verlag, Wiebelsheim. pp. 695–716.

Jahelková H. 2003. Přehled a srovnání echolokačních signálů čtyř evropských druhů netopýrů rodu *Pipistrellus* (Chiroptera: Vespertilionidae). Praha. Lynx n. s., 34: 13-38.

Jantzen MK, Fenton MB. 2013. The depth of edge influence among insectivorous bats at forestfield interfaces. Canadian Journal of Zoology 91: 287 – 292

Jefferies DJ. 1972. Organochlorine insecticide residues in British bats and their significance. Journal of Zoology 166: 245–263.

Jones G. 1999. Scaling of echolocation call parameters in bats. The Journal of Experimental Biology 202: 3359 – 3367.

Jones G, Rayner JMV. 1991. Flight performance, foraging tactics and echolocation in the trawling insectivorous bat *Myotis adversus* Chiroptera: Vespertilionidae. Journal of Zoology 225: 393 – 412.

Jones G, Duverge PL, Ransome RD. 1995. Conservation biology of an endangered species: field studies of greater horseshoe bats. Symposium of the Zoological Society London 67: 309 -324.

Jones G. 1996. Does echolocation constrain the evolution pulse emission rates in bats: why are aerial insectivorous bats so small? Functional Ecology 8: 450 – 457.

Jones KE, Purvis A, Gittleman JL. 2003. Biological Correlates of Extinction Risk in Bats. The American Naturalist 161: 601 – 614.

Jung K, Kalko EKV. 2010. Where forest meets urbanization: foraging plasticity of aerial insectivorous bats in an anthropogenically altered environment. Journal of Mammalogy 91: 144 – 153.

Jung K, Threlfall CG. 2016. Urbanisation and Its Effects on Bats- A Global Meta-Analysis. In: Bats in the Anthropocene: Conservation of Bats in a Changing World. Voigt CCH, Kingston T (eds.). Springer open. 606p.

Kalcounis MC, Brigham RM. 1995. Intraspecific variation in wing loading affects habitat use by little brown bats (*Myotis lucifugus*). Canadian Journal of Zoology 73: 89–95.

Kalcounis-Rüppell MC, Psyllakis JM, Brigham RM. 2005. The roost selection by bats: an empirical synthesis using meta-analysis. Wildlife Society Bulletin 33: 1123 – 1332.

Kalko EKV, Schnitzler H-U. 1993. Plasticity in echolocation signals of European pipistrelle bats in search flight: implications for habitat use and prey detection. Behavioral Ecology and Sociobiology 33: 415 – 428.

Kalko EKV, Handley CO Jr., Handley D. 1996. Organization, diversity, and long – term dynamics of a Neotropical bat community. In: Cody ML, Smallwood JA (eds.). Long-Term studies of Vertebrate Communities. San Diego, Academic Press: 503 – 553.

Kalko EKV, Friemel D, Handley Jr. CO, Schnitzler H-U. 1999. Roosting and foraging behaviour of two Neotropical gleaning bats, *Tonatia silvicola* and *Trachops cirrhosus* (Phyllostomidae). Bitropica 31: 344 – 353.

Kaňuch P, Danko Š, Ceľuch M, Krištín A, Pjenčák P, Matis Š, Šmídt J. 2008. Relating bat species presence to habitat features in natural forests of Slovakia (Central Europe). Mammalian Biology 73: 147 – 155.

Kaňuch P, Fornůsková A, Bartonička T, Řehák Z, Bryja J. 2010. Do the two cryptic pipistrelle bat species differ in their autumn and winter roosting strategies within the range of sympatry? Folia Zoologica 59: 102 – 107.

Karlsson BL, Eklöf J, Rydell J. 2002. No lunar phobia in swarming insectivorous bats (family Vespertilionidae). Journal of Zoology 256: 473 - 477.

Kerth G, Weissmann K, Konig B. 2000. Day-roost selection in female Bechstein´s bats (*Myotis bechsteinii*): a field experiment to determine the influence of roost temperature. Oecologia 126: 1 – 9.

Kofron CP. 1994. Bamboo-roosting of the thick-thumbed pipistrelle bat (*Glischropus tylopus*) in Borneo. Mammalia 58: 306 – 309.

Kovaříková K. 2013. Bat Monitoring of the Zbraslav region. [BSc.]: Czech University of LifeSciences Prague, 81p.

Kovaříková K, Neckářová J. New records of the Northern Bat (*Eptesicus nilssonii*) in Prague. In press.

Krapp F (ed). Die Fledermäuse Europas. Wiebelsheim, Aula-Verlag. 1202p.

Kronwitier F. 1988. Population structure, habitat use and activity patterns of the noctule bat, *Nyctalus noctula* Schreb., 1774 (Chiroptera: Vespertilionidae) revealed by radio-tracking. Myotis 26: 23-85.

Krull D, Schumm A, Metzner W, Neuweiler G. 1991. Foraging areas and foraging behaviour in the Geoffroy's bat, *Myotis emarginatus* (Vespertilionidae). Behavioral Ecology and Sociobiology 28: 247 – 253.

Krusic RA, Yamasaki M, Neefus CD, Pekins PJ. 1996. Bat habitat use in White Mountain National Forest. Journal of Wildlife Management 60: 625 - 631.

Kunz TH. 1982. Roosting ecology of bats. In: Ecology of Bats Kunz TH (ed.). New York. Plenum Press: 1 -55.

Kunz TH, Fenton MB. 2003. Bat Ecology. Chicago, University of Chicago Press: 779p.

Kunz TH, Lumsden LF. 2003. Ecology of cavity and foliage roosting bats. In: Kunz TH and Fenton MB (eds). Bat Ecology. Chicago, University of Chicago Press: 3 – 89.

Kunz TH, Reynolds DS. 2003. Bat colonies in buildings. In: Monitoring Trends in Bat Populations of the U.S. and Territories: Problems and Prospects. O'Shea TJ, Bogan MA (eds.). U.S Geological Survey, Biological Resources Division. Washington DC. Information and Technology Report: 91 – 102.

Kunz TH, Parsons S. 2009. Ecological and Behavioral Methods for the Study of Bats. Baltimore. The Johns Hopkins University Press: 901p.

Kunz TH, Arnett EB, Erickson WP. 2007. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Frontiers in Ecology and the Enviroment 5: 315 – 324.

