published in : McDonnell, M. J.;, Hahs, A. H., Breuste, J. H.: Ecology of Cities and Towns, Cambridge University Press, Cambridge 2009, p. 243-263

Chapter 15. Light pollution and the impact of artificial night lighting on insects

Gerhard Eisenbeis and Andreas Hänel

Introduction

The creation of urban environments has significant impacts on animals and insects throughout the world (Niemelä et al. Chapter 2; Caterall, Chapter 8; Nilon, Chapter 10; van der Ree, Chapter 11; Natuhara and Hashimoto, Chapter 12; Hochuli et al. Chapter; McIntyre and Rango Chapter 14). During the last decades both landscape and urban ecologists were confronted with a new phenomenon associated with cities and towns: 'light pollution'(Riegel 1973). Fast growing outdoor lighting as a threat to astronomy was first described by Riegel (1973). Astronomers need dark sky conditions to discriminate the faint light of astronomical sources from the sky background, which is due to a natural glow (airglow, scattered star light etc.) and artificial light scattered in earth's atmosphere. Since the invention of electric light and especially since World War II a steep increase of the outdoor lighting level has occurred and the natural darkness around human settlements has disappeared almost totally. Unwanted skylight produced by artificial night lighting is spreading from urban areas to less populated landscapes generating a modern sky glow.

The primary cause of this new phenomenal is the excessive growth of artificial lighting in the environment. It is related primarily to the general population growth, industrial development and increasing economic prosperity, but there has also occurred a significant technical improvement by applying lamps with higher and higher luminous efficiency. For example, the light output efficacy of an old-fashioned incandescent lamp is 10-20 lumens/watt and for a modern low pressure sodium vapor lamp it is nearly 200 lumens/watt. But, there is still another component that contributes significantly to light pollution which is the excessive and, at times, careless use of artificial outdoor lighting by humans, as well as the use of poorly design fixtures which allow a high proportion of upward flux of radiation. All these components contribute to an increased level of sky brightness often visible as 'sky glow' or as a far visible 'light dome' covering city centres.

This ubiquitous increase in night lighting in human settlements has resulted in a significant change in environmental conditions and should be regarded as a new challenge for ecologists involved in the conservation of biodiversity. Mizon (2002) and Cinzano (2002) have provided comprehensive reviews of the topic of light pollution. Several conference proceedings that are mainly focused on astronomical observations also discuss the negative influence of light pollution (Isobe and Hirayama, 1997, Cinzano, 2000, Cohen and Sullivan, 2001).

Although bright lights are associated with the world's thriving cities, there are some voices that are increasingly warning of the 'dark side of light' and its negative affects on plants, animals, and humans. The harmful impacts of night light on natural habitats and ecosystems have only recently been studied. In this context, an advisory report was published by the Health council of the Netherlands entitled 'Impact of outdoor lighting on man and nature' (Sixma 2000). There are many adverse effects of lighting known for animals, especially insects and birds (for a review see Schmiedel 2001, de Molenaar et al.

1997, 2000). The main effects on animals are the disturbance of biological rhythms, orientation and migration, and of basal activities like the search for nutrition, the mating behavior and the success of reproduction. Artificial night light can affect plants in many ways including altering their direction of growth, flowering times and the efficiency of photosynthetic processes.

The aim of this Chapter is to discuss the ecological impacts of light pollution in cities on insects. Insects are known for their great sensitivity to artificial light sources and in this context they can be regarded as a model group to demonstrate the negative effects of artificial lighting to nature. In addition, some thoughts of bad and good lighting design and placement are presented. Finally, our overall goal is to promote an environmentally friendly illumination system as an integral part of cities, town and villages and, finally the open landscape.

Light pollution from global to home level

The magnitude of artificial night lighting worldwide is best visualized by remote sensing techniques with the DMSP (Defence Meteorological Satellite Program) satellites applied by the Goddard Space Flight Centre of the NASA (data David Imhoff/Christopher Elvidge). The hot spots of night lighting in a continental view from the west coast of the USA to the east coast of Australia can be seen in Fig 15.1. It is evident that global city lights concentrate to the northern hemisphere of the earth. In the southern hemisphere only few big conurban areas (ie, aggregations of urban areas) are visible, e.g. Johannesburg conurban area, whereas most of the land mass belongs to the huge sparsely populated areas of South America, Africa and Australia. Further bright sources of artificial illumination can be found along many coasts of the Mediterranean,

Fig. 15.1 Global map of artificial night lighting based on remote sensing techniques with the Defence Meteorological Satellite Program - DMSP of the Goddard Space Flight Centre of the NASA (data according David Imhoff/Christopher Elvidge)

e.g. Cote d'Azur in France, Costa Brava in Spain and the coastal lines of Florida in USA. Another striking example are the big river valleys with a high population density, e.g. of the valley of the Nile which is visible as a winding light ribbon (Fig. 15.1). This kind of mapping gives a first impression of the distribution of artificial night lighting on earth.

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While these images show the direct light emitted from earth into space, Cinzano et al. (2000c) calculate the brightness of the sky background from calibrated satellite data. The upward emitted light is scattered in the atmosphere and using model calculation methods developed mainly by Garstang (1991), Cinzano et al. (2001) derived a world atlas of light pollution. They also compare the lighting level between years beginning with 1971. One of the best documented examples is that of Italy (Cinzano et al. 2000d). Cinzano and his group compared the increased level of artificial sky brightness with the level of natural sky brightness. They also compare the lighting levels in 1971 and 1998. Based on known growth rates for lighting between these periods they made a prediction for the year 2025 (Fig. 15.2). In 1971 the maximum sky brightness is about 1.1x the natural night brightness.

