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Bats and light pollution

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Eptesicus serotinus

This document has been updated to December 2010 in the framework of the project *Bats and lighting of monumental buildings*, promoted by UNEP/EUROBATS - Agreement on the conservation of populations of European bats with the financial support of Ministero dell'Ambiente e della Tutela del Territorio e del Mare of Italy and Ministère de l'Écologie, de l'Énergie, du Développement durable et de la Mer of France (EUROBATS Projects Initiative: http://www.eurobats.org/EPI/EPI.html).

UNEP EUROBATS

1. INTRODUCTION

Throughout evolution living organisms have adapted to the natural variations in available light. In the last 150-200 years, however, artificial light has profoundly changed nighttime light conditions. These changes affect both terrestrial and aquatic habitats and have potentially very widespread consequences on wildlife, which are difficult to characterise precisely. It also must be said that very little study has been dedicated to the subject, which results in poor knowledge on the real effects of artificial light on organisms, species and ecosystems.
This document will discuss the relationship between artificial light and bats, with the inclusion of considerations about insects, due to their being bat's main food source. We will summarise the information available, and will evidence potential problems relative to the critical aspects that have so far not been dealt with sufficiently, in so as not to let us evaluate their actual relevance to the problem objectively and fully. We will propose measures which could be adopted in order to minimise certified or potential problems (the precautionary principle obliges to take also the latter into account), and we will formulate suggestions to better the legal framework.
Among mammals, bats (chiroptera) represent one of the orders with the richest number of species (in Italy it is the richest). Bats are particularly exposed to light pollution due to their nocturnal habits. They have a high conservation interest (many species are threatened) and an important ecological role (being the principal predators of nighttime insects).
Insects make up the zoological class with the greatest number of species, most of which are nocturnal. They are the organisms that have the biggest impact on the functions of terrestrial ecosystems due to their many ecological roles (pollinators, prey, predators, decomposers, leaf eaters, etc.).

2. THE EFFECTS OF ARTIFICIAL LIGHTING ON BATS

2.1. Facilitation of foraging

Various species of bats often forage (hunt) in areas that are artificially lighted. *Tadarida teniotis*, a relatively large, fast flying bat, hunts high up above buildings and often above the highest street lamps and sport field lights. Its presence can be detected by the short acute cries, audible to the human ear, emitted at regular intervals, but the light glare and the height at which the individuals of this species fly makes it difficult to actually see them. Other species, for example *Eptesicus nilssonii* and *Nyctalus noctula*, fly back and forth in straight flight along rows of streetlights, keeping just above them and every so often entering into the light cones to catch their prey. Some smaller species, like *Pipistrellus kuhlii* and *Pipistrellus pipistrellus*, are much easier to be seen: they fly relatively fast, with many directional changes and use lighted areas profusely, often flying around a single lamppost.

Light, in particular that of certain wavelengths, has a very attractive effect on many species of insects. Under streetlights with the more attractive light a greater concentration of insects gathers (see 3.1) and bat activity is more intense (Rydell, 1992; Blake *et al*., 1994).
Besides being facilitated by the high concentration of insects, bat foraging is also favoured by behavioural alterations shown by many insects when exposed to light. Tympanate moths have special auditory organs ("tympani") which consent them to hear the ultrasounds emitted by bats, and to therefore adopt evasive responses in order avoid capture: they can adopt flying trajectories that are difficult to follow, they can let themselves fall as if they were inanimate objects, they can

stop flying temporarily or even emit sounds that deter attack. It has been observed that these moths, when flying around light sources, continue to fly normally also in the presence of bats (Acharya and Fenton, 1999) and it has been demonstrated experimentally that certain moths, when exposed to the light of mercury vapour lamps, adopt defensive behaviour much less frequently than normal (Svensson and Rydell, 1998).

Some studies have shown that bats' foraging at artificial light sources can be benefited. Research conducted in Sweden on *Eptesicus nilssonii*, for example, have demonstrated the food intake at lights can be much higher than in other places, in particular thanks to the capture of moths (Rydell, 1992). In Switzerland it has been hypothesized that one reason for the local demographic expansion of *Pipistrellus pipistrellus* is the concentration of insects under street lamps, where this species regularly feed (Arlettaz *et al.*, 1999).

In general terms, we could hypothesise that the presence of artificial lighting which attracts bat's prey is profitable to bats which forage there, provided the advantages are not outdone by the negative consequences of artificial lighting (we will discuss this in greater detail later). In particular, it is relevant that the negative impact of lighting on prey does not cause a fall in their numbers with a consequent negative impact on the bats themselves.
These considerations cannot be applied, in any case, to bats that do not feed near lighting.

2.2. Increased risk linked to some mortality factors

Foraging in illuminated areas exposes bats to an increased risk of being caught by predators: in lighted areas nocturnal (owls, cats) and diurnal (hawks, crows, gulls) predators both can be present. At streetlights bats also risk death from being hit by vehicles (Rydell, 1991; Brinkmann *et al.*, 2008).

2.3. Reduction in night activity environments, interference in transits

Several species of bats do not forage at streetlamps and are rarely seen in illuminated areas. Among these we find species of great conservation interest, in particular belonging to the *Rhinolophus* and *Myotis* genera (Reinhold, 1993; Fure, 2006; Rydell, 2006; Stone *et al.*, 2009). This light avoiding behaviour has been related to the need to minimise risk of predation (Jones, 2000), in analogy with the anti-predatory explanations for bat activity patterns essentially restricted to twilight and night (Speakman, 1991; Jones and Rydell, 1994; Rydell and Speakman, 1995; Rydell *et al.*, 1996; Duvergé *et al.*, 2000; Petrzelkova and Zukal, 2001).

It is also possible that this phenomenon is conditioned by bat sensorial capabilities.
Various data indicate that a bat's vision is better in dim light than in bright light (for a review: Eklöf, 2003).
It has long been believed that the retina of microchiropteran bats contains exclusively rods, the photoreceptors at the basis of "scotopic" vision (which occurs under low light conditions and does not permit colour vision). Successively this assumption has been put in doubt from contrasting evidence, and recently it has been demonstrated how at least some species (among which

Rhinolophus ferrumequinum) possess a significant number of cones, (Kim *et al.*, 2008; Muller *et al.*, 2009). According to Peichl (2005) the presence of cones could pertain to all microbats. This characteristic is necessary for daylight vision, colour and UV (ultraviolet) perception. For what concerns UV perception it must be specified that it depends also on the presence of UV-transmissive ocular media (cornea, lens, vitreous). UV sensitivity has been demonstrated in the two species of phyllostomid bats taken into consideration by Muller *et al.* (2009), but it is probably diffuse among microbats, as suggested by genetic evidence (Wang *et al.*, 2004; Zhao *et al.*, 2009).
The little electrophysiological data available suggests that the cones in bats efficiently contribute to vision at intermediate light levels (mesopic vision) but become increasingly saturated at daylight levels (Muller *et al.*, 2009). The discovery of cones does not devaluate, therefore, the hypothesis that bat visual sensitivity is less in bright light, and as Fure (2006) proposed, can condition light-avoidance behaviour.
It also highlights the possibility that lamps which emit UV radiation can cause problems to those bats which can perceive them, even if only because they change the natural presence of UV in the environment (that means their perceived environment changes). It has also been suggested that if bats do not have an eye filter that blocks out the UV radiation, the UV coming from the lamps can disturb their vision and cause damage to their retina (Fure, 2006).

The possibility that artificial light interferes with bat sensorial capabilities other than vision should also be taken into consideration.
It has been reported that individuals belonging to the American species *Myotis lucifugus* showed a drastic worsening in their ability to avoid a large obstacle under artificial lighting conditions (McGuire and Fenton, 2010). The Authors of these observations did not verify if the problem was due to the bats switching over from using echolocation to using the less reliable vision (when light was turned on) or if the light caused a decrease in the bat's ability to echolocate. The first hypothesis seems supported by results of experiments with other species of bats (review in: Eklof, 2003), but the second is suggested by the fact that at least some of the monitored bats showed a change in their echolocation emissions (by shortening inter-call interval) when in light.

In order to consider all the information on the subject of possible interaction between artificial light and perception, we must mention the ability to detect the Earth' magnetic field, which has been recently demonstrated in bats (Holland *et al.*, 2006; Wang *et al.*, 2007).
Trails on homing (returning to roost after being released at a distance) have showed that *Myotis myotis* uses an internal "magnetic compass" after having calibrated it with sunset cues (Holland *et al.,* 2010). This discovery is surprising as *Myotis myotis* takes up activity well after sunset, when the presence of the sun in the sky is but a glow on the horizon.
Researchers have set up experiments in order to exclude the possibility of sunlight getting to the animals in a polarized form (it is known that birds use polarized light to calibrate their magnetic orientation mechanism), but this did not impede the calibration. This does not exclude the possibility that in natural conditions, that is in the presence of polarized light, bats can use this type of information, but at present it is neither known if bats are sensitive to polarized light, nor if other mammals are (Horvath and Varju, 2004).
What has been discussed suggests that interactions between information relative to light and information relative to the magnetic field can be relevant to bats also in longer distance movements, i.e. in migrations (various species of bats seasonally migrate over short to long distances). Therefore, it becomes also necessary to consider the possibility that artificial light may interfere with bat movements determining errors in magnetic based orientation.

Whatever the reasons, experimental evidence has been collected that shows that artificial light can negatively condition bat use of the environment during night activity.

Under experimental lighting conditions it has been showen that individuals of *Myotis dasycneme* reacted to the light (from halogen lamps) by momentarily modifying their normal flight trajectories (Kuijper *et al.*, 2008).
For the species *Rhinolophus hipposideros* a dramatic reduction in activity (bat passes) in proximity of lighting (high-pressure sodium lamps) was recorded, and the onset of commuting behaviour (evening transferral from roost to foraging areas) was found to be delayed in the presence of lighting. It was also found that the numbers of bat passes reduced dramatically even when passing along a hedge which was illuminated on the other side, indicating that low levels of light (on average 4,17 lux) have a negative effect (Stone *et al.*, 2009).
Activity (bat passes) of *Myotis lucifugus* has been noted to be significantly lower when the area crossed was lighted to when the lights were turned off (McGuire and Fenton, 2010).
Artificial lights therefore can act as barriers that reduce habitat availability and obliges bats to change their flight routes to alternative ones, with possible negative consequences, as increased energetic costs (longer and more bendy travel distances) and higher risk due to hostile conditions (predators, exposure to bad weather conditions).