Kunz TH, de Torrez EB, Bauer D, Lobovat T, Fleming TH. 2011. Ecosystem services provided by bats. Annals of the New York Academy of Sciences 1223: 1 - 38p.

Kurta A, Bell GP, Nagy KA, Kunz TH. 1989. Energetics of pregnancy and lactation in free-ranging little brown bats (*Myotis lucifugus*). Physiological Zoology 62: 804 – 818.

Kurtze W. 1982. Beobachtungen zur Flugaktivität und Ernährung der Breitflügel-Fledermaus *Eptesicus serotinus* (Schreber). Drosera, 82: 39 – 46.

Kusch J, Weber C, Idelberger S, Koob T. 2004. Foraging habitat preferences of bats in relation to food supply and spatial vegetation structures in a western European low mountain range forest. Folia Zoologica 53: 113 – 128.

Lacki MJ, Hayes JP, Kurta A. (eds.) 2007. Bats in forests: Conservation and Management. Baltimore. The John Hopkins University Press. Baltimore: 329p.

Lausen CL. 2005. First record of hosts for the bat tick. *Carios kelleyi* (Acari: Ixodida: Argasidae) in Canada and Montana. Journal of Medical Entomolgy. 42: 497 – 501.

Lausen CL, Barcley RMR. 2006. Benefits of living in building: Big brown bats (*Eptesicus fuscus*) in rocks versus buildings. Journal of Mammalogy 87: 362 – 370.

Law BS, Chidel M. 2001. Bat activity 22 years after first round intensive logging of alternate coupes near Eden, New South Wales. Australian Forestry 64: 242 – 247.

Law B, Park KJ, Lacki MJ. 2016. Insectivorous Bats and Silviculture: Balancing Timber Production and Bat Conservation. In: Bats in the Anthropocene: Conservation of Bats in a Changing World. Voigt CCH, Kingston T (eds.). Springer open. 606p.

Lekagul B, McNeely JA. 1977. Mammals of Thailand. Bankog, Association for the Conservation of Wildlife: 758p.

Lesiński G, Fuszara E, Kowalski M. 1999. Foraging areas and relative density of bats (Chiroptera) in differently human transformed landscapes. Zeitschrift für Säugetierkunde 65: 129 – 137.

Lesiński G, Olszewski A, Popczyk B. 2011. Forest roads used by commuting and foraging bats in edge and interior zones. Polish Journal of Ecology 59: 611 – 616.

Lewis SE. 1995. Roost fidelity of bats: a review. Journal of Mammalogy 76: 481 – 496.

Lintott PR, Bunnefeld N, Minderman J, Fuentes-Montemyor E, Mayhew RJ, Olley L, Park KJ. 2015. Differential Responses to WoodlandCharacter and Landscape Context by Cryptic Bats in Urban Environments. PLoS One 10: e0126850. doi:10.1371/journal.pone.0126850.

Lisón F, Calvo JF. 2013. Ecological niche modelling of three pipistrelle bat species in semiarid Mediterranean landscapes. Acta Oecologica 47: 68 – 73.

Lloyd B, Mc-Queen S. 1997. Roosting behaviour of *Mystacina tuberculata* in central North Island, New Zealand. Australasian Bat Society Newsletter 7: 57.

Lučan RK, Hanák V, Horáček I. 2009a. Long-term re-use of tree roosts by European forest bats. Forest Ecology and Management 258: 1301 – 1306.

Lučan RK, Andreas M, Benda P, Bartonička T, Březinová T, Hoffmanová A, Hulová Š et al. 2009b. Alcathoe bat (*Myotis alcathoe*) in the Czech Republic: Distributional Status, Roosting and Feeding Ecology. Acta Chiropterologica 11: 61 – 69.

Lučan RK, Benda P, Reiter A, Zima J. 2011. Reliability of field determination in three cryptic whiskered bats (*Myotis alcathoe, M. mystacinus, M. brandtii*) and basic biometric characters: evidence from the Czech Republic. Vespertilio 15: 55 – 62.

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

Maeda K. 1974. Eco-ethologie de la grande noctule, *Nyctalus lasiopterus,* a Sappora, Japon. Mammalia 38: 461 – 487.

Maslo B, Valent M, Gumbs JF, Frick W. 2015. Conservation implications of ameliorating survival of little brown bats with white-nose syndrome. Ecologial Applications 25: 1832 – 1840.

McKenna MC, Bell SK. 1997. Classification of Mammals above the Species Level. New York, Columbia University Press. 640p.

Meij T, Strien AJ, Haysom KA, Dekker J, Russ J, Biala K, Bihari Z, Jansen E, Langton S, Kurali A, Limpens H, Meschede A, Peterson G, Presetnik P, Prüger J, Reiter G, Rodrigues L, Schorcht W, Uhrin M, Vintulis V. 2015. Return of the bats? A prototype indicator of trends in European bat populations in underground hibernacula. Mammalian Biology 80: 170 – 177.

Menzel MA, Carter TC, Ford WM, Chapman BR. 2001. Tree-roost characteristics of subadult and female adult evening bats (*Nycticeius humeralis*) in upper coastal plain of South Carolina. American Midland Naturalist 145: 112 – 119.

Meyer CFJ, Schwarz CJ, Fahr J. 2004. Activity Patterns and Habitat Preferences of Insectivorous Bats in a West African Forest-Savanna Mosaic. Journal of Tropical Ecology 20: 397 – 407.

Meyer CFJ, Fründ J, Lizano WP. 2008. Ecological correlates of vulnerability to fragmentation in Neotropical bats. Journal of Applied Ecology 45: 381 - 391.

Mitchell-Jones AJ, Cooke AS, Boyd IL, Stebbings RE. 1989. Bats and remedialtimber treatment chemicals – a review. Mammal Review 19: 93–110.

Mitchell-Jones T, Amori G, Bogdanowicz W, Kryštufek B, Reijnders PJH, Spitzenberger F, Stubbe M, Thissen JBM, Vohralík V, Zima J. 1999. The atlas of European mammals. London. Academic Press. 250p.

Morrison DW. 1979. Apparent male defense of tree hollows in the fruit bat, *Artibeus jamaicensis.* Journal of Mammalogy 61: 20 – 29.

Mortimer J. 2006. Foraging, roosting and survival of Natterer´s bat (*Myotis nattereri*), in a commercial coniferous plantation. [Ph.D]. St. Andrews: University of St Andrews, 199p.