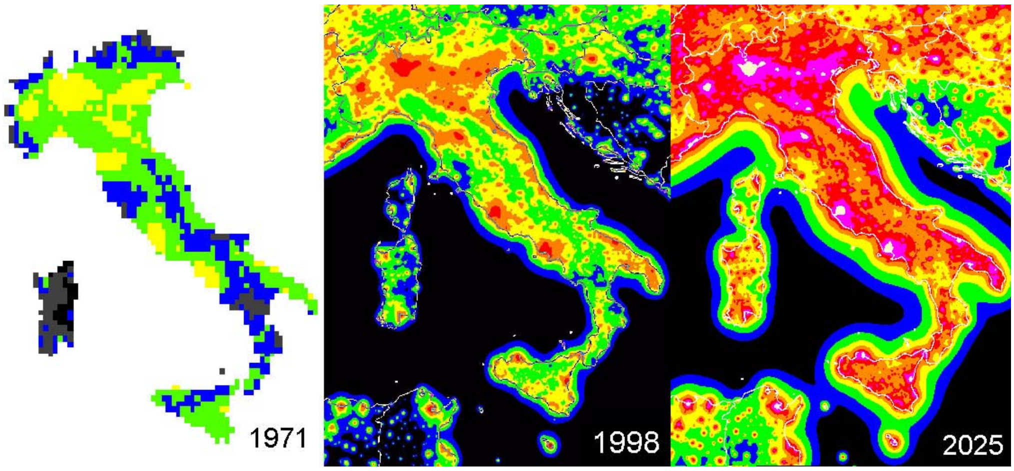

Fig. 15.2 Mapping of the artificial night lighting brightness of Italy for 1971 and 1998, and an estimated brightness for 2025 according to Cinzano et al. (2000b). The artificial sky brightness is given as increase above a reference natural sky brightness of 8.61 10^7 V phot cm^{-2} s^{-1} sr^{-1} (photons in the visual spectral range), corresponding approximately to 252 µcd/m² or 21.6 V mag $arcsec^{-2}$ (astronomical visual brightness (magnitude)). Key: green = 1X reference; red = 27X reference and white = >80X reference.

In 1998 the centres of conurbation of Milano and Roma are about 27 times brighter as the natural night brightness, and for the year 2025 they predict for these areas more than 100x. The same will occur in other parts of Europe, such as Belgium, the Netherlands, Great Britain and selected parts of Germany. Consequently it is possible that the natural darkness will disappear in extended areas of Europe, and also in other developed areas of the world.

An current example of a city with high levels of lighting is illustrated by a night photograph of Los Angeles from the nearby Mount Wilson Observatory (Fig. 15.3). On a smaller scale such over lighting is visible nearly in all modern cities but nowhere such an extended illuminated area can be found as in LA. City lighting planners distinguish different sorts of lighting: 1) primary lighting (public must lighting) which includes lighting for streets and public places, 2) secondary lighting (commercial must lighting) which involves lighting for each kind of advertising, public buildings and monuments, and tertiary lighting or non obligatory 'event lighting'. Flood lighting with cut-off floodlights, e.g. of sports grounds used for normal activities, should be classified as secondary lighting. But if a Mega soccer stadium is illuminated from the outside the whole night or if floodlights are visible from many kilometers we have clearly a case of tertiary lighting. Also citizens contribute to light pollution by illumination of gardens and houses for security or prestige reasons. White house fronts are true insect traps and gardens are losing their function as refugia for nature. If a residential building is illuminated by 20,000 Christmas lights it must be consequently regarded as very bad case of tertiary lighting. There is an urgent need to educate city planners, architects and the public to prevent the excessive use of bad lighting which can result in a variety of negative impacts on insects, animals and plants. It is apparent from the photograph of LA

Fig. 15.3 Artificial lighting panorama of Los Angeles February-19-2002 taken 9:00 p.m. from Mount Wilson with Nikon Coolpix 995, 100 ASA and 4 sec/F3

that all sorts of lighting sources contribute to the observed high overall lighting level. In a standard city it must be assumed, that the main sources of lighting are primary and secondary. Some cities though are introducing more tertiary lighting as a special local feature such as the city of Lyon (Cité lumière) in France and the city of Lüdenschein in Germany (Stadt des Lichtes). If such a tendency becomes more common practice then the projected light levels of Cinzano will become reality sooner than expected. Secondary and tertiary lighting are the main components of a new marketing strategy of cities which is called 'city marketing with light'. It is obvious, that light will be more and more used to promote the economic status of towns and cities. We regard this development for purely commercial and economic reasons as a great danger for the urban environment with potential unknown consequences. Some cities now plan to establish lighting master plans to improve their appearance and image. Principally we can support the idea of developing lighting master plans, but these plans need to include physical, social, economic and ecological considerations in order to develop truly sustainable cities.

A strong growth of settlement areas, and consequently of artificial lighting, can be observed more and more in the rural landscapes throughout the world. Haas et al. (1997)

estimate that the increase of developed land in Germany is about 1 sq. km each day. The total yearly loss of the open, undeveloped landscape in Germany is about the size of Bremen County, one of the smaller Federal States in Germany. The typical European landscape shifts to a fine-meshed mosaic of settled areas, small isles of forests and open rural space. It is like an octopus that the illuminated areas penetrate deeply into formerly undeveloped and dark landscapes. A good indicator of the consequences of this development is the local sky domes and the bright horizons which are reducing the darkness and the exponential increase of streetlights. According to Kolligs (2000) the street light pool of the city of Kiel increased from 380 in 1949 to nearly 20,000 in 1998. Based on a population size of 240,000 in 1998 this equates to about 12 street lights per person. Similar trends have been reported for Great Britain (Campaign to Protect Rural England, 2003). Another example of the loss of darkness comes from the Eifel region of Germany. In the 1950's the Hoher List Observatory at Bonn University was an excellent location for viewing the night sky, but today with the growth of nearby towns it is affected by light pollution).