2.4. Lowering of quality of roosting sites

Bats use large roosting sites (caves, abandoned mines, rooms in buildings) that are prevalently characterised by darkness, or small roosts (cavities or splits in rocky cliffs, buildings and trees; spaces behind shielding objects such as loose bark of dead trees or shutters left open in buildings), all these at least to some extent protected from light.
Some species, such as *Myotis emarginatus* and *Rhinolophus ferrumequinum*, show a certain tolerance in respect to light levels recorded in their roosts and can be found in sites that are in total darkness and in sites which are moderately lit. This does not mean that dark sites and moderately lit site are the same to them. We have observed more than once the dispersion of reproductive colonies of *Myotis emarginatus* that roosted in dim lighted stables due to the predation by magpies (Debernardi *et al.*, 2010); this suggests that non dark sites are a suboptimal choice for bats, exposing them to higher predation risks.

Artificial lighting inside roost sites represents a factor that alters one of their most usual characteristics. Among disturbing factors due to visitor presence inside a cave (light, noise, number of people), light intensity was found to determine the greatest agitation in a maternity colony of the American species *Myotis velifer* (Mann *et al.*, 2002). Full illumination of roosts has been shown to cause sudden and dramatic decreases in numbers of bats present (Laidlaw and Fenton, 1971) and it is considered to be one of the reasons why bats abandon caves open to tourists.

External lighting of roosts can also have negative effects, above all if it intercepts the accesses and passage ways that the bats use when coming and going from the sites.
In several species of bats “light sampling” behaviour has been described: at the beginning of the evening activity, some bats can be seen flying out from the dark internal part of their roost to the lighter areas closer to the entrances or briefly venturing out and then returning back into the roost darkness (Erkert, 1982; Fure, 2006). Light sampling behaviour is shown by just a part of the individuals of the colonies, despite this, the evening emergence from the roost appears to be highly synchronised. In the Asiatic species *Hipposideros speoris* it has been demonstrated that synchronisation is due to social contacts among individuals (Marimuthu *et al.*, 1981).
Many Authors have suggested that the need to avoid leaving the roost too early is related to higher risks of predation (see, for example, Duvergè *et al.*, 2000), but it is also possible that sensorial capabilities discussed in 2.3 play a role in the timing of evening emergence.

Studies and local surveys have shown that external artificial lighting delays the onset and sometimes also slows down the evening emergence of bats and, as a consequence, shortens their feeding time (Downs *et al.*, 2003; Verkem and Moermans, 2002; Theiler, 2004; Beck, 2005; Krattli and SSF, 2005; Boldogh *et al.*, 2007), causing the loss of a time span that is particularly rich in small aerial insect prey (Racey and Swift, 1985; Rydell *et al.*, 1996). It is worth mentioning that, as far as we know, the studies about roost lighting show that all the species considered are sensitive to lighting, including species like *Pipistrellus pygmaeus* that forage under street lamps (Bartonicka *et al.*, 2008).
In maternity colonies of *Myotis emarginatus* and *M.* (*blythii*) *oxignathus* roosting in buildings illuminated from the outside, young bats were found to be smaller that young bats from colonies roosting in non-illuminated buildings (Boldogh *et al.*, 2007). This is a relevant factor as it is very important for bats to reach a certain body weight before the winter in order to permit them to survive hibernation.
As internal roost lighting, also external illumination can cause decreases in colony sizes and can lead to desertion of roosts (Beck, 2005).

The consequences of roost abandonment may be worsened because of the phylopatric behaviour described in many species of bats: females born in one roost tend to return to their birth place to give birth themselves and when their original roost has become unsuitable they may have difficulty in finding an alternative reproductive site.
Experience of lighting from outside roosts of *Pipistrellus pygmaeus* (Downs *et al.*, 2003) and from inside roosts of *Myotis velifer* (Mann *et al.*, 2002) have shown the disturbance experienced by the bats was primarily due to the light intensity and secondarily to the spectral characteristics of the light, this being more incisive when white light was used, intermediate with blue light and lesser with red light.

2.5. Biological rhythm alteration

We have seen that bat nocturnal activity can be delayed due to artificial lighting at their roosts. The alteration of the natural light/dark conditions in reality has a potentially much larger influence, for the understanding of which we must recall a few concepts of chronobiology.

Numerous biochemical, physiological and behavioural processes in organisms vary cyclically (that is they repeat at regular intervals) depending on internal biological factors which are synchronised, or "entrained", to the outer temporal rhythms by external stimuli called *zeitgebers* ("time-givers"). The "anatomic mechanism" that controls internal factors and synchronises them to the environment cues is called the biological clock.
The biological rhythms that have a cycle of about 24 hours (e.g. some patterns in body temperature, hormone release, sleep/wake cycle, etc.) are called circadian rhythms, and circannual rhythms those which have an approximately yearly cycle (e.g. the seasonal reproductive cycle, moulting, hibernation, migrations, feeding and fat energy storage, etc.).
The variations of light in the natural environment during the 24 hours and (in those areas of the planet that experience seasonality) the progressive variations in the length of the day and night during the year represent the most important information for the synchronisation of biological clocks in living organisms. By consequence, we can hypothesise that artificial light can interfere with these regulation processes, determining alterations in the controlled functions.
Unfortunately knowledge on the functioning of biological clocks in the different species, the relevant environmental parameters (for what concerns light: variations of light intensity, spectral characteristics, length of exposure, etc.) and mechanisms (anatomic, physiological, ethological, etc.) with which organisms respond to such stimuli is still very limited.

In mammals, the primary biological clock is located in the suprachiasmatic nuclei of the hypothalamus, but numerous peripheral “oscillators” interact more or less intensely with this central pacemaker, contributing to the expression of the rhythms.
The suprachiasmatic nuclei receive information on light (quantity and quality of the light, length of the light phases in relation to the dark phases) through the eyes. Long known retinal photoreceptors, rods and cones, are involved in the process, but recent research has shown that the most central role in it is of a recently discovered photoreceptor (Berson *et al.*, 2002; Hattar *et al.*, 2002), corresponding to the cells that have been named “intrinsically photosensitive retinal ganglion cells” or “melanopsin-expressing retinal ganglion cells” (from their photosensitive pigment). This “new” photoreceptor has been found in every mammalian species so far examined, that is various species belonging to the orders of lagomorphs, rodents, carnivores and primates (Do and Yau, 2010). According to nine different in vivo studies conducted in rodents and primates (including man) their physiological responses peak when exposed to light at a wavelength between 459 and 484 nm, that is in the blue region of the visible spectre (Brainard and Hanifin, 2005 for a review). Various studies have provided compelling evidence that it is melanopsin that mediates the phototransduction (in particular Melyan *et al*., 2005; Qiu *et al*., 2005; Panda *et al.*, 2005) although further study is required for a full comprehension of the photochemical characteristics of this molecule (Brainard *et al*., 2008; Do and Yau, 2010).
The intrinsically photosensitive retinal ganglion cells reach, through their axons, over a dozen regions in the brain, among which the suprachiasmatic nuclei and the ventral subparaventricular zone, which is implicated in the “negative masking” phenomenon (a reduction in locomotor activity, caused by light, in nocturnal species).
The suprachiasmatic nuclei are in turn connected to other regions in the brain and with peripheral systems. Their relation with the pineal gland merits a particular mention here. The suprachiasmatic nuclei communicate to the gland information on external lighting received from the retina and this conditions the secretion of a neurohormone, melatonin. This molecule is in fact produced only during the night, in both nocturnal and diurnal mammals (Challet, 2007), and its secretion is suppressed by exposure to light. In humans the suppression is already significant at a wavelength of 420 nm and peaks between 446 and 477 nm (blue light) (Brainard *et al*., 2008).
Melatonin therefore transforms information about occurrence and duration of darkness into an endocrine signal and by interacting with glands and target organs, it has an important role in conditioning circadian and circannual rhythms (see, for example: Paul *et al*., 2008; Zawilska *et al.*, 2009). Moreover, the molecule, secreted under the direct dependence of the suprachiasmatic nuclei, influences the nuclei themselves acting through specific receptors located in the area and contributes in this way to the synchronisation of the biological clock.

The above mentioned subject is at present object of exceptionally intense research. A strong stimulus to better knowledge is given by the fact that exposure to light at night, above all due to the suppression of melatonin production (but not only), has been put in relation to numerous pathologies, among which some forms of cancer (melatonin also has antioxidant and oncostatic properties) (see, for example: Pauley, 2004; Navara and Nelson, 2007; Stevens *et al*., 2007).
Notwithstanding this, a full understanding of the mechanisms that regulate circadian and circannual rhythms in mammals is still far off. In particular, as regards bats, at the time we are writing (November 2009) we do not know of any published work about the possible presence of the “new” retinal photoreceptor.

The information concerning the role of light in conditioning biological rhythms in microbats is fragmentary and prevalently relative to species from outside Europe.
Just in a microbat, the neotropical species *Molossus molossus*, it has been observed the lowest illuminance threshold (10^{-5} lux) for photic entrainment of circadian activity rhythms found thus far

in vertebrates (Erkert, 2004); in this specific case the mediation by rods is retained probable, these being the most sensitive receptors at low light intensities.
Hipposideros speoris, an Asiatic species which uses underground roosts, is probably the most studied microbat for what concerns the expression of circadian rhythms. Continuous lighting inside a cave-roost was found to suppress the synchronisation of activity/rest rhythm, normally activated by social contacts (Marimuthu and Chandrashekaran, 1983). When individuals were exposed to monochromatic light impulses, phase shifting was observed which suggested the presence of two photoreceptors that condition the circadian rhythm of activity: one more important for the regulation of the onset of evening activity, with a peak of sensitivity at 430 nm (when light of this wavelength was used a evident delay of evening phase shifting was observed), the other relevant to mediate the return to rest (evoking advance phase shifts), with a peak sensitivity at 520 nm. The white light produced by fluorescent lamps, even if presenting both spectral components, principally provoked a delay in the evening, as if it more greatly stimulated the short wavelength sensitive photoreceptors (Joshi and Chandrashekaran, 1985).
Indian individuals of *Taphozous nudiventris* roosting in rock crevices, showed a greater response in phase shifting for wavelengths higher than 600 nm (Sripathi, 1982). This data, together with results from electroretinograms (which measured the electrical responses of the retina to light stimuli of various wavelengths) conducted on a few species of bats that showed peaks of retinal sensitivity at 500 and 570 nm (Hope and Bhatnagar, 1979a) have brought various Authors to suggest a possible correspondence between retinal sensitivity to higher wavelengths and the use of roosts which are more exposed to light (Hope and Bhatnagar, 1979a, b; Joshi and Chandrashekaran, 1985). However, the fact that the sensitivity to wavelengths lower that 440 nm was not verified by at least a part of the studies considered has recently been underlined (Muller *et al.*, 2009).
In reference to the eventuality that illumination determines alterations in biological rhythms interfering with the secretion of melatonin, it can be said that this problem is certainly potentially relevant also for bats. Even if the data available on the subject is very limited, it has been suggested, for example, that in some species of microbats melatonin may condition the reproductive activity (Kawamoto, 2003), sperm storage (Beaseley *et al.*, 1984), delayed ovulation (Srivastava and Krishna, 2010a), delayed implantation (Haldar and Yadav, 2006) and glucose metabolism during hibernation (Srivastava and Krishna, 2010b); more general functions on the regulation of circadian and circannual rhythms have been hypothesised basing on the distribution of melatonin receptors in the brain (Schwartz *et al.*, 2009).