Müller J, Brandl R, Büchner J, Pretzsch H, Seifert S, Strätz Ch, Veith M, Fenton B. 2013. From ground to above canopy – Bat activity in mature forest is driven by vegetation density and height. Forest Ecology and Management 306: 179 – 184.

Napal M, Garin I, Goiti U, Salsamendi Em Aiharza J. 2009. Selestion of maternity roosts by Myotis bechsteinii (Kuhl. 1817) in the Southwestern Iberian Peninsula. Acta Chiropterologica 11: 425 – 433.

Napal M, Garin I, Goiti U, Salsamendi E, Aihartza J. 2013. Past deforestation of Mediterranean Europe explains the present distribution of the strict forest dweller *Myotis bechsteinii*. Forest Ecology and Management 293: 161 – 170.

Neuweiler G. 1983. Echolocation and adaptavity to ecological constraints. In: Neuroethology and behavioural physiology. Huber F, Markl H (eds.). Berlin. Springer-Verlag: 280 – 302.

Neuweiler G. 1989. Foraging ecology and audition in echolocating bats. Trends in Ecology and Evolution 4: 160 – 166.

Neuweiler G. 1990. Auditory adaptations for prey capture in echolocating bats. Physiological Reviews 70: 615 – 641.

Norberg UM. 1985. Flying, gliding and soaring. Pp. 129 – 158. In: Functional Vertebrate Morphology. Hildebrand M, Bramble DM, Liem FK, Wake DB (eds.). Cambridge, Mass. Harward University Press: 430p.

Norberg UM. 1994. Wing design, flight performance, and habitat use in bats. In: Ecological morphology: inegrative organismal biology. Wainwright PC, Reilly SM (eds.). Chicago. University of Chicago Press: 205 – 239.

Norberg UM, Rayner JMV. 1987: Ecological morphology and flight in bats (Mammalia, Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. Philosophical Transactions of the Royal Society of London. B Biological Sciences, 316p. 335–427.

O'Connor. 2014. New report of European Bat population trends. Online at: http://batsurveysireland.com/2014/01/30/european-bat-population-trends/ (25. 1. 2016).

O'Shea TJ, Vaughan TA. 1977. Nocturnal and seasonal activities of the pallid bat, Antrozous pallidus. Journal of Mammalogy 58: 269 – 284.

Ormsbee PC. 1996. Selection of day roosts by female long-legged myotis (*Myotis volans*) in forests of the Central Oregon Cascades. MSc. thesis. Corvallis: Oregon State University, 63p.

Parsons KN, Jones G. 2003. Dispersion and habitat use by *Myotis daubentonii* and *Myotis nattereri* during the swarming season: implications for conservation. Animal Conservation 6: 283 – 290.

Patriquin KJ, Barclay RMR. 2003. Foraging by bats in cleared, thinned and unharvested boreal forest. Journal of Applied Ecology 40: 646 – 657.

Patriquin KJ, Hogberg LK, Chruszcz BJ, Barclay RMR. 2003. The influence of habitat structure on the ability to detect ultrasound using bat detectors. Wildlife Society Bulletin 31: 475 – 481.

Patterson BD, Willig MR, Stevens RD. 2003. Trophic strategies, niche partitioning and patterns of ecological organisation. In: Bat Ecology, pp. 536–579. Kunz TH, Fenton MB (eds.). Chicago: The University of Chicago Press 779p.

Pierson ED. 1998. Tall trees, deep holes, and scarred landscapes: conservation biology of North American bats. In: Kunz TH, Racey PA (eds). Bat biology and conservation. Washington DC. Smithsonian Institution Press: 309 – 325.

Popa-Lisseanu AG, Bontadina F, Ibáñez C. 2009. Giant noctule bats face conflicting constraints between roosting and foraging in fragmented and heterogenous landscape. Journal of Zoology 278: 126 – 133.

Primack RB. 1998. Essentials of Conservation Biology. Sunderland, Sinauer Associates. 603p.

Rabe MJ, Morell TE, Green H, deVos JC Jr., Miller CR. 1998. Characteristics of ponderosa pine snag roosts used by reproductive bats in northern Arizona. Journal of Wildlife management 62: 612 – 621.

Racey PA. 1973. Environmental factors affecting the length of gestation in heterothermic bats. Journal of Reproduction and Fertility (Supplement) 19: 175 - 189.

Racey PA. 1998. Ecology of European bats in relation to their conservation. In: Kunz TH & Racey PA (eds), Bat biology and conservation. Washington and London Smithsonian Institution Press: 249-260.

Racey PA. 2015. The uniquness of bats. In: Bats and Viruses: A New Frontier of Emerging Infectious Diseases. Wang L, Cowled Ch (eds.). New Jersey. John Wiley & sons: 1 – 22.

Racey PA, Swift SM, Rydell J, Brodie L. 1998. Bats and insects over two Scottish rivers with contrasting nitrate status. Animal Conservation 1: 195 – 202.

Rachwald A. 1992. Habitat preference and activity of the noctule bat *Nyctalus noctula* in the Bialowieza Primeval Forest. Acta Theriologica, 37: 413 - 422.

Rainho A, Augusto AM, Palmeirim PM. Ponzoni FJ, Hirota MM 2010. Influence of vegetation clutter on the capacity of ground foraging bats to capture the prey. Journal of Applied Ecology 47: 850 – 858.

Ribeiro MC, Metzger JP, Martensen AC. 2009. The Brazilian Atlantic Forest: how muc is left, and how is the remaining forest distributed? Implications for conservation. Biol Conserv 142:1141–1153

Richarz K, Krull D, Schumm A. 1989. Quartiereansprüche und Quartierverhalten einer mitteleuropäischen Wochenstubenkolonie von *Myotis emarginatus* im Rosenheimer Becken, Oberbayern, mit Hinweisen zu den derzeit bekannten Wochenstubenquartieren dieser Art in der BRD. Myotis 27: 111 – 130.

Rindle Z, Zahn A. 1997. Untersuchungen zum Nahrunggpektrum der Kleinen Bartfledermaus (*Myotis mystacinus*). Nyctalus 6: 304 – 308.

Robertson PB. 1992. Small islands, natural catastrophes, and rapidly disappearing forests: a high vulnerability recipe for island populations of flying foxes. Pp 41 – 45. In: Pacific Island Flying Foxes: Proceedings of an International Conservation Conference. Wilson DE, Graham GL (eds.). U. S. Fish and Wildlife Service, Biological Report 90, Washington: 176p.