Animal Behaviour Around Street Lamps and Other Light Sources

Many animals appear to be attracted by night lights. This applies primarily to flying insects, but also birds flying in swarms and those that migrate at night. Sometimes they are trapped by big light sources, particularly during periods of inclement weather. Approaching the lights of lighthouses, floodlit obstacles, ceilometers (light beams generally used at airports to determine the altitude of cloud cover), communication towers, or lighted tall buildings, they become vulnerable to collisions with the structures themselves. If collision is avoided, birds are still at risk of death or injury. Once inside a beam of light, birds are reluctant to fly out of the lighted area into the dark, and often continue to flap around in the beam of light until they drop to the ground with exhaustion. Then there is a secondary threat of predation resulting from their aggregation at lighted structures. In early August 2003, Eisenbeis (unpubl.) has observed a swarm of silver gulls orbiting permanently at the lighted top of Sydneys AMP Tower (305 m in height). It is possible that the gulls were searching for food but for whatever reason, they were attracted by the towers light space. From other observations it is known that if the light is turned off such a swarm is dispersed very fast (Cochran and Graber 1958).

Flight-to-light behavior of insects around artificial light sources disturbs the ecology of insects in many ways and can lead to high mortality (Bauer 1993, Eisenbeis 2001a). On the other hand there are many external factors, especially clear or cloudy conditions, that can also affect insect night behavior (Mikkola 1972, Blomberg et al. 1978, Kurtze 1974, Bowden 1982, Eisenbeis 2001a). Hsiao (1972) distinguished a 'near' from a 'far' phase for the approaching behavior of insects to lamps. Bowden (1982) emphasizes that most studies have focused on the 'near' phase within the zone of attraction, but 'far' effects derived from a changing background illumination, e.g. by moonlight, are very important determining how many insects are brought within the influence of a light source at all.

In this section we discuss observations of insect behavior near lamps which can be used to classify three different scenarios in which flight-to-light behavior manifests itself (Eisenbeis, 2006). In the first scenario, insects are disturbed from their normal activity by contact with an artificial illumination source such as a street lamp. For example, the scenario may begin with a moth searching for flowers. When it comes into the "zone of attraction" of a street lamp it can react in at least two different ways. The insect may fly directly onto the hot glass cover of the lamp and dies immediately. Far more frequently, the insect orbits the light endlessly until it is caught by predators or falls exhausted to the ground where it dies or is caught by other predators. Some insects are able to leave the nearest light space and to fly back seeking the shelter of the darker zone. There they rest on the ground or in the vegetation. It is assumed that the trigger for this behavior is a strong dazzling effect of the lamp. Some are able to recover and fly back to the lamp once more, and others proceed to be inactive, being exposed to an increased risk by predators. Many insects may fail to reach the light because they become dazzled and immobilized approaching the light. They may also rest on the ground or in the vegetation. Hartstack et al. (1968) have shown that more than 50% of moths approaching a light stopped their flight on the ground. We have termed all these variants of behavior the 'fixation' or 'captivity' effect, which means that insects are not able to escape from the near zone of lighting. Schacht and Witt (1986) neglect the fact that insects are actively attracted by lights themselves, for they argue that the flight to light behavior is only a blinding effect. The animals would try to flee, however, but they are no longer aware of the dark surroundings.

The second scenario describes the disturbance of long distance flights of insects by lights encountered in their flight path. The scenario begins with three insects flying through a valley along a small stream. They use natural landmarks such as trees, stars, the moon, or the profile of the horizon to have an orientation. The course of the flight is then intersected by both a street and a row of street lamps. The lights prevent the insects from following their original flyway. They fly directly to a lamp and are unable to leave the illuminated zone, suffering the same fate as described above for the first scenario. We have termed this the 'crash barrier' effect because of the interruption of insect's long distance fly way across the landscape.

The third scenario mentioned is called the 'vacuum cleaner' effect. During a summer season insects are attracted to the lights in large numbers. They are "sucked" out from their habitats as if by a vacuum, which may deplete local populations. Work by Kolligs (2001) and Scheibe (2003) suggest that outdoor lighting can significantly eliminate insects.

The magnitude of each of the effects on insect behavior depends on background illumination. Moonlight always competes with artificial light sources (Bowden, 1982, Danthanarayana 1986). Illumination from artificial lighting often creates higher illumination levels than natural night light sources such as the full moon. Kurtze (1974) measured near a parking lot at the city center of Kiel, Germany, an illumination level of 0.5 lux, about the double value of the full moon (0.3 lux), and the overall illumination by the urban sky glow of Vienna with a cloudy sky was measured at 0.178 lux (Posch, pers. comm., 2002). As yet no data are available about insect activity within settled areas which are constantly illuminated. More research is necessary to characterize such fundamental changes in the level of darkness.

Insects therefore perceive artificial lights at full moon only when they are in close proximity to the lights and consequently fewer insects are attracted to any given light. Under natural conditions, therefore, the zone of attraction changes during a lunar cycle. Additionally, changes may occur during a single night depending on weather by changing from clear to cloudy sky. Consequently the efficiency of catches around lamps depends on background illumination. On the other hand the low flight activity at artificial light sources during full moon doesn't necessarily mean that fewer insects fly on bright moon lit nights. For insects and many other animal groups it is known that the moonlight is steering their rhythmic activity (Bowden 1981, 1982). Numerous animals are active particularly at full moon or the days before or after, others behave opposite, they are active around the new moon (Endres and Schad 1997). To investigate insect's true nocturnal activity, other catch methods in addition to the light trapping have to be employed.

The Importance of Lamp Type

Several older studies reported that sodium street lamps are approached much less by insects than mercury lamps. The reason for is that the white shining mercury lamps do emit radiation both in the ultraviolet and blue green spectral range which is known to be very attractive to insects (Cleve 1967, Mikkola 1972). However, some of these examinations were not carried out under practical conditions and the data sets often were too small to statistically analyse. Therefore in 1997 a new project has been established by the nature conservation group BUND (German branch of Friends of the Earth) in cooperation with the University of Mainz and supervised by the local energy provider (Electric Power Plant of Rheinhessen – EWR) (see Eisenbeis and Hassel 2000). The aim of the project was to study insects flight to light activity around street lights during a full summer season in the rural landscape of the Rheinhessen district in southwest Germany.