2.6. Alteration in competition

The fact that some species of bats avoid artificially lighted areas, while others frequent them, in particular for foraging, renders the latter potentially more competitive in using illuminated areas.
In Switzerland, it has been suggested that this has contributed to a possible case of competitive exclusion between *Pipistrellus pipistrellus* and *Rhinolophus hipposideros*. The first species, foraging under street lamps, may have exploited trophic resources being essential for the other species in periods of low prey availability (Arlettaz *et al.*, 2000). It must be underlined that the Authors of the work are extremely cautious in suggesting this hypothesis. We add, that due to the lack of a quantification of the relevance for *R. hipposideros* of the decrease in prey availability caused solely by the street lights (that is even if there was no *P. pipistrellus* to prey on


R. hipposideros photo E. Bodon

them) it is difficult to clarify the role of the competitive species (the street lamps alone may have been sufficient to determine the exclusion).

Competition due to artificial lighting can be speculated also among bats and species belonging to other zoological groups. A possibility has been suggested by Allegri (2007), who observed large flocks (up to 300 individuals) of gulls (Larus ridibundus), preying upon moths attracted to a high mast light tower equipped with metal halide lamps and to some lower street lamps.

2.7. Impoverishment (quantitative/qualitative) of food resources

European bats fundamentally feed on invertebrates, above all insects. The effects of artificial light on these components is therefore relevant. An eventual demographic decrease in insect population would mean a decrease in the abundance of potential prey, while a differential impact on diverse species of insects would determine variations in the relative availability of prey species (rarefaction of sensitive species).
Following we will briefly outline some aspects of this problem, however, also in this case, we must underline that many topics have been little studied and therefore the information available is far from complete.

3. THE EFFECTS OF ARTIFICIAL LIGHTING ON INSECTS

3.1. Mortality and deviation from natural behaviour and habitats due to the attractive effect of light

The most well known effect of artificial light at night is its attraction (positive phototaxis) of insects. It largely affects many orders of insects, among which lepidopters, coleopters, dipters, hemipters, neuropters, tricopters, hymenopters and ortopters. It can vary according to different factors such as species, biological stage, sex, amount of environmental light as a whole (attraction diminishes as the contrast is less marked between the source of light and the background light) and other environmental characteristics (for a detailed discussion on this subject with particular reference to moths see: Frank, 2006).
Several theories have tried to explain flight-to-light behaviour. According to one of these, artificial light sources are mistaken for natural ones (in particular the moon) which are used as a reference in the movements. Other theories postulate that artificial light disturbs insect vision in some way.

The most evident consequence of flight-to-light behaviour is direct death. It can be provoked by burns, being caught inside the lamp housing, loss of energy due to over activity at the light source, or being captured by predators attracted to the site by the high concentration of insects (various species of bats, geckoes, toads, nocturnal spiders, etc.) and eventually by visibility conditions (diurnal predators as sea gulls, kestrels, swallows, diurnal spiders, etc.).

When attracted to artificial light sources, insects deviate from their natural habitats and from their natural behaviour and also this can lead to demographic losses.
Migrating or dispersing insects can be taken by artificial lights to hostile environments: as an example, there are accounts of swarms of insects on oil platforms ten kilometres from land (Wolf *et al.*, 1986).
Many times flight to light determines a decrease in reproductive success. About this, cases of insects that reproduce in water habitats such as mayflies, stoneflies and caddisflies, deserve a special comment.
Literature describes, for example, mass swarming flights of the mayfly *Ephoron virgo* attracted to street lamps near water bodies. The adult-stage span of these insects lasts only a few hours, during which females must lay their eggs on water. Being attracted to the light they end up laying their eggs on the road below the street lights; an estimated 1.5 million individuals were found dead in one night on the road surface of a bridge, after having deposited eggs destined to be lost (Tobias, 1996).
Some years ago it was discovered that asphalted surfaces and other dark and/or smooth surfaces of man-made objects polarize light in a similar way that water does. The phenomenon, recently termed "polarized light pollution", fools mayflies and many other water insect species (Kriska *et al.*, 1998; Horvath *et al.*, 2009; for more information see also: Labhart and Meyer, 2002; Horváth and Varjú, 2004; Horváth *et al.*, 2010).
The *Ephoron virgo* case should therefore probably be attributed to a kind of synergy between two forms of alterations of the natural light conditions: the mayflies are attracted first by the street lights, and once there, they are confused by the polarized light caused by the light reflecting on the tarmac.

In section 2.1 we discussed behaviour changes shown by tympanate moths around street lights. In artificially illuminated areas also other forms of behavioural alterations have been described. Insects attracted, often remain quiescent in illuminated areas for long periods of time.
This is particularly true for most species of moths. When we consider that an adult moth's life span often is of barely a few days, we can easily understand how even a few hours of lost activity time can have negative consequences. Moreover, moths can remain still in the areas which have been illuminated at night also during the day, and this exposes them to diurnal predators.

Species attracted to artificial lights include many insects which are predators or parasitoids of other insects (parasitoids are parasites that consume and kill their hosts) (Frick and Tallamy, 1996; Sustek, 1999). Given that predators and parasitoids are biological regulators for the species they prey on or live on, this phenomenon may have repercussions on the compositions of insect communities.

The attractive effect of light tends to increase as the wavelength decreases. In many orders of insects the maximum attraction has been recorded for UV light (prevalently around 350 nm), high attraction levels shown for blue light (420-490 nm) and blue-green light (about 500 nm) and lower attraction levels for light of higher wavelengths (Ashfaq *et al.*, 2005; Mikkola, 1972; Robinson, 2005). This trend, however, cannot be generalised. Certain dipters which reproduce in water, for example, are more attracted to yellow light (575-585 nm) than to blue light (Scheibe, 2000).
Various works have considered the attractive power of different lamp types.
In the arena of lamps currently used for public lighting the following white light or whitish light lamps emit decreasing amounts of UV radiation: high-pressure mercury vapour lamps (widely used for a long time in Italy and still today relatively common), metal halide lamps (these are frequently used in sport centres and for decorative lighting), fluorescent tubes and the white light variety of high-pressure sodium vapour lamps.
Today, especially for street lighting, high-pressure sodium vapour lamps are generally preferred. In their standard type they produce a bright pinkish-yellow light, with a marginal UV component (fig.

1). These lamps have a significantly less attractive effect for insects than formerly mentioned lamps. According to a German study, they attract about 40% less insects than their sodium-xenon white variant (Eisenbeis and Hassel, 2000). When compared with mercury lamps, standard high-pressure sodium lamps result even more advantageous: six different studies in Germany have shown they attract on average 57% less insects, and in particular their effect on moths is greatly reduced (Einsenbeis, 2006).

An even more reduced attractive effect, which is almost nil for a great number of species of insects is shown by low-pressure sodium vapour lamps (Schanowsi and Spath, 1994; Rydell, 1992; Rydell and Racey, 1995). These latter lamps do not produce UV and emit a practically monochromatic, yellow-orange light (589-590 nm), that does not permit the perception of colour (in Italy they are rarely used, mostly for out of town roads, industrial areas and foggy areas).

Recently, some results from a first survey about insects and LED lamps have been released (Eisenbeis, 2010). At present such lamps are used only very rarely (in Italy and elsewhere) due to their non competitive prices. They do not produce UV, but have strong emissions in the blue region of the spectrum (especially the "cool white" type). The preliminary results show a very scarce insect attractiveness, which can be compared to that of the low-pressure sodium lamps. On one hand this confirms the importance for the absence of UV in order to reduce insect attraction, on the other hand it is surprising as the significant emissions of blue light suggested higher attractiveness. The complete publication of this work will permit the evaluation of this type of lighting more precisely.

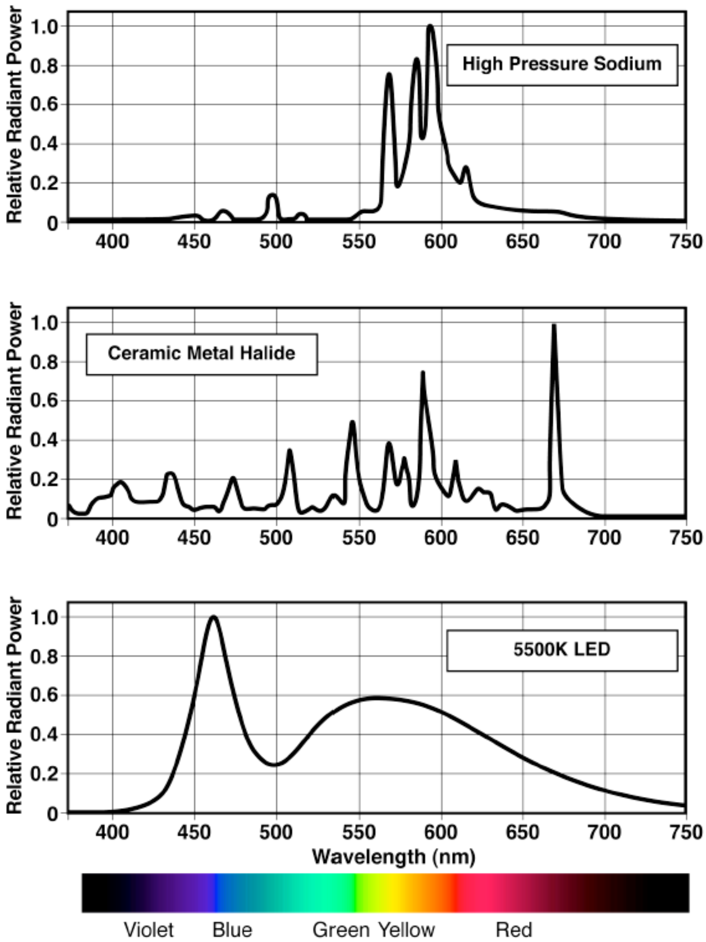


Fig. 1. Spectral power distribution of some lamps; from above: high-pressure sodium, metal halide and cool white LED lamps (from: IDA, 2010 - http://docs.darksky.org/Reports/IDA-Blue-Rich-Light-White-Paper.pdf).