Rodrigues L, Bach L, Dubourg-Savage MJ, Karapandža B, Kovač D, Kervyn T et al., 2014. EUROBTAS. Guidelines for Consideration of Bats in Wind Farm Projects Revision 2014. Online at: http://www.eurobats.org/sites/default /files/documents/pdf/Meeting_of_Parties/Doc.MoP7 _.13.Annex_incl_annexes_0.pdf. (Available 16. 2. 2016).

Roer H, Egsbaek H. 1966. Zur Biologie einer Skandinavischen population der wasserfledermaus (*Myotis daubentonii*). Zeitschrift für Säugetierkunde 31:440 – 453.

Ruczyński I, Bogdanowicz W. 2005. Roost Cavity Selection by *Nyctalus noctula* and *N. leisleri* (Vespertilionidae, Chiroptera) in Białowieża Primeval Forest, Eastern Poland. Journal of Mammalogy 86: 921 – 930.

Ruczyński I, Bogdanowicz W. 2008. Summer Roost Selection by Tree-Dwelling Bats Nyctalus noctula and N. leisleri: A Multiscale Analysis. Journal of Mammalogy 89: 942 – 951.

Russ JM, Briffa M, Montgomery, WI. 2003. Seasonal patterns in activity and habitat use by bats (*Pipistrellus* spp. an *Nyctalus leisleri*) in Northern Ireland, determined using a driven transect. Journal of Zoology 259: 289 – 299.

Russo D, Jones G. 2003. Use of foraging habitats by bats in a Mediterranean area determined by acoustic surveys: conservation implications. Ecography 26: 197 – 209.

Russo, D, Cistrone L, Jones G, 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, Cistronec L, Jones G. 2007. Emergence time in forest bats: the influence of canopy closure. Acta oecologica 31: (2007) 119 – 126.

Rydeell J. 1986. Feeding territoriality in female northern bats, *Eptesicus nilssonii*. Ethology 72: 329 – 337.

Rydell J. 1989. Feeding activity of the northern bat *Eptesicus nilssoni* during pregnancy and lactation. Oecologia 80: 562 – 565.

Rydell J. 1991. Seasonal use of illuminated areas by foraging bats *Eptesicus nilsonii*. Holarctic Ecology 14: 203 – 207.

Rydell JL, Bach L, Dubourg-Savage M-J, Green M, Rodrigues L, Hedenström A. 2010. Bat mortality at wind turbines in northwestern Europe. Acta Chiropterologica 12: 261 – 274.

Řehák Z, Bartonička T, Zukal J, Simprová P, Džingozová Ž. 2007. Flight activity of bats in a forest. In: Zoologické dny Brno, Brno: 198p.

Sachanowicz K, Ruczynski I. 2001. Summer roost site of *Myotis brandtii* (Chiroptera, Vespertilionidae) in Eastern Poland. Mammalia 65: 531 – 535.

Safi K, Kerth G. 2004. A Comparative Analysis of Specialization and Extinction Risk in Temperate-Zone Bats. Conservation Biology 18: 1293 – 1303.

Saunders MB, Barclay RMR. 1992. Ecomorphology of insectivorous bats: a test of predictions usin two morphologically similar species. Ecology 73: 1335 – 1345.

Sazima I, Fischer WA, Sazima M, Fischer EA. 1994. The fruit bat *Artibeus lituratus* as a forest and city dweller. Ciência e Cultura 46: 164 – 168.

Sedgeley JA. 2001. Quality of cavity microclimate as a factor influencing selection of maternity roosts by a tree-dwelling bat, *Chalinolobus tuberculatus*, in New Zealand. Journal of Applied Ecology 38: 425 – 438.

Sedgeley JA, O'Donnell CFJ. 1999. Factors influencing roost cavity selection by a temperate rainforest bat (*Chalinolobus tuberculatus,* Vespertilonidae) in New Zealand. Journal of Zoology 249: 437 – 446.

Schnitzler HU, Kalko EKV. 2001. Echolocation by Insect-Eating bats. Bioscience 51: 557 – 569.

Schnitzler HU, Kalko EKV, Kaipf I, Grinell AD. 1994. Hunting and echolocation behaviour in the fisherman bat, *Noctilio leporinus*, in the field. Behavioral Ecology and Sociobiology 35: 327 – 345.

Schofield H, Morris C. 2000. Ranging behaviour and habitat preferences of female Bechstein´s Bat *Myotis bechsteinii* (Kuhl, 1818), in summer. Leadbury. The Vincent Wildlife Trust: 27p.

Schulz M. 1997. Bats in bird nests in Australia: a review. Mammal Review 27: 69 – 76.

Sedgeley JA. 2001. Quality of cavity microclimate as a factor influencing selection of maternity roosts by a tree-dwelling bat, *Chalinolobus tuberculatus*, in New Zealand. Journal of Applied Ecology 38: 425 - 438.

Sedgeley JA, O'Donnell CFJ. 1999. Roost selection by the long-tailed bat, *Chalinolobus tuberculatus*, in temperate New Zealand rainforest and its implications for the conservation of bats in managed forests. Biological Conservation 88: 261 – 276.

Shiel CB, Fairley JS. 1998. Activity of Leisler's Bat *Nyctalus leisleri* (Kuhl) in the Field in South-East County Wexford, as Revealed by a Bat Detector. Biology and Environment: Proceedings of the Royal Irish Academy 98B: 105 – 112.

Shiel CB, Fairley JS. 1999. Evening emergence of two nursery colonies of Leisler's bat *(Nyctalus leisleri)* in Ireland. Journal of Zoology 247: 439 – 447.

Shung. 2015. In: Bats. Gouge D, Li S, Nair S. The University of Arizona Cooperative Extension. Touscon. College of Agriculture and Life Sciences. az 1675. 11p. Online at: https://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1675-2015.pdf (Available 17. 2. 2016).

Siemers BM, Schnitzler HU. 2000. Natterer´s bat (*Myotis nattereri*) hawks for prey close to vegetation using echolocation signals of very broad brandwith. Behavioral Ecology and Sociobiology 47: 400 – 412.

Siemers BM, Güttinger R. 2006. Prey conspicousness can explain apparent prey selectivity. Current Biology 16: 157 – 159.