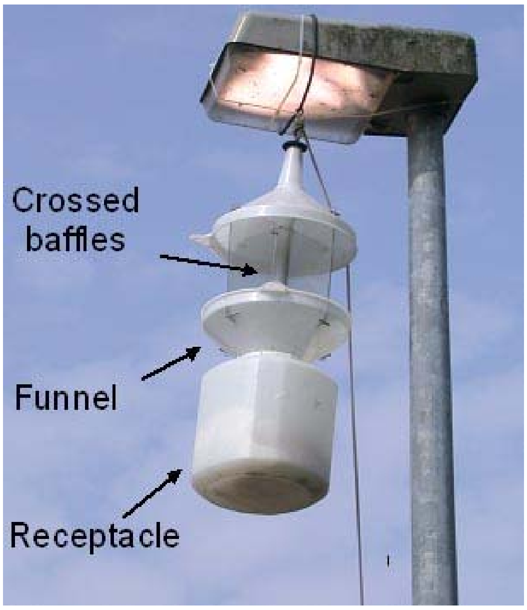

Fig. 15. 4 Insect trap exposed below a standard luminaire (street light).

The area is nearly treeless and characterized by viticulture and cultivation of cereals and sugar beet. Three sites were studied: 1) a housing area of Sulzheim village (with some garden ponds), 2) a farmhouse site (far from any water bodies), and 3) a road site near Sulzheim village. Nineteen light traps (Fig. 15.4) were mounted just below street lamp fixtures (luminaires) to capture insects. They were prepared each day before dusk, and remained exposed during the night until morning. We used two slightly modified trap models, but at any particular site, only one kind of trap was used. Insects were trapped in receptacles containing soft tissues and small vials filled with chloroform. The trapping period was June until the end of September 1997. The types of luminaires and lamps in the study were standard types commonly used for outdoor lighting in Germany. The lamps were high pressure mercury vapor (80 Watts) or high pressure sodium vapor (70 or 50 Watts).

Additionally, we tested high pressure sodium-xenon vapor lamps (80 Watts), and for special purposes some of the high pressure mercury vapor lamps were fitted with an ultraviolet absorbing filter membrane covering the glass cover of luminaires. From beginning of June to the end of September we collected 536 light trap samples containing a total of 44,210 insects, which were categorised into 12 orders. The main flight activity was in July with a maximum night catch of nearly 1700 insects in a single trap and some other catches were around 1000 insects trap^{-1} night^{-1}. Normal catch rates were less than 400 insects trap^{-1} night^{-1}. The main result is shown in Fig.15.5 giving the average catches for lamps and control in a single night. Most important are the data for high pressure mercury and high pressure sodium which are used to make the catch ratio. When we include all insects of the three study sites, we obtained a catch ratio of 0.45 which indicates that 55% less insects have been caught around high pressure sodium lamps. If we include only moths then the catch ratio is 0.25 which represents a 75% reduction in flight activity.

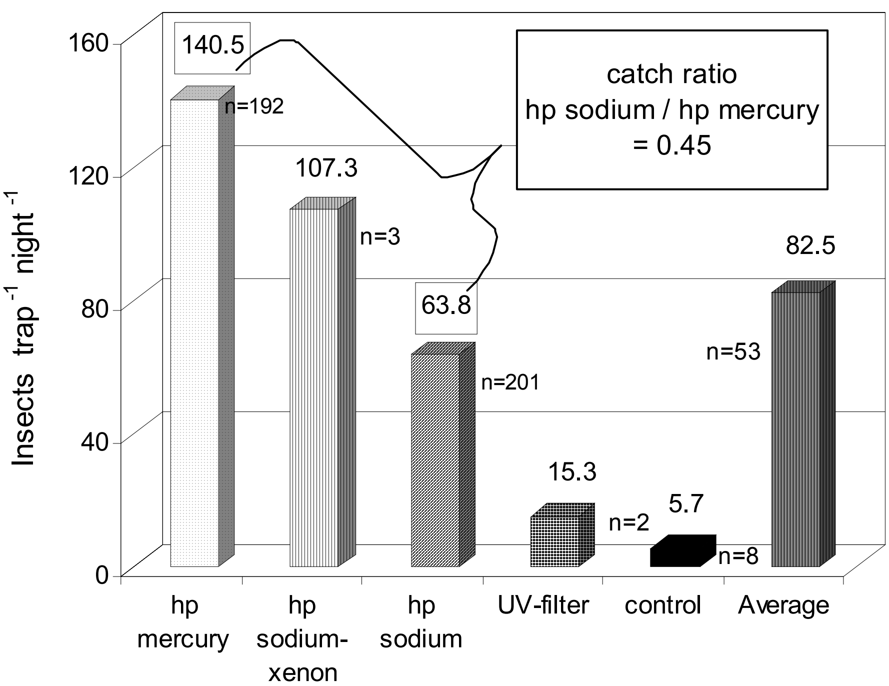

Fig. 15.5 Average insect catch rates for different lamp types in the rural landscape of Rheinhessen/Southwest Germany (according to Eisenbeis and Hassel 2000).

These data indicate that insects react differently depending on the light source. These data are only representative for the specific street light system used in our study. Besides the quality of lamps some other accessory parameters such as construction of luminaries, permeability of glass covers, the height of light fixtures, and the composition of the insect fauna in the adjacent habitats determine the rates and the catch ratio. Therefore the catch ratios given above should be regarded as an estimation of the potential reduction for the flight activity of insects around street lights.

The pattern of twelve insect orders found at the three study sites is shown in Figure 15.6. The community at the road site near an open landscape with fields and vineyards was dominated by flies (Diptera, 67.6%), and the percentage of each of the other orders was lower than 10%. Insects caught at the housing area of Sulzheim village were dominated by beetles (Coleoptera, 30.7%) followed by moths (Lepidoptera, 15.9%), aphids (Aphidina 14.3%), flies (Diptera, 9.8%), caddisflies (Trichoptera, 8.1%), bugs (Heteroptera, 8.0%) and hymenopterans (Hymenoptera, 5.9%). The proportion of each of the remaining orders remained less than 5%. At the farm site three orders dominated the insect community: beetles (Coleoptera, 38.9%), moths (Lepidoptera, 19.4%) and bugs (Heteroptera, 12.8%). Each of the others contributed less than 10%. The aquatic caddisflies (Trichoptera) were found in high proportions (5.0, 8.1%) only at two sites, which were near small bodies of water such as ponds in gardens. The proportion of this order was small (0.7%) at the farmhouse site, where there were no aquatic habitats. These results indicates that each site has its specific insect community which reflects the type of vegetation and land use.