3.2. Habitat loss and interference with movements due to the repulsive effect

If the attractive effect of light is directly perceivable, the same is not true for the opposite: the repulsive effect on other species of insects or insects in other biological stages (larval and adult stages can differ in their responses to light) is far more difficult to monitor. Flight-from-light behaviour is prevalently thought to be linked to the risk of predation, which is in general greater in lighted conditions. It can be manifested in various ways, for example (when light is brighter) with an inhibition of certain behaviours, a general reduction in activity or a limitation of activity to darker areas.

Examples worth of note for light avoidance (negative phototaxis) are the movements of aquatic invertebrates, that in freshwater habitats include the larvae of many insect species.
The levels of illumination at the surface of various North American lakes due to artificial light sources (measured on new moon nights) have been registered to greatly exceed natural values observed on full moon nights. It has been experimentally shown that this can suppress the zooplankton vertical migration (that is the ascending of plankton at dusk for foraging and its return to greater depths at sunrise, in order to decrease predation risk). One of the species most effected is the chaoborid dipter *Chaoborus punctipennis*, which exhibits negative phototaxis even at light intensities inferior to that of the stars (Moore *et al.*, 2006).
In flowing water, light conditions the "drift" behaviour of macroinvertebrates that live on streambeds, including, at their larval stage, insects of various orders (ephemeropters, plecopters, tricopters, dipters, etc.). During the day these organisms scarcely move, while after sunset, in low light conditions, they leave the streambed and drift downstream to look for new foraging areas. The onset of the evening drift is conditioned by the progressive decrease in light intensity and on full moon nights the phenomenon is greatly reduced. This has suggested that macroinvertebrate drift can be retarded or even suppressed due to artificial light sources, that often produce lighting levels exceeding those recorded on full moon nights (Moore *et al.*, 2006).
The above account on insects with aquatic larvae is pertinent to the problem of the impact of lighting on bats as these larvae are potential prey for bats when they reach the adult stage (they become flying insects) and in some cases even before (*Myotis daubentonii* and *Myotis capaccini* can take pupae from the water surface).

As in aquatic habitats, it can be speculated that also in terrestrial habitats, for insects characterised by negative phototactic behaviour, artificial lighting may determine negative consequences such as loss of feeding sites, reproduction sites, and transit corridors (with relative effects on their life expectancy, species dispersal, etc.).
Just like the attractive effect, light avoidance can be expected to be influenced by not only the intensity but also the spectrum of the light. For aquatic environments this is evident as the wavelength conditions light penetration in water, but available information for terrestrial environments is inconclusive.

3.3. Other interferences

The inhibition of activity of insects in illuminated areas, as reported for insects attracted to light that then remain inactive for long periods, has been also described for light sources without attractive effect, as in the case of low-pressure sodium lamps (Uffen, 1994). Unfortunately there is no quantitative data to evaluate this phenomenon. These lamps on the one hand very rarely elicit flight to light and this mitigates their effect (if the insects are not attracted to the light they risk less becoming victims to the inhibition of activity), on the other hand they are large and difficult to shield (Emery, 2008) and this provokes light spillage, with potential negative effects on a broader area of that to be lit.

We have mentioned only the most evident aspects of the interaction between artificial light and insects.
Also for insects, light represents the most important environmental reference in the conditioning of many physiological and metabolic phenomena, circadian activity rhythms, reproductive behaviour, development and life cycle (including diapausa phenomena), etc. Consequently, artificial light presents the potential to interfere in a very wide range of biological processes. Given the complexity of the subject and the nature of this paper we will not dwell on these aspects.

3.4. Considerations on the impact of artificial lighting on divers groups of insects

Some groups of insects, in particular belonging to dipters, coleopters and nocturnal lepidopters, are more exposed to the above mentioned risks. Artificial lighting can be particularly negative in certain ecological situations, for example in wetland areas where mass swarms of insects, that depend on water for reproduction, gather. Some species are more sensitive than others due to their migrating behaviour (route disruption of large swarms), their reproductive strategy (k-selected species) or because they are rare and/or have fragmented habitats.
According to Frank (2006) the most widespread and serious impact that artificial light has on moths probably is disruption of dispersal of threatened species. Generally these are species with fragmented habitats due to anthropization, whose survival strongly depends on the possibility to move from one fragment of suitable habitat to another. Lighting is typically located in the territorial matrix among suitable habitat fragments, where it acts as a barrier that limits the probability of a successful dispersal.

The potential interactions between artificial light and insects is extremely vast, the basic knowledge on the mechanisms with which organisms respond to light (including natural light) is very incomplete, and the ecological processes in which insects have a key role are so numerous, that the exact comprehension of the consequences of artificial lighting on this zoological component is still a far off objective.
If insects were in good conservation state we could possible ignore the problem, but unfortunately it is not so. The results of the two most important long term surveys inherent to insects so far conducted – *Hungarian Light-trap Network* in Hungaria and *Rothamsted Insect Survey* in Great Britain– provided evidence of alarming demographic declines (Szentkiralyi F., 2002; Conrad *et al.*, 2006).
In particular, the data collected in Great Britain in the period 1968-2002 relative to 337 species of macromoths, considered common and widespread in the country, highlighted declines for two-thirds of them, and in the last ten years of the study period 21% of the species showed demographic losses superior to 30%. The Authors of the study see in these results the evidence of a more general insect biodiversity crisis (Conrad *et al.*, 2006).
It is not known how important the role of artificial lighting is in the loss of insect biodiversity, but a precautionary conservation approach calls for the adoption of efficient measures to minimise the probability that this phenomenon have a significant impact.

4. HOW TO MINIMIZE PROBLEMS

In the preceding paragraphs we listed various negative effects that night artificial lighting has on bats and their prey. In some cases these effects have been ascertained, in other cases they still have

to be verified, but it is however necessary to take them into consideration as they are possible negative effects (precautionary principle).
In order to minimise these problems, the fundamental rules that must be respected are to keep the lighting to a strictly necessary minimum and to choose type of lamps that potentially disturb less.
Often lighting is used where it is not necessary or in an irrational way: with light dispersing out of the area to be lit, lighting at times when it is not necessary, and using light bulb types with high energy consumption and high running costs. It is therefore necessary to rationally establish "where", "how", and "when" it is right to have lighting and, while doing this, to take into consideration (together with the anthropic needs) the ecological consequences of lighting, a concern rarely taken into consideration.

4.1. Where to have lighting

No lighting would always be the best choice for what concerns the biocenoses, but for various anthropic reasons, the opposite can become necessary, foremost for security and safety. This is not the place to discuss such matter, it is however right to note that it is often tackled irrationally, not basing on objective data but on generic and unfounded assumptions: we speak of "perception of security" rather than "security".
It is common opinion that the more a street is lit up the safer it is, but there are studies that show how real conditions are a lot more complex. Lighting reduces road accidents, but serious accidents, including mortal accidents, are often more frequent on illuminated roads than on unlit ones (see, for example: Direction Interdépartementale des Routes Nord , 2007).
In Italy, it is common opinion that well lit town parks discourage crime, but a simple, practical consideration could put this belief in doubt: in the dark it is easier for police to individuate presences of people who need to use their own light source. In contrast to Italian ones, other European cities close their parks at night and keep them in darkness.
With this, we do not want to say it is wrong to use lighting when it effectively increases security and safety, but we ask to better evaluate cases when light is not strictly necessary or is of secondary importance, and its effects could be of disturbance.

Preserving darkness at the local level is of limited importance to astronomers, since lighting at great distances can negatively affect sky observation. For the ecologist, on the contrary, local lighting or darkness is of utmost importance: local conditions affect biotic communities and it is important to preserve areas from light pollution starting from those of higher ecological and naturalistic value.
How to recognise the areas which is more important to keep in natural darkness to the benefit of the conservation of bats?
Surveys on nighttime activity of bats can give useful information for the respectful planning of lighting, for example furnishing information about the location of the principle foraging areas and the "corridors" used for commuting between such areas and roost sites.
Today, the quickest way to collect data of this type is by using the bat detector. This instrument has advantages (many species are easily recorded; it is a non invasive technique and a faster way of collecting data than with other methods; the survey can be carried out even by a single recorder) and defects (some species emit calls which are difficult to reveal; calls of many species are similar, so that species identification can be difficult or even impossible; multiple recordings can refer to the same individual) and the operator must be aware of these limitations.
The radiotracking technique gives better defined results (it precisely characterises the movements of defined individuals) but is limited by the fact that the number of monitored bats is always low, the survey normally requires more operators and it is time consuming.
Unfortunately, apart for specific areas (usually protected areas), surveys are rarely promoted to understand how bats use territory. In most situations, when deciding about lighting, decisions

should therefore be taken according to more general knowledge, derived from literature and concerning the habitat preferences and movement behaviour of bats. As these characteristics are often similar for different species of bats, it is possible to identify areas of general value for the bat fauna.

Among the foraging areas that deserve priority efforts to preserve natural darkness, there are still-water wetland habitats (lakes, ponds, oxbows and slow flowing water), woodland areas and their margins, eco-mosaics characterised by meadows and grassland alternated by tree/shrub vegetation.