Siemers BM, Kaipf I, Schnitzler HU. 1999. The use of day roosts and foraging grounds by Natterer´s bat (*Myotis nattereri*) from a colony in southern Germany. Zeitschrift fűr Säugetierkunde 64: 241 – 245.

Sierro A. 1999. Habitat selection by barbastelle bats (*Barbastella barbastellus*) in the Swiss Alps (Valais). Journal of Zoology 248: 429 – 432.

Sierro A. 2003. Habitat use, diet and food availability in a population of *Barbastella barbastellus* in a Swiss alpine valley. Nyctalus 8: 670 -673.

Sierro A, Arlettaz R. 1997. Barbastelle bats (*Barbastella barbastellus*) specialize in the predation of moths: implications for foraging tactics and conservation. Acta Oecologica 18: 91 – 106.

Simmons JA, Stein RA. 1980. Acoustic imagining in bat sonar: echolocation signals and the evolution of echolocation. Journal of Comparative Physiology 135: 61 – 84.

Simmons NB, Voss RS. 1998. The Mammals of Paracou, French Guiana: a Neotropical lowland rainforest fauna. Pt. 1 Bulletin of the American Museum of Natural History 237: 1 – 219.

Simmons NB, Geisler JH. 1998. Phylogenetic relationships of *Icaronycteris*, *Archaeonycteris*, *Hassianycteris*, and *Palaeochiropteryx* to extant bat lineages, with comments on the evolution of echolocation and foraging strategies in Microchiroptera. Bulletin of the American Museum of Natural History 235: 1 – 182.

Skiba R. 2003. Europäische Fledermäuse: Kennzeichen, Echoortung und Detektoranwendung. 1. Auflage. Hohenwarsleben. Die neue Brehm Bücherei, 212p.

Sparks DW, Simmons MT, Gummer CL, Duchamp JE. 2003. Disturbance of roosting bats by woodpeckers and racoons. Northeastern Naturalist 10: 105 – 108.

Speakman JR, Thomas DW. 2004. Physiological ecology and energetics of bats. In: Bat ecology. Kunz T, Fenton MB (eds.). The University of Chicago Press, Chicago: 430 – 490.

Srinivasulu Ch, Srinivasulu B. 2002. Greater Short-Nosed Fruit Bat (*Cynopterus sphinx*) Foraging and Damage in Vineyards in India. Acta Chiropterologica 4: 167 – 171.

STATSOFT. 2001. Statistica for Windows (Computer program manual). StatSoft, Inc., Tulsa, USA.

Struebig MJ, Kingston T, Zubaid A. Mohd-Adnan A, Rossiter SJ. 2008. Conservation value of forest fragments to Palaeotropical bats. Biological Conservation 141: 2112 – 2126.

Swift SM. 1998. Long-eared Bats. London. T & A.D. Poyser, Ltd. 182p.

Šuba J, Vietniece D, Pētersons G. 2010. The parti-coloured bat *Vespertilio murinus* in Riga (Latvia) during autumn and winter. Environmental and Experimental Biology 8: 93– 96.

Taake KH. 1984. Strukturelle Unterschiede zwischen den Sommerhabitaten von Kleiner und Grosser Bartfledermaus *Myotis mystacinus* und *Myotis brandtii* in Westfalen. Nyctalus 2, 16–32

Tan KH. Zubaid A, Kunz TH. 1997. Tent construction and social organization in *Cynopterus brachyotis* (Muller) (Chiroptera: Pteropodidae) in peninsular Malaysia. Journal of Natural History 31: 1605 – 1621.

Taylor LR. 1963. Analysis of the Effect of Temperature on Insects in Flight. Journal of Animal Ecology 32: 99 – 117.

Thomas SP. 1987. The physiology of bat flight. p75 – 99. In: Recent Advances in the Study of Bats. Fenton MB, Racey P, Rayner JMV (eds.). Cambridge. Cambridge University Press: 484p.

Threlfall CG, Law B, Penman T, Banks PB. 2011. Ecological processes in urban landscapes: mechanisms influencing the distribution and activity of insectivorous bats. Ecography 34: 814 – 826.

Threlfall CG, Law B, Banks PB. 2012a. Influence of Landscape Structure and Human Modifications on Insect Biomass and Bat Foraging Activity in an Urban Landscape. PLosONE 7: 1 – 10.

Threlfall CG, Law B, Banks PB. 2012b. Sensitivity of insectivorous bats to urbanization: Implications for suburban conservation planning. Biological Conservation 146: 41 – 52.

Tilman D, Lehman C. 2001. Human-caused environmental change: Impacts on plant diversity and evolution. Proceeding of National Academy of Sciences the United States of America. 98: 5433 - 5440.

Uhrin M, Hüttmeir U, Kipson M et al. 2016. Status of Savi's pipistrelle *Hypsugo savii* (Chiroptera) and range expansion in Central and south-eastern Europe: A review. Mammal Review 46: 1 - 16.

Utzurrum RCB. 1998. Geographic patterns, ecological gradients, and the maintenance of tropical fruit bat diversity. The Philippine model. Pp. 342 – 353. In: Bat Biology and Conservation. Kunz TH, Racey P (eds.). Smithsonian Institution Press, Washington: 365p.

Van der Kooij J, 1999. Northern bat *Eptesicus nilssonii* found in a scree. Fauna 52: 208 – 211.

Vaughan N. 1997. The diets of British bats (Chiroptera). Mammalian Review 27: 77 – 94.

Vaughan N, Jones G, Harris S. 1997. Habitat use by bats (Chiroptera) assessed by means of a broad-band acoustic method. Journal of Applied Ecology 34: 716 – 730.

Vehrencamp SL, Stiles FG, Bradbury JW. 1977. Observations on the foraging behaviour and avian prey of the Neotropical carnivorous bat *Vampyrum spectrum*. Journal of Mammalogy 58: 469 – 478.

Verboom, B, Spoelstra K. 1999. Effects of food abundance and wind on the use of tree lines by an insectivorous bat. Pipistrellus pipistrellus. Canadian Journal of Zoology 77: 1393 – 1401.

Voigt CCH, Kingston T. (eds). 2016. Bats in the Anthropocene: Conservation of Bats in a Changing World. Springer open. 606p.