Further evaluation of the catches revealed that the ambient temperature and the moon phase are important key factors for insect’s flight to light activity (Eisenbeis 2001b). If the ambient temperature at 10 p.m. Central European daylight saving time was significantly lower than 17°C then the flight activity dropped down to zero. Reversed the normal and the peak activity occurred at temperatures significantly higher than 19°C at 10 p.m. Central European daylight saving time. Our data agree with previously published research in that the lowest flight activity around lamps occurred during the full moon, and the peak activity accumulated at and near the new moon. This can primarily be explained by the fact that there is a competition between moonlight (as a background light) and the artificial light source. Previous research also indicates that insects behave very differently depending on the moon phases, and both weather and cloudy conditions are important co-factors (Williams 1936, Kurtze 1974, Nowinszky et al. 1979, Bowden 1981, Danthanarayana 1986, Kolligs 2000).

One interesting observation often discussed in literature is that insects flight activity is different if street lamps such as high pressure mercury or high pressure sodium are used competitive (simultaneously) or non-competitive (only one type of lamp is visible for insects). According to Scheibe (1999) an increased flight activity to high pressure mercury would only occur under the condition of light competition, i.e. if high pressure mercury and high pressure sodium would be switched on together. Therefore Eisenbeis and Hassel (2000) made a separate study in which the types of lamps were changed from day to day over a period of weeks. The site for this experiment was at the farmhouse in a true dark area without any other light sources. The high pressure sodium lamps attracted

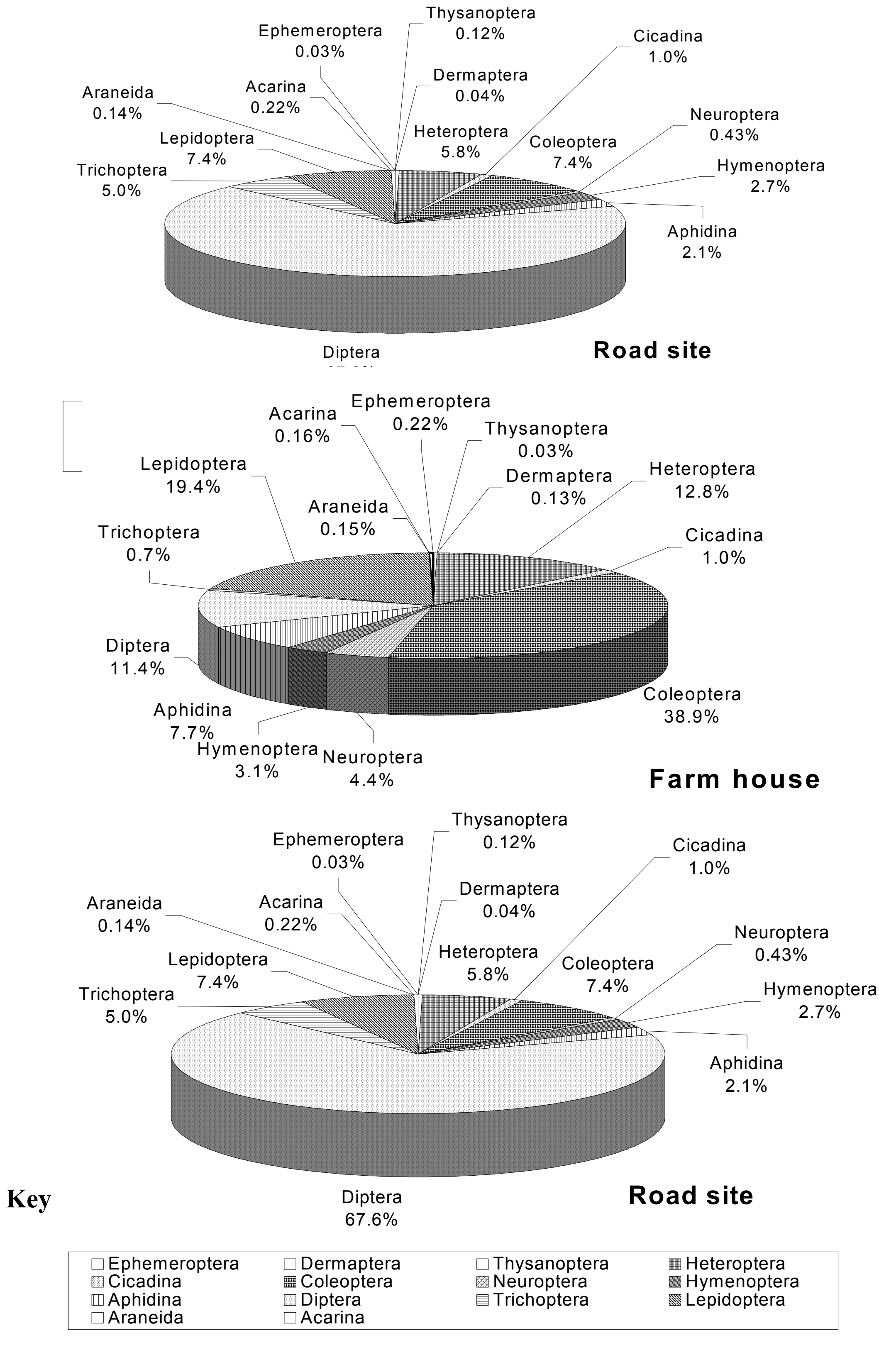

Fig. 15.6. Faunal diversity of insect groups at three sites in Germany according to Eisenbeis and Hassel 2000.

significantly less insects (1164 vs 2739; U-test, p=0.004) than high pressure mercury lamps with a catch ratio of 0.48. In addition, the average catch rate per night was higher in traps under mercury bulbs (average of 114 insects trap^{-1} night^{-1}) as opposed to those under sodium bulbs which had an average of 55 insects trap^{-1} night^{-1}. Bauer (1993) conducted a similar experiment and found that each type of lamp has its own power of attraction, although he noted that the data could not be confirmed statistically because only a few night catches were taken. To summarize, it is evident that the flight to light behavior of insects is influenced by the quality of light. High pressure mercury and high pressure sodium vapor lamps differ significantly. Comparing all known data about light trapping it is evident that insects are significantly less attracted by high pressure sodium lamps. Comparing the results of 6 German studies the insect attraction is reduced to about 57% (average catch ratio 0.43) (Fig. 15.7) for this lamp type.