The corridors that bats use for their habitual transits can be preliminary identified by landscape linear features such as forest margins, riparian vegetation, tree lines and hedgerows (bats tend to avoid open spaces, and prefer to fly coasting linear elements).

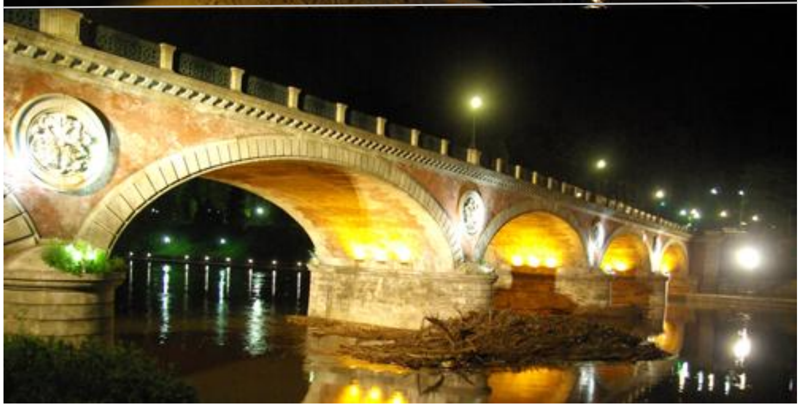
Whenever these corridors come to cross illuminated infrastructures, if something can be interposed between the lighted area and the corridors such as a line of trees and shrubs, this could help to keep the corridors in darkness and help to facilitate the passage of bats in appropriate points such as overpasses and underpasses. It has also been suggested to keep 10 m unlit stretches of road on each side of bat flight routes (BCT and ILE, 2009). For more information: Limpens *et al.*, 2004; Brinkmann *et al.*, 2008; Highways Agency, 2006.

If roost sites hosting bat colonies of major conservation concern are known, it is of particular importance to keep darkness inside them, at bat access points and, as much as possible, in the surrounding areas, in particular along the linear elements that can represent flight routes (tree lines, hedges, rows of buildings, etc.).

Frequently, important bat roosts are inside monumental buildings (castles, palaces, towers, forts, churches, etc.) or in other historical, artistic or archaeological sites (old bridges, necropolises, ancient aqueducts, rock dwellings, etc.) which are part of our Cultural heritage. Thanks to the presence of rooms unused or rarely used by man, in the dark and with a microclimate consonant to bats, such buildings and sites are particularly suited to various species of rare and threatened bats for daytime rest, reproduction, and, more rarely, hibernation.

In the last decades there has been an increase in the illuminating of Cultural heritage buildings and sites, in order to render them even more appreciable. In section 2.4 it has been underlined how roost lighting can have a strong negative effect on bats, either if external or internal (for example in the case of towers and bell towers) or with light beams restricted under bridges, arches and galleries. Moreover, lighting can constitute a violation of the international legislation which forbids the disturbance of bats and the deterioration of their breeding or resting sites (Bern Convention, ch. III, art.6; Agreement on the conservation of populations of European bats, art. III; 92/43/EEC Habitats Directive, art. 12). According to legislation, serious interferences such as a damage to an important bat colony during reproduction or hibernation, can be sanctioned as with environmental damage (2004/35/EC and 2008/35/EC Directives).

For conservation reasons and to guarantee the respect of the law, it is therefore advisable that the decorative lighting of buildings and sites of Cultural heritage which are potential roost sites be preceded by an inspection for bat usage of them. Such a survey need not take a lot of time but must be undertaken by an expert, as not only the presence of bats in act (sometimes evident also to a non expert) but also traces of frequentation in other periods of the year must be checked for. If usage by bats is ascertained, lighting will have to be excluded during the period of bat presence or at least limited accordingly, so that there is no light inside roosts, at bat accesses and along their transit routes.



Care must be taken also to contemplate “false negatives” in surveys, due, for instance, to the location of bats inside crevices or other spaces difficult to inspect. In these cases, i.e. if bat presence is detected at a later date, measures will have to be taken in order to exclude damaging interference, changing previous decisions if necessary.
Analogue conservation attentions should be taken to restore darkness at buildings/sites known to have been used by bat colonies in the past.
For what regards lighting for security reasons in connection to scaffolding in restructuring sites , the interference to bats can be annulled using alternative solutions, such as scaffolding with an alarm system or short circuit video based on infrared lighting.
Buildings and sites of Cultural heritage where natural darkness is preserved or partial lighting have been adopted for bat conservation reasons are described at
http://www.centroregionalechirotteri.org/introd_eurobats_it.html
If you know about other similar virtuous cases we ask you to submit them for their insertion onto the same web page.

4.2. How to light

For all the different reasons to contrast light pollution, lighting should be undertaken in such a way as not to go significantly over the minimum requirements given in the safety regulations.

For what concerns the need to avoid the dispersion of light out of the designed area to be lit, there is a vast reference literature that considers the way the lighting is installed, the accessories to reduce light spillage, the height and orientation and the distribution of the intensity of the light. For more in depth information see the website www.cielobuio.org (click on “5 concetti fondamentali dell’illuminazione” and see, in particular, the first criterion, currently at:
http://www.cielobuio.org/index.php?option=com_content&view=article&id=1050&Itemid=40).

The need for energy conservation and to limit CO_2 emissions, makes it important to choose energy saving lamps with high luminous efficiency (lumens per watt). It goes without saying that performance measurements must consider parameters during usage, taking into account eventual shielding accessories, lenses, etc.
At present (2010) the most efficient lamps are low-pressure sodium lamps (90-200 lm/W) followed by high-pressure sodium lamps (90-130 lm/W). The current tendency in public lighting is for high-pressure sodium lights because low-pressure sodium lamps do not permit chromatic vision and have a limited use, mainly restricted to suburban areas (it has been stressed, however, that the chromatic

vision often is not necessary and the use of low-pressure sodium lamps could be much more widespread: IDA, 2002; on the other hand it must be said that, being scarcely used, it is expected these lamps will go out of production in a few years time).
Public illumination also uses less efficient lamp types, as mercury vapour lamps (with a luminous efficiency of only 30-60 lm/W and with high waste disposal costs), fluorescent tubes (70-90 lm/W) and metal halide lamps (60-120 lm/W). The latter are employed for special uses such as lighting in sport centres and for monuments, as they have a high intensity for unit of surface area.
Recently, locally, LED lighting has been used for monumental buildings, parking lots of large commercial centres and in pilot projects for public street lighting. LED technology has been developed only since the early 1990s, but the perfectioning of the bulbs and their gains in efficiency have had exponential growth in a few years. Today LED lamps, emitting white light, are marketed by several companies for public lighting; their luminous effectiveness is close to that of the low-pressure sodium lamps, but they cannot be considered competitive yet due to their high installation cost (they require a narrow pole spacing) (CieloBuio, 2008; Radetsky, 2010). However it is probable that with future technological developments LED technology will become the most advantageous lighting from an energetic point of view.
The choice of lamp type conditions also the possibility to control the light flow, reducing it when a less intensive illumination is sufficient. This also is a way in which to contain energy consumption and light pollution. Low-pressure sodium lamps are not suitable for this purpose, while high-pressure sodium lamps are and, in perspective, LED lamps are also suitable. LEDs also have the advantage of lighting up immediately, which could allow, wherever possible, an energy saving use through lighting activation by movement sensors.

In parallel to the need for energy saving, the choice in lamps must be oriented in such a way to minimise eventual conflict with natural environment components and other anthropic needs and interests (health, astronomical observation, cultural and recreation activities in night sky observation).
Considering conservation of insects, bat's main food source, and in particular to avoid problems due to the attractive effect of light (see 3.1), the results of surveys carried out by Eisenbeis *et al.* in Germany (2006; 2010) direct towards the use of LEDs (it must be clarified that the published preliminary data do not explain if there are differences, with respect to insect attraction, between cool-white and warm-white light LEDs) or low-pressure sodium lamps and, as a second choice, to high-pressure sodium lamps (in their standard models). High-pressure sodium-xenon lamps, metal halide lamps and mercury lamps, probably due to their UV emissions, have been found to be progressively more attractive (and therefore negative) to insects.
The possibility that UV emissions can be perceived by bats (at least by some species) and can interfere with their vision (see 2.3) must be also taken into account.
Numerous works of the last few years point out potential problems in the use of white light lamps at night and particularly of those emitting rich-in-blue white light, such as cool white LEDs. As far as biological aspects are concerned (but there are also negative effects on astronomy), compared to both low- and high-pressure sodium lamps, white light lamps and particularly cool white LEDs show a greater potentiality of impact on a wide spectrum of animals behaviours, biological functions and rhythms. Potential negative effects are relevant also to bats (see 2.4 and 2.5) and human health (2.5; ANSES, 2010).
Even if we still need to further our understanding in this area to better comprehend the relationships between causes and effects, the opportunity to follow a precautionary approach discourages the night use of lamps which produce white light (it always contain the blue component) and in particular that of cool white LED lamps.

A further criteria to be taken into consideration when choosing lamp types, concerns containment and dispersion of the light emitted. Generalising, the more light spill away from the area to be lit, the higher the probability of negative consequences also at a distance from the light source.
In this case the low-pressure sodium lamps, which have the advantages mentioned earlier, are not suitable due to their large size, that makes the emitted light hard to control. As has been said, this kind of lamp has almost no attractive effect on insects, but it may interfere with insects in other ways: through repulsive effect or by inhibiting activity (see 3.2 and 3.3). Unfortunately it is not known to what extent these potential negative effects are related to the intensity of the lighting and how much they are conditioned by the spectral characteristics of the light.

At the present state of knowledge, mediating the considerations stated above, we suggest:

- the use of high luminous efficiency lamps with low or inexistent emission of ultraviolet or blue light, or lamps filtered to obtain an analogous effect, for public lighting (at present this means preferring the use of low- or high-pressure sodium lamps (the latter in their standard models);
- the exclusion of other types of lamps in all cases where it is not strictly necessary (the aesthetic appearance rarely is a necessity);
- an increase in research to better understand the biologic effects of LED lighting;
- to direct lighting technology taking into consideration the results of such research and, if the negative effects of white LEDs are confirmed, orient production towards LEDs of other colours, with a lower environmental impact.