Voigt CCH, Phelps KL, Aguirre LF, Schoeman MC, Vanitharani J, Zubaid A. 2016. Bats and Buildings: The Conservation of Synanthropic Bats. In: Bats in the Anthropocene: Conservation of Bats in a Changing World. Voigt CCH, Kingston T (eds.). Springer open. 606p.

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

Walsh AL, Harris S. 1996a. Foraging habitat preferences of vespertilionid bats in Britain. Journal of Applied Ecology 33: 508 – 518.

Walsh AL, Harris S. 1996b. Factors Determining the Abundance of Vespertilionid Bats in Britain: Geographical, Land Class and Local Habitat Relationships. Journal of Applied Ecology 33: 519 – 529.

Warren RD, Waters DA, Altringham JD, Bullock DJ. 2000. The distribution of Daubenton's bats (*Myotis dabentonii*) and pipistrelle bats (*Pipistrellus pipistrellus*) (Vespertilionidae) in relation to small-scale variation in riverine habitat. Biological Conservation 92: 85 – 91.

Waters DA, Jones G. 1995. Echolocation call structure and intensity in five species of insectivorous bats. Journal of Expetimental Biology 198: 475 – 489.

Wickramasinghe LP, Harris S, Jones G, Vaughan N. 2003. Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. Journal of Applied Ecology 40: 984–993.

Wilde C, Kerr M, Knight C, Racey P. 1995. Lactation in vespertilionid bats. Symposia of the Zoological Society of London 67: 139 - 149.

Wilkinson GS. 1985. The social organization of the common vampire bat. I. Pattern and cause of association. Behavioural Ecology and Sociobiology 17: 111 – 121.

Willis CKR, Kolar KA, Karst AL, Kalcounis-Rüppel MC, Brigham RM. 2003. Medium- and long-term reuse of trembling aspen cavities as roosts by big brown bat (*Eptesicus fuscus*). Acta Chiropterologica 5: 85 – 90.

Wolz I. 2002. Beutespektren der Bechsteinfledermaus (*Myotis bechsteinii*) und des Groβen Mausohrs (*Myotis myotis*) aus dem Schnaittenbacher Forst in Nordbayern. Schriftenreihe für Landschaftspflege und Naturschutz 71: 213 – 224.

Yanzhen B, Yanmei W, Chan Z, Wei L. Huixian Z, Yan Y, Hongxing N. 2015. Geographical distribution, roost selection, and conservation state of cave-dwelling bats in China. Mammalia: International Journal of the Systematics, Biology & Ecology of Mammals 79: 409 – 417.

Zahn A, Haselbach H, Güttinger R. 2005. Foraging activity of central European *Myotis myotis* in a landscape dominated by spruce monocultures. Mammalian Biology 70: 265 – 270.

Zeale MRK, Bennit E, Newson SE, Packman C, Browne WJ et al. 2016. Mitigating the Impact in Historic Churches: The Response of Natterer´s bat *Myotis nattereri* to Artificial Roosts and Deterrence. PLoS ONE 11: e0152531. doi? 10,1371/journal.pone.0152531.

Zukal J, Řehák Z. 2006. Flight activity and habitat preference of bats in a karstic area, as revealed by bat detectors. Folia Zoologica 55: 273 – 281.

Appendices

Figure 22. Map of recorded locality in Bečov nad Teplou (16. 7. 2015). No. 1 shows locality further from human settlements, No. 2 shows locality closer to human settlements (www.mapy.cz).

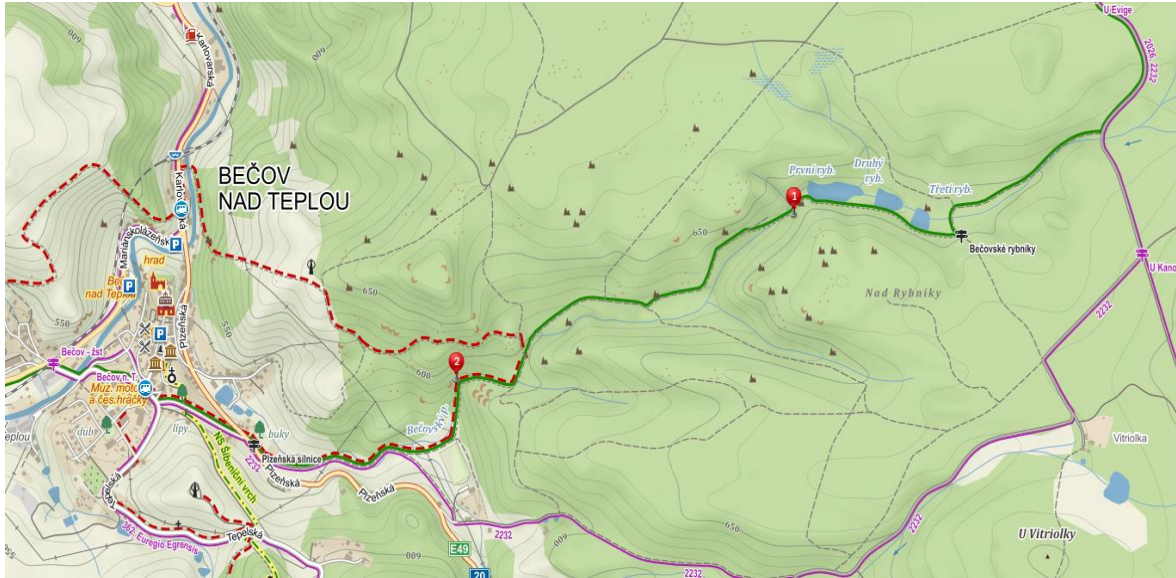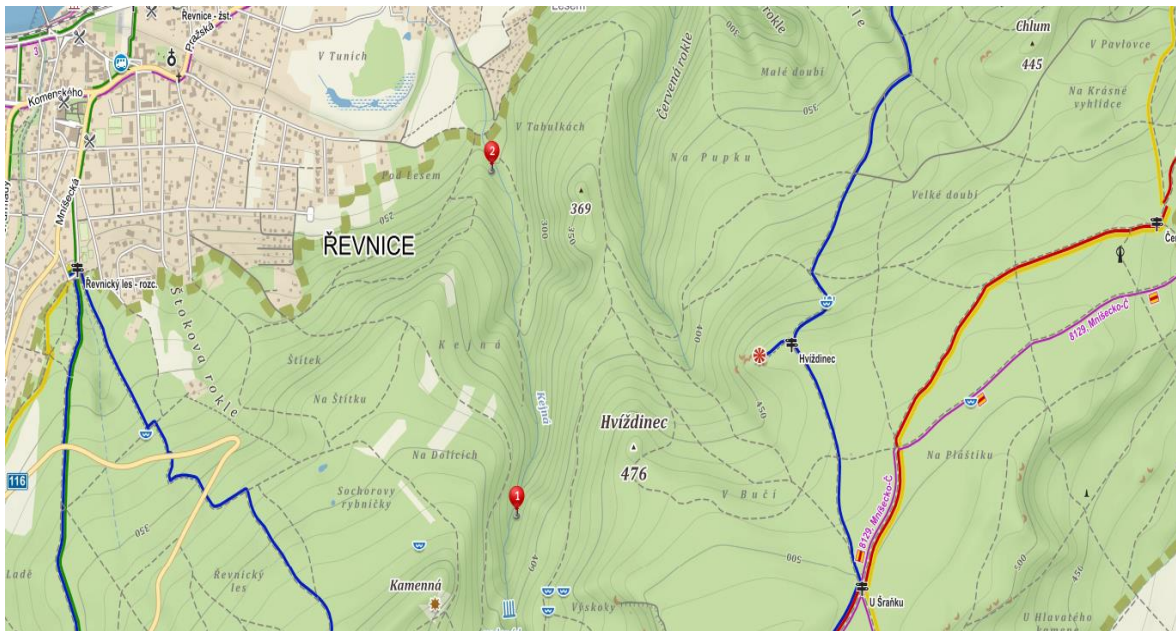Figure 23. Map of recorded locality in Řevnice (11. 7. 2015). No. 1 shows locality further from human settlements, No. 2 shows locality closer to human settlements (www.mapy.cz).