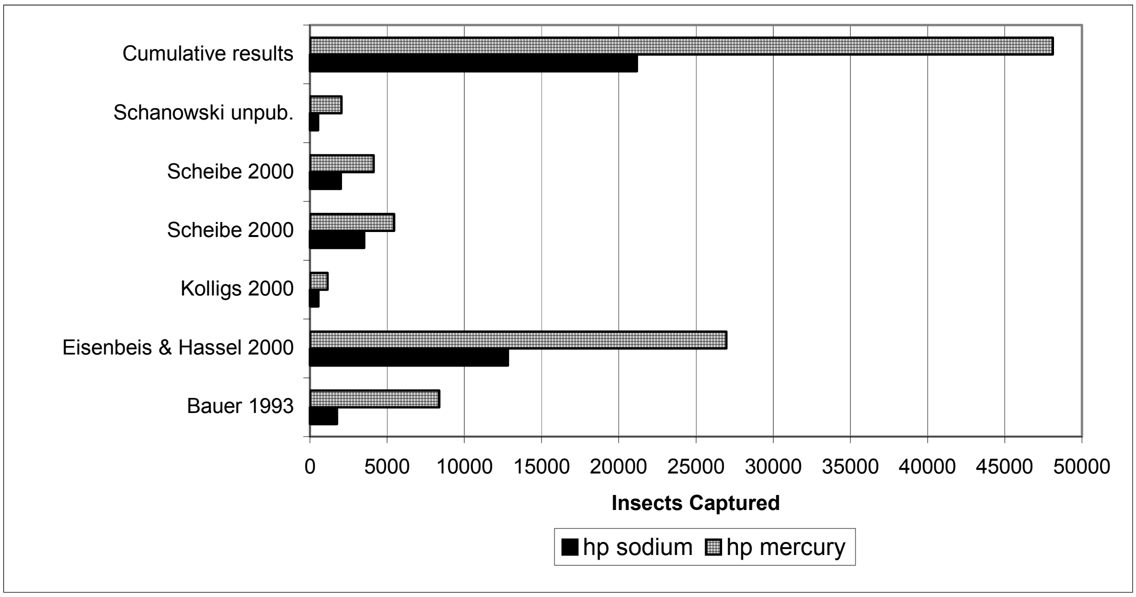

Fig. 15.7 Comparison of insect catch rates for hp sodium and hp mercury lamps based on 6 German studies.

On the other hand there are some 'losers' among insects which prefer to fly to high pressure sodium vapor lamps. In a recent study Schanowski, (unpubl.) reported 53 specimen of glow worms caught at high pressure sodium lamps and only 2 specimen were found around high pressure mercury vapor lamps. Other insect species show an indifferent behaviour, e.g. the bug *Pentatoma rufipes*, which was found in equal numbers around high pressure mercury and high pressure sodium lamps (Bauer 1993). There are also some groups of aquatic insects, especially the Chironomids, which seem to prefer the yellow light (Scheibe 2000, 2003). Therefore Scheibe (2003) recommended not to use yellow lighting near waters. In our opinion this recommendations is questionable for on the one hand the bulk of insects in Scheibe's experimental series near a stream bank were attracted by a high pressure mercury lamp, on the other hand Scheibe never tested the yellow low pressure sodium lights. The relative high proportion of aquatic insects showing an increased preference for high pressure sodium lamps is reflected by the comparatively high catch rates found in Scheibe's investigation. Thirdly the spectrum of insects trapped in Scheibe's investigation is comparatively small, e.g. no nocturnal Lepidoptera (moths) and nearly no Coleoptera, Heteroptera (bugs), Hymenoptera and Neuroptera were found. Normally these groups are also found near waters and they should never be neglected in the context of the ecological consequences of artificial night lighting. In our opinion such an unfounded statement published by Scheibe (2003) contradicts all efforts to minimize the dying of insects around lamps used for outdoor lighting.

The Decline of Insects in Cities

In January 2003, the Wall Street Journal published an interview with Dr. Gerhard Tarmann, a Lepidopterologist from the Tyrolean State Museum Ferdinandeum at Innsbruck/Austria. The topic was the decline of butterflies in the Alps during the last decades. Dr. Tarmann is one of the founders of the Austrian Action against the ecological consequences of artificial night lighting which is called: 'Die helle Not' – freely translated 'The lighting disaster', and which has engaged the people to preserve the formerly very rich insect and butterfly fauna in Austria by the conversion of the public lamp systems to sodium lamps. In Tarmann's opinion the biggest impact on the butterfly fauna in Innsbruck were the Winter Olympics in 1964. The spectacular hyper lighting of bridges and walkways was succeeded by a strong devastation of city's butterflies. Within just three years the rich fauna disappeared to a minimum level. According to Tarmann the same sequence has been observed in remote valleys of the Alps. There the meadows contained a remarkable diverse fauna with hundreds of butterfly species, but after the opening of these valleys for tourists and the implementation of a far lighting infrastructure such as petrol stations, billboards, hotels and restaurants etc., the rich fauna significantly declined within few years of the installation of the lights.