4.3. When to use lighting

The rationalization of lighting dictates that, first of all, lighting should be avoided when it is not significantly useful. For bat conservation, the decision about "when" to light, should also take into consideration the differential impact that lighting has on bats during different times of the year and the night.
During hibernation, artificial lighting has a lesser potential to interfere with bats and insects, whose activity is down to a minimum, even if it is possible that it plays a negative role towards the species of insects that are active in the winter and may also effects bats during their winter arousals. Of course the lighting of bat roosting sites need not be limited when the bats are not present, but when they return it becomes necessary.
In general terms, and above all during periods of full bat activity, any limitation of lighting is to be considered a positive move, but it should also be said that the part of the night which is the most important for bat foraging is during twilight and the early hours of darkness, when excluding lighting can be impossible for anthropic reasons. However, the traffic flows recorded in some Italian towns show how it could be possible to reduce lighting in time slots of interest for the protection of bats. In the city of Turin, for example, traffic is very limited after 9 pm, therefore a correspondent reduction in lighting along certain roads does not seem unproposable (CieloBuio, 2006).
In the case of extreme weather conditions (heavy and persistent rain, strong winds), which impedes bat activity, there is no need to limit lighting for bat conservation.

5. PROPOSALS FOR THE IMPROVEMENT OF LEGISLATION IN THE MATTER OF LIGHT POLLUTION

Artificial night lighting is a relevant environmental factor, which has unfortunately been overlooked for too long by ecologists; knowledge on its effects on living organisms is therefore still fragmentary. This fact has influenced Italian legislation, which is lacking on the front of the protection of the biocenoses despite light pollution matter has been largely afforded: at present there is no (national) outline law on the subject, but the majority of local administrations with legislative power have introduced specific local laws (17 of the 19 Regions have adopted laws hereafter named "regional laws" and 1 of the 2 Autonomous Provinces has adopted a "provincial law").

The following notes mainly recall concepts already elaborated together with CieloBuio and exposed in CRC (2009). They are aimed at evidencing provisions relevant for the protection of biotic communities, with particular reference to bats and insects. In part these are already present in some Italian laws (regional/provincial), in part these are further dispositions that are not contemplated in the current laws. We suggest the adoption of these provisions in the existing legislation or in new laws when discussed.

When writing, we took into account also the need to save energy, to protect the night landscape and the possibility of making astronomical observations.

Given the vastness of the subject and the limits on present knowledge on the ecological effects of light pollution, we want to underline the necessity for future updating of this text.

As species react to artificial light in many different ways, and on occasions even show opposite reactions, in order to better respect biotic communities a great deal of work remains task of the territorial planning, which must consider local specific requirements.

Juridical definition of light pollution

According to the most used acceptation in Italian legislation, light pollution is every irradiance of artificial light outside competence areas (the area to be lit) and in particular off the horizontal plain. This definition takes into consideration the "astronomic" problem connected with lighting, but it is insufficient from an ecological point of view: it does not consider the negative effects that light has on many species (from attraction, repulsion, alteration of biological rhythms, etc.), even if well directed on the area to be illuminated and not dispersed upwards.

Taking into account the physical definition of light pollution proposed by Cinzano *et al.*, 2000 ("an alteration of the natural quantity of light in the external environment due to the introduction of artificial light") and the ecological definition by Longcore and Rich, 2004 ("artificial light that alters the natural patterns of light and dark in ecosystems"), we suggest to use the following definition: *"Light pollution is any alteration of the natural quantity of light due to the introduction of artificial light, in particular if this light is dispersed off the horizontal plain and/or induces negative effects on living organisms"*.

This definition transposes the more general definition of light pollution and brings attention to the problems that this phenomenon determines, both for astronomy and ecology.

This new definition makes it necessary to consider internal and inside lighting as possible pollution sources. In the existing laws in many Italian Regions, it is on the contrary specifically affirmed that such lighting is not polluting. Unfortunately, lighting on the inside of a bell tower or under the arches of a bridge can have a devastating effect on bats!

The objective for environmental protection and provisions to direct territorial management to the same aim

Some of the current Regional laws about light pollution identify protection of ecological equilibria as one of their objectives. We suggest that this element be introduced in all laws on the subject, together with general provisions on territorial management, as follows: *"an objective of the present law is the respect of ecological equilibria, to be put into practice by protecting natural darkness, in particular where ecosystems characterized by good naturalness, ecological corridors and relevant feeding, resting and reproduction sites and movement routes are present".*

Provisions for the spatial containment of lighting

It should be recommend that the applicative instruments of the laws (regulations, guidelines, lighting plans, etc.) orient towards the identification of the territorial areas where it is a priority to limit artificial lighting, taking ecological criteria in good consideration.
Habitat types where to safeguard natural darkness for the conservation of bats as a priority have been described in 4.1. They are environmental typologies of a primary importance not only for bats but also for many other species; this measure is therefore relevant for the more general aim of the protection of biodiversity and ecological equilibria.
It has also been stressed that it is very important to conserve darkness inside and around buildings and sites of Cultural heritage which are used as roost sites by bats. Existing laws dictate that bats and their roosts must be protected, but those charged with the management of our Cultural heritage often do not know about this, neither have idea of the potential interference that lighting projects can have.
In order to make it easier to respect norms which are often unintentionally ignored and to avoid unlawful actions to the damage of public interest (fauna is protected in the interests of the national and international community: art. 1, L. 157/1992, i.e. the Italian law on wildlife protection and hunting activity), often performed using public money, we suggest the introduction of the following in laws on light pollution:
"Decorative night lighting of buildings and sites of Cultural heritage, which house bat roosting sites, by the use of internal or external floodlights, must be subordinated to a bat survey aimed at assessing if the lighting is compatible with laws and regulations on the protection of bats and, whenever necessary and possible, at suggesting corrective measures to be taken in order to guarantee the respect of the current legislation. In cases in which the lighting results incompatible with bat conservation and it is not possible to enact sufficient mitigation measures, it will be necessary to renounce to the lighting project altogether."

Provisions for the temporal containment of lighting

The applicative instruments of the laws (regulations, guidelines, lighting plans, etc.), when deciding about lighting, should take into account its effects on biocenoses during the different times of the day and the year. For what regards bats and insects, we have discussed the problem in section 4.3.
In some Italian regional laws there is already a limitation on the times permitted for lighting, but it is seldom applied. Moreover, the limitation is for the central hours of the night, while it would be much better for bats to have a limitation at twilight and the early hours of the night.

Provisions for the modality of illumination

The modality for illumination conditions the dispersion of light, that is the loss of light outside the designed area. This loss is a waste of energy and the light radiation that is lost upwards determines the brightening of the night sky above populated areas known as “sky glow”. This creates conditions in which it is difficult make astronomical observations and can interfere negatively on the behaviour of living organisms.
Various Italian regional laws have fixed successful criteria to minimise the problem of light dispersion. In particular they call for: “*the luminaires, where installed, must have a maximum luminous intensity at a gamma angle of ≥ 90°(that is horizontally or upwards) between 0.00 and 0.49 cd/Klm”.* Over more, in order to control indirect light flow, “ *the average luminance level on the surface to be illuminated and the illuminance shall be no more than the minimum defined by technical safety norms”.*
As the lighting needs can change from hour to hour (in particular on roads, depending on the traffic), it is almost always a good thing that the lighting systems be equipped by devices able to reduce lighting flux when possible.

It is also necessary to consider the characteristics of the light produced.
If the choice of lamp to be used was based solely on energy saving and lighting requirements it would be sufficient to chose “the ones with the highest efficiency in relation to the available technology”, apart from those cases where exceptions can be permitted for special illumination needs (e.g. where lighting with a high chromatic level is needed). These criteria however are insufficient when the protection of the biotic communities is considered.
In section 4.2, considerations on the impact of different lamps on bats and insects have been set out. The urgency and importance for further research on the matter has also been underlined, in order to obtain more precise data on which to base legislation.
That said, and allowing for the possibility of derogations that are adequately justified, for what concerns the lamps more widely used, (mostly for street lighting), we suggest to insert a reference to systems equipped with “*lamps characterised with high luminous efficiency and low or no emissions of wavelengths inferior to 500 nm, or filtered at source in such a way as to have a similar result”* in the laws.
Such a provision is coherent with the guidelines recently developed by International Dark-Sky Association in order to safeguard the possibility of astronomical observation (IDA, 2010).

Provisions for what concerns information and awareness

The general public is still very unaware of the problem of light pollution, therefore we underline the possibility that laws on the matter evidence the importance of developing initiatives towards giving information and sensitize the population about the astronomical, biological and ecological consequences of the phenomenon and the needs for energy conservation.

REFERENCES

Acharya L., Fenton M.B., 1999. Bat attacks and moth defensive behavior around streets lights. Can. J. Zool., 77(1): 27-33.

Allegri M., 2007. Gabbiani che vicariano pipistrelli. *Bats replaced by gulls*. Pianura, 21: 215-216.

ANSES, Agence nationale de Securite sanitaire de l'alimentation, de l'Environnement et du Travail, 2010. Effets sanitaires des systèmes d'éclairage utilisant des diodes électroluminescentes (LED). Avis de l'Anses, rapport de expertise collective. Edition scientifique, Octobre 2010, 282 pp.
http://www.afsset.fr/upload/bibliotheque/089644610364204796042979030103/10_10_LED_Rapport_Couv_A4.pdf

Arlettaz R., Berthoud G., Desfayes M., 1999. Tendances démographiques opposées chez deux espéces sympatriques de chauves-souris, *Rhinolophus hipposideros* et *Pipistrellus pipistrellus*: un possible lien de cause à effet? Le Rhinolophe, 13: 35-41.

Arlettaz R., Godat S., Meyer H., 2000. Competition for food by expanding pipistrelle bat populations (*Pipistrellus pipistrellus*) might contribute to the decline of lesser horseshoe bats (*Rhinolophus hipposideros*). Biological Conservation, 93: 55-60.

Ashfaq M., Khan R.A., Khan M.A., Rasheed F., Hafeez S., 2005. Insect orientation to various color lights in the agricultural biomes of Faisalabad. Pak. Entomol., 27(1): 49-52.

Bartonicka T., Bielik A., Rehak Z., 2008. Roost switching and activity patterns in the soprano pipistrelle, *Pipistrellus pygmaeus*, during lactation. Ann. Zool. Fennici, 45: 503-512.