Figure 24. Flight corridor above water side. Study point closer to human settlements. Jarov, 21. 7. 2015.
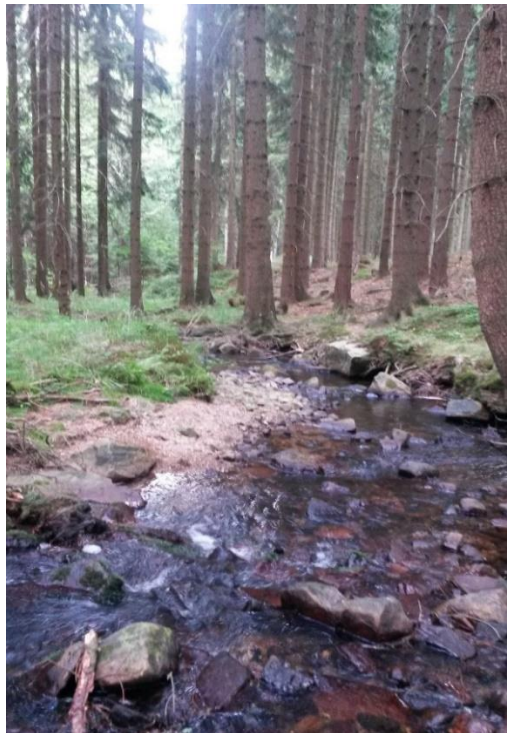

Figure 25. Flight corridor above Obecnický stream on locality far from human settlements. Obecnice, 20. 7. 2015.

Table 5. Call parameters of particular bat species in the Czech Republic, used for analysis of records (www.ceson.org).

Bat species	FMAX (kHz)	FSTART (kHz)	FEND (kHz)	Call duration (ms)	Interpulse interval (ms)	Type of signal
R. ferrumequinum	79-84	60-70	50-70	35-75	90-100	FM-CF-FM
R.s hipposideros	108-114	90-100	80-100	30-60	do 100	FM-CF-FM
R. euryale	102-107	90-100	80-100	30-60	do 100	FM-CF-FM
M. alcatoe	45-60	110-130	40-50	till 4	80-90	STFM
M. brandti	38-50	65-95	26-36	4-7	80-100, 180	STFM
M. mystacinus	40-55	65-100	28-40	3-6	80-90	STFM
M. emarginatus	50-70	90-140	38-48	1,5-3,5	40-90	STFM
M. natererri	32-48, 50	80-150	20-35	1,5-5	75-110	STFM
M. bechsteini	41-48	80-100	25-40	2,5-5,5	80-120	STFM
M. myotis	30-35	50-75	21-26	5-10	do 135	WFM, STFM
M. oxygnathus	30-35(42)	50-75	21-26	5-10	do 135	WFM, STFM
M. daubentonii	38-47	55-95	25-40	3-7	65-95	STFM
M. dasycneme	(32)36-41	65-85	25-35	4-8 (10-20)	90-120	STFM, WFM, QCF
V. murinus	23-26	30-45	21-24	12-20	260-320	QCF, NFM, WFM
E. nilssonii	27-30	35-45	26-29	9-15	160-200	NFM, WFM
E. serotinus	24-27	35-60	22-27	10-16	130-180, 240-290	NFM, WFM
H. savii	32-35	40-50	31-36	7-11	190, 280-370	FM-QCF, QCF
N. leisleri	22-28	25-40	21-26	7-16	200-300, 300-400, 100-200	QCF, NFM, WFM
N. noctula	18-26	17-22, 30-60	16-21, 22-28	6-26, 6-13	380-400	QCF, NFM, WFM
N. lasiopterus	15-20	15-25	14-20	15-25	400-550	QCF, NFM, WFM
P. nathusii	37-41	38-70	35-41	7-10	100-300	FM-QCF, QCF
P. pipistrellus	43-49	50-60	42-49	4-8	75-95	FM-QCF, QCF
P. pygmaeus	52-57	60-80	51-56	4-8	65-90	FM-QCF, QCF
P. kuhli	36-41	37-70	35-40	6-10	90-130	FM-QCF, QCF
B. barbastellus	31-33 a 40-43	38-42 a 45-55	25-31 a 28-35	2,3-3,3 and 4-6,5	50-70	QCF-FM, FM, STFM
P. auritus	25-35	45-60	13-18	2-5	70-200	STFM
P. austriacus	23-28	35-55	16-20	3-6	80-230	STFM

Table 6. Presence/absence of particular bat species CS×FS in actual numbers.