Similar observations have been described in the older entomological literature. Malicky (1965) reported from his observations around newly built and strongly illuminated fuel stations that there was a high initial flight activity of insects during the first two years, which then quickly faded away. The same observation was made by Daniel (1950) around newly installed light points close to nature. In our opinion such personal observations must be considered as a serious indicator of a significant change of a local insect population caused by the 'vacuum cleaner' effect mentioned above.
Entomologists from the second half of the last century frequently reported extremely large light trap catches of many thousand insects in a night, but more recent catches have been much smaller. For example, Robinson and Robinson (1950) caught more than 50,000 moths in a single trap (equipped with a 125 Watts mercury lamp) in the night of August 20/21, 1949. Worth and Muller (1979) caught 50,000 moths with a single 15 W black light trap from May 2 to September 12, 1978 on an isolated farm site not close to competing lights. Eisenbeis and Hassel (2000) caught only 4,338 moths with 192 light trap samples at 80 Watts high pressure mercury lamps from May 29 to September 29, 1997, which corresponds to a rate of 22.6 moths $trap^{-1}$ $night^{-1}$. Of course such simple enumeration (the sites, the lamps and the traps were different) does not allow for statistical evaluation, but these data strongly suggest a progressive decline in insect populations.

Eisenbeis (2001a) has calculated that about one third of insects approaching a street lamp are caught by a light trap. Based on Bauer's observations (Bauer 1993) he estimated a death rate in the same order of magnitude. Thus, if about 450 insects approached a high pressure mercury street light during a night, we would expect about 150 would perish. As yet there are not quantitative data on the number of animals which become inactive in the nearer surroundings of a street light that are ultimately lost by secondary predation. There are estimated to be 8.2 million street lights in Germany and based on these early data on insect catches the loss of insects due to the lights throughout the Country could be in the order of 10^{11} during a summer season.

Heath (1974) describes in his report “A Century of Change in the Lepidoptera” some profound changes in Macrolepidoptera in Great Britain, which mainly can be attributed to changes in land use. Most changes involved extinction, declines, or restriction of species to few local spots, but there were some examples of colonization of new species and extension of existing ranges. Heath (1974) notes the main causes for the change of insect habitats are: 1) clear cutting of many acres of deciduous forests and their replacement with coniferous plantations, 2) conversion of heath lands and forests to agricultural use, 3) the agricultural revolution and changes in woodland management, 4) use of chemicals such as herbicides and insecticides in the environment, 5) urban sprawl, 6) construction of motorways, 7) human recreational pressure on the countryside, and 8) periods of climatic change. There was no discussion at that time the report was written of light pollution as a serious new hazard for insects.

Taylor et al. (1978) reported on the Rothamsted Agricultural Research Centre’s insect survey with relation to the urbanization of land in Great Britain, which was based on a light-trapping network. The industrial region of middle England and the London area were clearly identified on faunal maps as islands of low diversity and density. The authors used light trapping as their basic method, but they offered no comments about the possible role of increasing artificial lighting for the decline in diversity.

Bauer (1993) investigated the insect activity of three housing areas normally illuminated by street lamps and a semi-natural habitat that was not regularly illuminated before the study. He used light traps exposed in the light space of street lamps in the suburban area of Konstanz, a mid-sized town in Southern Germany. In the illuminated areas, the catch rates (5, 29, and 47 insects per trap per night in city centre and two housing areas) were about 2–5 times lower than in the semi-natural non-illuminated habitat (143 insects per trap per night), but altogether the results from the illuminated areas were heterogeneous. Moths were the dominant species and showed an average proportion of 14.9% for the illuminated sites and 34% at the non-illuminated site, but the differences among illuminated sites was high (2.7, 11.6 and 30.5%). For this reason, such data should only be regarded as a first quantitative monitoring of changes in the insect population.
Scheibe (1999) used suction trapping to study night flying insects along a wooded stream bank in a low mountain range of the Taunus area in Germany far from any artificial lighting. During eight nights he caught 2,600 insects per trap night with maximum catches of 11,600 and 5,100 insects. These data of flight activity outnumber all other data recently reported from illuminated areas in Germany. The results must be regarded as further evidence that the dark zones in the landscape have a much richer insect fauna than do lighted zones.

In his Ph.D. thesis, Scheibe (2000) tried to determine the capacity of such a trap to catch insects flying within the zone of attraction of a single street lamp. He measured the number of all aquatic insects (e.g. mayflies, caddis flies, dipterans, etc.) emerging from a small stream in the low mountain range of the Taunus area, standardized as “number of emerging insects” per 72 h per 1 m length of the stream bank. During the night following such a test of the emergence, he determined the number of aquatic insects flying to a street lamp positioned near the bank. He found that different taxa of aquatic insects reacted differently, but in many instances light catches significantly outnumbered the number of emerging insects. For example, the number of caddis flies caught in an August night by the lamp was approximately the same as the number of caddis flies emerging along 200 m of the bank. Therefore it can be concluded that the lamp has a long distance effect for light susceptible insect species and that by far more insects are attracted than would potentially be found in the are immediately surrounding a lamp. By extrapolation, if there were a row of street lamps along a stream, a species could become extinct locally in short time, which can be explained again by the "vacuum cleaner" effect of street lamps.

Another example of attraction of large numbers of insects around lamps is reported from mayflies along riversides and bridges. The swarming of the species *Ephoron virgo* (or other species) is described as summer snow drifting (Kureck 1996, Tobias 1996) because the insects are attracted in such masses that the ground near lights is covered by a centimeter thick layer of these insects. An estimated 1.5 million individuals have been recorded in one night on an illuminated road surface of a bridge. It is part of the fatal destiny of the animals that each female loses her egg cluster upon first contact with an object. Eggs that are not released into water must be regarded as a loss for the population, with potentially significant effects on the local population.

As discussed by Frank (1988), rare species are vulnerable to effects of artificial lighting. Kolligs (2000) reported capturing endangered “Red List” species as single individuals in a large study of assimilation lighting at a greenhouse. Such species can be regarded as endangered by artificial lighting. K-selected species with specialized habitat requirements and stable population sizes are most likely to be disrupted by artificial lighting (see also Eisenbeis 2001a,b). Reichholf (1989) research on moth populations revealed steep urban gradient between the outskirts with gardens close to nature (650 species), intermediate parks (small, 330 species), and city central (housing area, reduced density, 120 species). This growing body of evidence strongly suggest that the diversity of insects has declined dramatically in Germany and England during the last decades. The implementation of insect friendly lighting systems may reduce the negative impacts on insects, but if the absolute lighting levels continue to increase then our cities will develop to nearly insect (and perhaps bird) free ghost towns far away from the formerly rich animal life.