BCT (Bat Conservation Trust) & ILE (Institution of Lighting Engineers), 2009. Bats and lighting in the UK. Bats and the Built Environment Series. Versione 3, maggio 2009.
http://www.bats.org.uk/data/files/bats_and_lighting_in_the_uk__final_version_version_3_may_09.pdf

Beasley L.J., Smale L., Smith E.R., 1984. Melatonin influences the reproductive physiology of male pallid bats. Biology of Reproduction, 30: 300-305.

Beck A., 2005. Aargauer Beispiele zur Problematik Fledermäuse / Licht. Zusammenstellung des Kantonalen Fledermausschutz-Beauftragten des Kantons Aargau.

Berson D.M., Dunn F., Takao M., 2002. Phototransduction by retinal ganglion cells that set the circadian clock. Science, 295: 1070-1073.

Blake D., Hutson A.M., Racey P.A., Rydell J., Speakman J.R., 1994. Use of lamplit roads by foraging bats in southern England. J. Zool., Lond. 234: 453-462.

Brainard G.C., Hanifin J.P., 2005. Photons, clocks and consciousness. J. Biol. Rhythms, 20: 314-325.

Brainard G.C., Silney D., Hanifin J.P., Glickman G., Byrne B., Greeson J.M., Jasser S., Gerner E., Rollag M.D., 2008. Sensitivity of the human circadian system to short wavelength (420 nm) light. J. Biol. Rhythms, 23(5): 379–386.

Brinkmann R., Biedermann M., Bontadina F., Dietz M., Hintemann G., Karst I. , Schmidt C., Schorcht W., 2008. Planung und Gestaltung von Querungshilfen fur Fledermause. – Ein Leitfaden fur Strassenbauvorhaben im Freistaat Sachsen. Sachsisches Staatsministerium fur Wirtschaft und Arbeit, 134 pp.

Boldogh S., Dobrosi D., Samu P., 2007. The effects of the illumination of buildings on house-dwelling bats and its conservation consequences. Acta Chiropterologica, 9(2): 527-534.

Cinzano P., Falchi F., Elvidge C.D., Baugh K.E., 2000. The artificial night sky brightness mapped from DMSP satellite Operational Linescan System measurements. Mon. Not. R. Astron. Soc., 318: 641-657.

Challet E., 2007. Minireview: entrainment of the suprachiasmatic clockwork in diurnal and nocturnal mammals. Endocrinology, 148(12): 5648-5655.

CieloBuio, 2006. Quinto criterio: gestione della luce. http://www.cielobuio.org/index.php?option=com_content&view=article&id=1075&Itemid=40

CieloBuio, 2008 (aggiornato 2009). Facciamo chiarezza sui LED. ControLuce, Osservatorio del libero pensiero illuminotecnico, di scienza e cultura. http://www.cielobuio.org/index.php?option=com_content&view=article&id=1247

Conrad K., Warren M.S., Fox R.., Parsons M.S., Woiwod I.P., 2006. Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. Biol. Conserv., 132: 279-291.

CRC (Centro Regionale Chirotteri), 2009. Non metteteli in cattiva luce! Proposte per adeguare le normative sull'inquinamento luminoso alla conservazione dei chirotteri. Atti II Convegno Italiano sui Chirotteri. Serra S. Quirico (AN), 21-23/11/2008. Pp. 127-134.

Debernardi P., Patriarca E., Toffoli R., 2010. Monitoraggio delle colonie di chirotteri riproduttive e svernanti di particolare interesse conservazionistico note in piemonte e dati preliminari sull'attività di *swarming*. Stato delle conoscenze al 30 aprile 2010. CRC, Regione Piemonte - Direzione ambiente - Settore pianificazione e gestione aree naturali protette (relazione interna).

Direction Interdépartementale des Routes Nord (Ministère des Transports de l'Equipement du Tourisme et de la Mer, République Francaise), 2007. Etude de sécurité comparative sur les autoroutes de rase campagne du Nord-Pas de Calais, avec ou sans éclairage. http://astrosurf.com/anpcn/documents/A16_rapport_complet.pdf

Do M.T.H., Yau K.W., 2010. Intrinsically photosensitive retinal ganglion cells. Physiol. Rev., 90: 1547-1581.

Downs N.C.; Beaton V., Guest J., Polanski J., Robinson S.L., Racey P.A., 2003. The effects of illuminating the roost entrance on the emergence behaviour of *Pipistrellus pygmaeus*. Biological Conservation, 111: 247-252.

Duvergé P.L., Jones G., Rydell J., Ransome R.D., 2000. Functional significance of emergence timing in bats. Ecography, 23: 32-40.

Eisenbeis G., Hassel F., 2000. Attraction of nocturnal insects to street lights - a study of municipal lighting systems in a rural area of Rheinhessen (Germany). Natur und Landschaft, 75(4): 145-156.

Eisenbeis, 2006. Artificial night lighting and insects. In: Rich C., Longcore T. eds., Ecological Consequences of Artificial Night Lighting, Island Press, Washington, 281-304.

Eisenbeis, 2010. Insekten und kunstliches Licht. In: Posch T., Freyhoff A., Uhlmann T. (Hg.), Das ende der nacht. Die globale Lichtverschmutzung und ihre Folgen. WILEY-VCH Verlag Gmbh & Co. KGaA, 61-80.

Eklöf J., 2003. Vision in echolocating bats. PhD th. University of Göteborg, Sweden. http://www.fladdermus.net/thesis.htm

Erkert H.G., 1982. Ecological aspects of bat activity rhytms. In: Kunz T.H. ed. Ecology of Bats. Plenum press, New York, 201-241.

Erkert H.G., 2004. Extremely low threshold for photic entrainment of circadian activity rhythms in molossid bats (*Molossus molossus*; Chiroptera – Molossidae). Mammalian Biology – Zeitschrift fur Saugetierkunde, 69(6): 361-374.

Emery M., 2008. Effect of street lighting on bats. Urbis lighting LTD. 24 pp. http://ilpac.eu/main/wp-content/uploads/2010/05/Effect-of-Street-Lighting-on-Bats.pdf

Frank K.D., 2006. Effects of artificial night lighting on moths. In: Rich C., Longcore T. eds., Ecological Consequences of Artificial Night Lighting, Island Press, Washington, 305-344.

Frick T.B., Tallamy D.W., 1996. Density and diversity of nontarget insects killed by suburban electric insect traps. Entomological News, 107: 77-82.

Fure A., 2006. Bats and lighting. The London Naturalist 85, 20 pp.

Haldar C., Yadav R., 2006. Melatonin, gestation and fetal development. Jer., 10(1) : 32 – 42.

Hattar S., Liao H.W., Takao M., Berson D.M., Yau K.W., 2002. Melanopsin-containing retinal ganglion cells: architecture, projections and intrinsic photosensitivity. Science, 295: 1065-1070.

Highways Agency, 2006. Best practice in enhancement of highway design for bats Literature review report March 2006. Halcrow Group Limited, 83 pp.

Holland R.A., Thorup K., Vonhof M.J., Cochran W.W., Wikelski M., 2006. Bat orientation using Earth's magnetic field. Nature, 444: 702.

Holland R.A., Borissov I., Siemers B.M., 2010. A nocturnal mammal, the greater mouse-eared bat, calibrates a magnetic compass by the sun. Proc. Natl. Acad. Sci. USA,107(15): 6941-6945.

Hope G.M., Bhatnagar K.P., 1979a. Electrical response of bat retina to spectral stimulation: comparison of four microhiropteran species. Experientia, 35: 1189–1191.

Hope G.M., Bhatnagar K.P., 1979b. Effect of light adaptation on electrical responses of the retinas of four species of bats. Experientia, 35: 1191–1193.

Horvath G., Kriska G., Malik P., Robertson B., 2009. Polarized light pollution: a new kind of ecological photopollution. Frontiers in Ecology and the Environment, 7 (6): 317-325.

Horváth G., Kriska G., Malik P., Hegedüs R., Neumann L., Akesson S., Robertson B., 2010. Asphalt surfaces as ecological traps for water-seeking polarotactic insects: how can the polarized light pollution of asphalt surfaces be reduced? Series: Environmental Remediation Technologies, Regulations and Safety. Nova Science Publishers, Inc., Hauppauge, New York, USA, 47 pp. http://arago.elte.hu/files/AsphaltPol_NovaSciPubl.pdf

Horváth G., Varjú D., 2004. Polarized Light in Animal Vision - Polarization Patterns in Nature**.** Springer-Verlag, Heidelberg - Berlin - New York, 447 pp.

IDA, International Dark-Sky Association, 2002. Outdoor lighting code handbook, version 1.14 (December 2000/September 2002). http://data.nextrionet.com/site/idsa/Lighting%20Code%20Handbook.pdf

IDA, International Dark-Sky Association, 2010. Visibility, environmental, and astronomical issues associated with blue-rich white outdoor lighting (May 4, 2010). http://docs.darksky.org/Reports/IDA-Blue-Rich-Light-White-Paper.pdf

Jones G., Rydell J., 1994. Foraging strategy and predation risk as factors influencing emergence time in echolocating bats. Phil. Trans. R. Soc. Lond. B, 346: 445-455.

Jones J., 2000. Impact of lighting on bats. www.lbp.org.uk/downloads/Publications/Management/lighting_and_bats.pdf

Joshi D.S., Chandrashekaran M.K., 1985. Spectral sensitivity of the photoreceptors responsible for phase shifting the circadian rhythm of flight activity of the bat, *Hipposideros speoris.* J. Comp. Physiol. A, 156: 186-98.

Kawamoto K, 2003. Endocrine control of the reproductive activity in hibernating bats. Zoological Science, 20(9): 1057-1069.

Kim T.J., Jeon Y.K., Lee J.Y., Lee E.S., Jeon C.J., 2008. Photoreceptors in the greater horseshoe bat. Mol. Cells, 26: 373–379.

Krättli, H., SSF, 2005. Fassaden-Beleuchtungen: eine Bedrohung für Fledermäuse? Fledermaus-Anzeiger FMAZ, 80: 10-11.

Kriska G, Horváth G, Andrikovics S., 1998. Why do mayflies lay their eggs *en masse* on dry asphalt roads? Water-imitating polarized light reflected from asphalt attracts Ephemeroptera. J. Exp. Biol., 201: 2273–2286.

Kuijper D.P.J., Schut J, van Dullemen D., Toorman H., Goossens N., Ouwehand J., Limpens J.G.A., 2008. Experimental evidence of light disturbance along the commuting routes of pond bats (*Myotis dasycneme*). Lutra, 51 (1): 37-49.