	FS (% of + points)	CS (% of + points)
Bbar	28	52
Enil	16	40
Eser	12	40
Malc/ema	44	60
Mbech	52	60
Mdau	48	68
Mmyo	32	36
Mbra/mys	68	76
Mnat	39,13043478	28
Nlas	0	4
Nlei	28	52
Nnoc	24	48
Pnat/kuh	12	44
Ppip	28	60
Ppyg	20	32
Paur/aus	28	36
Vmur	4	28

Table 7. Total activity of particular bat species CS×FS in actual numbers with undistinguished groups. Myosp includes all *Myotis* species; ENVsp group includes *Eptesicus, Nyctalu*s and *Vespertilio* sp., and group Pip50, which includes *P. pipistrellus* and *P. pygmaeus*.

	FS	CS
Bbar	100	68
Enil	13	41
Eser	25	92
Malc/ema	56	84
Mbech	227	129
Mbra/mys	229	419
Mdau	156	408
Mmyo	20	37
Mnat	27	12
Nlas	0	1
Nlei	56	132
Nnoc	47	83
Pnat/kuh	5	128
Ppip	110	393
Ppyg	57	150
Paur/aus	22	61
Vmur	7	23
Myosp	72	80
ENVsp	15	71
Pip50	1	7
Total	1245	2419

Table 8. Detailed results of Mann-Whitney U test used for analysis of activity of particular bat species on CS×FS sites.

	Rank Sum	Rank Sum	U	Z	p-value	Z	p-value	Valid N	Valid N	2*1sided
gleaners	385,0000	395,0000	175,0000	-0,407415	0,683704	-0,409095	0,682470	20	19	0,687015
hawkers	499,0000	281,0000	91,0000	2,767611	0,005647	2,768872	0,005625	20	19	0,004737
broadwing	382,5000	397,5000	172,5000	-0,477659	0,632893	-0,478872	0,632030	20	19	0,626677
narrowwing	486,5000	293,5000	103,5000	2,416391	0,015676	2,421913	0,015440	20	19	0,013869
nat_roost	436,0000	344,0000	154,0000	0,997464	0,318540	0,998374	0,318099	20	19	0,322386
artif_roost	509,0000	271,0000	81,0000	3,048587	0,002299	3,050749	0,002283	20	19	0,001715
nat_hab	423,0000	357,0000	167,0000	0,632195	0,527260	0,632516	0,527050	20	19	0,531473
altered_hab	500,5000	279,5000	89,5000	2,809757	0,004958	2,835854	0,004571	20	19	0,003902

Table 9. List of studied localities with coordinates.

Name of the Locality + date	Coordinates
NNR Ranšpurk (FS) 24. 6. 15	48°40'54.326"N 16°56'34.364"E
Lanžhot (CS) 24. 6. 15	48°42'46.776"N 16°58'25.253"E
U Šembery (FS) 30. 6. 14	50°1'9.338"N 14°48'52.598"E
Svatbín (CS) 3. 7. 14	49°59'23.238"N 14°52'29.683"E
NNR Žofín (FS) 28. 6. 15	48°40'15.662"N 14°42'25.741"E
Černé údolí (CS) 28. 6. 15	48°41'38.029"N 14°40'6.618"E
Chotětín (CS) 28. 6. 15	49°51'22.850"N, 13°43'9.599"E
Chotětín (FS) 30. 6. 15	49°51'21.331"N, 13°42'36.498"E
NNR Velká Pleš (FS) 1. 7. 15	49°59'25.311"N, 13°48'42.893"E
Karlova Ves (CS) 1. 7. 15	49°59'13.392"N 13°51'52.305"E
Kohoutov (FS) 2. 7. 15	49°55'17.312"N 13°46'39.027"E
Přehrada Jablečno (CS) 2. 7. 15	49°53'19.500"N 13°45'33.984"E
Rezervace Polom (FS) 3. 7. 15	49°49'14.898"N, 15°48'17.198"E
Polom (CS) 3. 7. 15	49°47'37.711"N, 15°45'1.684"E
Žákova hora (FS) 4. 7. 15	49°39'41.742"N, 16°0'9.486"E
Žákova hora (CS) 4. 7. 15	49°40'29.138"N, 15°55'9.147"E
Bumbálka, Salajka (FS) 6. 7. 15	49°24'4.083"N 18°25'6.721"E
Horní Bečva (CS) 6. 7. 15	49°24'56.155"N 18°23'10.696"E
Mionší (FS) 7. 7. 15	49°32'15.976"N 18°39'46.186"E
Horní Lomná (CS) 7. 7. 15	49°32'47.066"N 18°40'28.440"E
Řevnice (FS) 11. 7. 15	49°54'10.778"N, 14°15'21.020"E
Řevnice (CS) 11. 7. 15	49°54'42.418"N, 14°15'16.694"E
Bečov (FS) 16. 7. 15	50°5'17.760"N, 12°52'15.939"E
Bečov (CS) 16. 7. 15	50°5'1.205"N, 12°51'15.841"E
Obecnice (FS) 20. 7. 15	49°43'10.861"N, 13°54'23.651"E
Obecnice (CS) 20. 7. 15	49°42'58.824"N, 13°55'56.348"E
Mníšek (FS) 23. 7. 15	49°53'34.354"N, 14°14'19.222"E
Mníšek (CS) 23. 7. 15	49°52'1.967"N, 14°13'57.593"E
Březí (CS) 1. 7. 14	50°0'43.216"N 14°42'5.754"E
Medový Újezd (FS) 29. 6. 15	49°45'39.125"N 13°44'14.641"E
Číčová (FS) 16. 7. 15	50°4'19.589"N 16°11'21.655"E
Říčka Rezerva (FS) 17. 7. 15	49°42'29.767"N 13°49'32.120"E
Mourový potok (FS) 17. 7. 15	49°44'1.359"N, 13°51'47.766"E
Na Cikánce (CS) 18. 7. 15	49°59'49.954"N 14°19'24.848"E
Zadní Kopanina (CS) 18. 7. 15	50°0'14.234"N 14°18'50.627"E
Rousínov (FS) 20. 7. 15	50°2'30.446"N 16°7'21.067"E
Březany (CS) 21. 7. 15	49.9702333N, 14.4024150E
Jarov (CS) 21. 7. 15	49°56'35.532"N, 14°24'40.868"E
Chrustenice (CS) 15. 7. 15	50°0'35.408"N, 14°9'14.944"E