Labhart T., Meyer E.P., 2002. Neural mechanisms in insect navigation: polarization compass and odometer. Current Opinion in Neurobiology, 12: 707–714.

Laidlaw G.W.J., Fenton M.B., 1971. Control of nursery colony populations of bats by artificial light. Journal of wildlife management, 35: 843-846.

Limpens H.J.G.A., Twisk P., Veenbaas G., *2004.* Met vleermuizen overweg. *Rijkswaterstaat en Vereniging voor Zoogdierkunde en Zoogdierbescherming (VZZ), 24 pp.*

Longcore T., Rich C., 2004. Ecological light pollution. Front. Ecol. Environ., 2(4): 191-198. http://www.urbanwildlands.org/Resources/LongcoreRich2004.pdf

Mann S.L., Steidl R.J., Dalton V.M., 2002. Effects of cave tours on breeding *Myotis velifer*. J. Wildl. Manage., 66(3): 618-624.

Marimuthu G., Rajan S., Chandrashekaran M.K., 1981. Social entrainment of the circadian rhythm in the flight activity of the microchiropteran bat *Hipposideros speoris*. Behav. Ecol. Sociobiol., 8: 147-150.

Marimuthu G., Chandrashekaran M.K, 1983. Continuous light inside a cave abolishes the social synchronization of the circadian rhythm in a bat. Behav. Ecol. Sociobiol., 12: 321-323.

McGuire L.P., Fenton M.B., 2010. Hitting the wall: light affects the obstacle avoidance ability of free-flying little brown bats (*Myotis lucifugus*). Acta chiropterologica, 12(1): 247-250.

Melyan Z., Tarttelin E.E., Bellingham J., Lucas R.J., and Hankins M.W., 2005. Addition of human melanopsin renders mammalian cells photoresponsive. Nature, 433: 741-745.

Mikkola K., 1972. Behavioural and electrophysiological responses of night-flying insects, especially Lepidoptera, to near-ultraviolet and visible light. Annales Zoologici Fennici, 9: 225-254.

Moore M.V., Kohler S.J., Cheers M.S., 2006. Artificial light at night in freshwater habitats and its potential ecological effects. In: Rich C., Longcore T. eds., Ecological Consequences of Artificial Night Lighting, Island Press, Washington, 365-384.

Müller B., Glösmann M., Peichl L., Knop G.C., Hagemann C., Ammermuller J., 2009. Bat eyes have ultraviolet-sensitive cone photoreceptors. PLoS ONE 4(7): e6390. doi:10.1371/journal.pone.0006390

Navara K.J., Nelson R.J., 2007. The dark side of light at night: physiological, epidemiological and ecological consequences. J. Pineal Res., 43: 215-224.

Panda S., Nayak S.K., Campo B., Walker J.R., Hogenesch J.B., Jegla T., 2005. Illumination of melatonin signaling pathway. Science, 307: 600-604.

Paul M.J., Zucker I., Schwartz W.J., 2008. Tracking the seasons: the internal calendars of vertebrates. Phil. Trans. R. Soc. B, 363: 341–361.

Pauley S.M., 2004. Lighting for the human circadian clock: recent research indicates that lighting has become a public health issue. Medical Hypotheses, 63: 588-596.

Peichl L., 2005. Diversitiy of mammalian photoreceptor properties: adaptation to habitat and lifestyle? Anat. Rec. A, 287A: 1001–1012.

Petrželková K., Zukal J., 2001. Emergence behaviour of the serotine bat (*Eptesicus serotinus*) under predation risk. Netherlands Journal of Zoology, 51(4): 395-414.

Qiu X., Kumbalasiri T., Carlson S.M., Wong K.Y., Krishna V., Provencio I., Berson D., 2005. Induction of photosensitivity by heterologous expression of melatonin. Nature, 433: 745-749.

Racey P.A., Swift S.M., 1985. Feeding ecology of *Pipistrellus pipistrellus* (Chiroptera: Vespertilionidae) during pregnancy and lactation. I. Foraging behaviour. Journ. Anim. Ecol., 54: 205-215.

Radetsky L., 2010. Streetlights for collector roads. NLPIP (National Lighting Product Information Program) Specifier Reports, 13(1), September 2010 (Rev. 2, November 2010). 48 pp.

Reinhold J.O., 1993. Lantaarnpalen en laatvliegers. Nieuwsbrief VLN, 15(5): 2-5.

Reiter G., Zahn A., 2006. Bat roosts in the alpine area: guidelines for the renovation of buildings. INTERREG IIIB Project Habitat Network. Pp.131 - www.livingspacenetwork.bayern.de

Robinson W.H., 2005. Urban insects and arachnids. A handbook of urban entomology. Cambridge University Press. 472 pp.

Rydell, 1991. Seasonal use of illuminated areas by foraging northern bats *Eptesicus nilssonii*. Holarctic Ecology (Ecography), 14(3): 203-207.

Rydell J., 1992. Exploitation of insects around streetlamps by bats in Sweden. Functional Ecology, 6: 744-750.

Rydell J., 2006. Bats and their insect prey at streetlights. In: Rich & Longcore eds. Ecological Consequences of Artificial Night Lighting, Island Press, Washington, 43-60.

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

Rydell, J., Racey P. A., 1995. Street lamps and the feeding ecology of insectivorous bats. Symposium of the Zoological Society of London, 67: 291–307.

Rydell, J., Speakman, J.R., 1995. Evolution of nocturnality in bats: potential competitors and predators during their early history. Biol. J. Linn. Soc., 54: 183–191.

Schanowski A., Spath V., 1994. Uberbelichtet: Vorschlage fur eine umweltfreundliche Aussenbeleuchtung. Naturschutzbund Deutschland (NABU), Kornwestheim.

Scheibe A.M., 2000. Quantitative Aspekte der Anziehungskraft von Straßenbeleuchtungen auf die Emergenz aus nahegelegenen Gewässern (*Ephemeroptera, Plecoptera, Trichoptera, Diptera: Simuliidae, Chironomidae, Empididae*) unter Berücksichtigung der spektralen Emission verschiedener Lichtquellen. Dissertation, Johannes Gutenberg-Universität, Mainz. 156 p. und Anhang.

Schwartz C., Bartell P., Cassone V., Smotherman M., 2009. Distribution of 2-[^{125}I]iodomelatonin binding in the brain of Mexican free-tailed bats (*Tadarida brasiliensis*). Brain Behav. Evol., 73(1): 16-25.

Speakman J.R., 1991. Why do insectivorous bats in Britain not fly in daylight more frequently? Functional Ecology, 5: 518-524.

Sripathi K., 1982. Light relations of the circadian rhythm in the tropical bat *Taphozous nudiventris kachhensis* Dobson,1872 under seminatural and laboratory conditions. PhD thesis, Madurai Kamaraj University, Madurai.

Srivastava R.K., Krishna A., 2010a. Melatonin modulates glucose homeostasis during winter dormancy in a vespertilionid bat, *Scotophilus heathi*. Comparative Biochemistry and Physiology – Part A: Molecular & Integrative Physiology, 155(3): 392-400.

Srivastava R.K., Krishna A., 2010b. Melatonin affects steroidogenesis and delayed ovulation during winter in vespertilionid bat, *Scotophilus heathi*. J. Steroid. Biochem. Mol. Biol. 118(1-2): 107-116.

Stevens R.G., Blask D.E., Brainard G.C., Hansen J., Lockley S.W., Provencio I., Rea M.S., Reinlib L., 2007. Meeting Report: The Role of Environmental Lighting and Circadian Disruption in Cancer and Other Diseases. Environ Health Perspect 115(9): 1357–1362.

Stone E.L., Jones G., Harris S., 2009. Street lighting disturbs commuting bats. Current Biology, 19 (13): 1123-1127.

Sustek Z., 1999. Light attraction of carabid beetles and their survival in the city centre. Biologia (Bratislava), 54(5): 539-551.

Svensson A.M., Rydell J., 1998. Mercury vapour lamps interfere with the bat defence of tympanate moths (*Operophtera* spp., Geometridae). Anim. Behav., 55: 223-226.

Szentkiralyi F., 2002. Fifty-year-long insect survey in Hungary: T. Jermy's contributions to light-trapping. Acta Zoologica Academiae Scientiarum Hungaricae, 48(Suppl. 1): 85–105.

Theiler A., 2004. Unterschiedliche Ausflugszeiten bei der Kleinen Hufeisennase - Landschaftsstrukturen beeinflussen den Aufbruch zur Jagd. FMAZ, 79: 4.

Tobias W., 1996. Sommernächtliches "Schneetreiben" am Main. Zum Phänomen des Massenfluges von Eintagsfliegen. Natur und Museum, 126 (2): 37-54.

Uffen R., 1994. Report of East Region meeting, Nottingham University, 13/11/1993. Antenna, 18: 80-81.

Verkem S., Moermans T., 2002. The influence of artificial light on the emerging time of Geoffroy's bat *Myotis emarginatus*. Abstracts Bat Research Symposium, Le Havre, 2002. Bat Research News, fall 2002: 113.

Wang D., Oakley T., Mower J., Shimming L.C., Yim S., Honeycutt R.L., Tsao H., Li W.H., 2004. Molecular evolution of bat color vision genes. Mol. Biol. Evol., 21: 295–302.

Wang Y., Pan Y., Parsons S., Walker M.M., Zhang S., 2007. Bats respond to polarity of a magnetic field. Proc. R. Soc. Lond. B Biol. Sci**.,** 274**:** 2901–2905.

Wolf W.W., Sparks A.N., Pair S.D., Westbrook J.K., Truesdale F.M., 1986. Radar observations and collections of insects in the Gulf of Mexico. In: Danthanarayana W. ed., Insect Flight: Dispersal and Migration . Springer-Verlag: Berlin Heidelberg: 221-234.

Zawilska J.B., Skene D.J., Arendt J., 2009. Physiology and pharmacology of melatonin in relation to biological rhythms. Pharmacological Reports, 61: 383-410.

Zhao H., Rossiter S.J., Teeling E.C., Li C., Cotton J.A., Zhang S., 2009. The evolution of color vision in nocturnal mammals. Proc. Natl. Acad. Sci. USA, 106(22): 8980-8985.