Street lighting in Germany

Riegel (1973) and Sullivan (1984) estimated the growth of emitted light from electric power consumption for road lighting in the USA. While the power consumption increases linearly, the emission of light increased exponentially at an annual rate of 23 percent between 1967 and 1970. This is due to the use of more efficient lamps changing from incandescent to mercury high pressure and even sodium high pressure lamps. We have tried to estimate the light emission for Germany (Hänel, 2001). Therefore we compared the percentage increase of electric power consumption for the city of Osnabrück, for which we had detailed data about the road lighting, with Germany and the USA (Fig. 8).

published in : McDonnell, M. J.;, Hahs, A. H., Breuste, J. H.: Ecology of Cities and Towns, Cambridge University Press, Cambridge 2009, p. 243-263

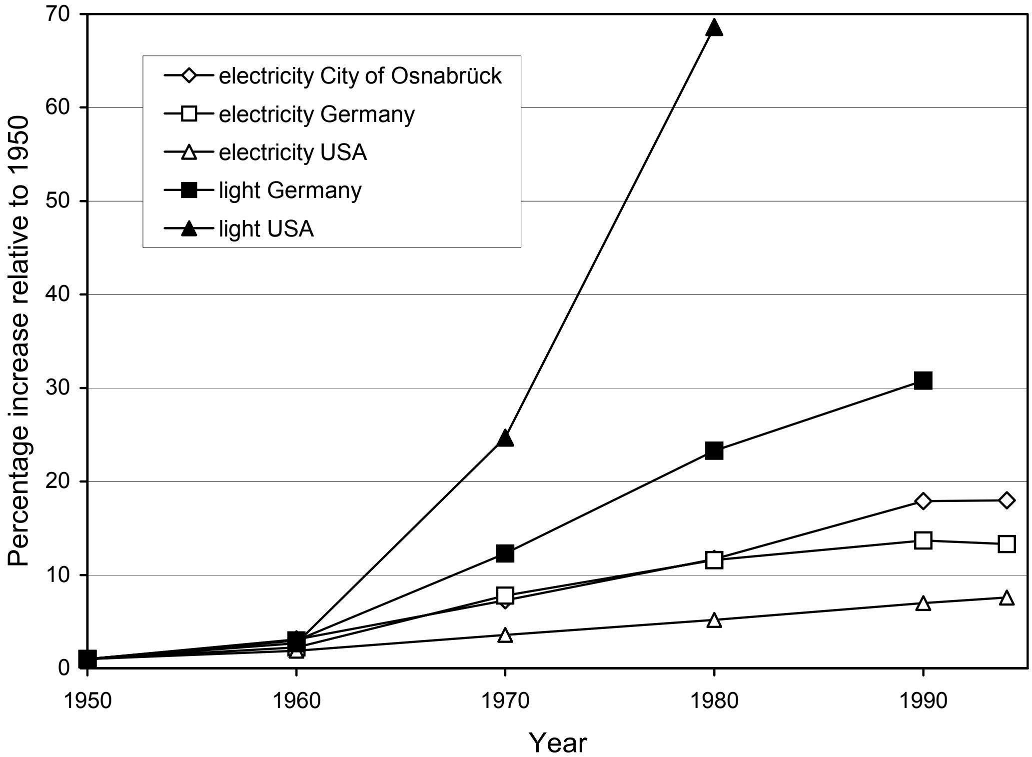

Fig. 8 The growth of electric power consumption and of light emission in the City of Osnabrück/Germany, Germany and the USA.

Assuming also a gradual change to sodium high pressure lamps we estimate a growth rate for the light emission of 7 percent annually between 1980 and 1990 and even less since then. These values provide an estimate of the increase of light. The amount of light emitted to the sky which ultimately increases the artificial sky brightness can not be estimated because we lack data on the numbers and manner of lamp housings. Nevertheless these indirectly derived values can be compared to the measurements of sky brightness in Italy which increased by about 10 percent annually between 1960 and 1995 (Cinzano 2000a). The growth of light pollution in Europe is less than in the USA most likely due to a variety of reasons. In addition, in Europe road lighting is regulated by norms, which require only minimal luminance values at the road surface. Germany also has a regulation that delimitates light emissions at 1-2 Lux.

Good Lighting and steps for the protection of the dark sky

In Europe, light pollution regulations have been issued in the provinces of Catalunya and Tenerife in Spain, Lombardia and others in Italy and in the Czech Republic for the first time on a nationwide level. These regulations mainly forbid any use of upward light and demand a cautious use of light. In addition, some cities in the USA have developed regulations for the use of artificial light during the night. Table 15.1 provides a list~~s~~ of suggested measures that could reduce the harmful impacts of night lighting on insects.

Table 15.1. Suggested methods to reduce the harmful impacts of night lighting on insects.

1. Use light only when it is necessary and use only as dim a light as possible.
2. Direct illumination of the sky should only be allowed if absolutely necessary, searchlights for commercial purposes must be forbidden.
3. Only full cut-off luminaries help to reduce the light glow domes over cities. The light emitted in horizontal planes contributes even more to these light domes than the direct upward light (Cinzano 2000b). Even luminaries installed with small inclinations to illuminate the opposite road side should be avoided and when possible they should be installed horizontally.
4. There is some research (Schanowski and Späth 1994) that indicates sodium low pressure lamps attract fewer insects. Therefore these lamps should be used when colour vision is not important and on streets in or close to rural landscapes. Colour perception with these lights is reduced due to the monochromatic sodium light (589 nm wavelength). But already small amounts of broad-spectrum lights from house lighting or automobile headlights can render essentially normal colour perception (Luginbuhl, 2001).
5. Elsewhere sodium high pressure lamps should be used while mercury pressure should not be used.
6. Road lighting should be dimmed or even switched off, when road use is negligible (eg.11pm. – 5 am.).

There are typically economic reasons proposed as to why measures to reduce light pollution are not feasible. But, there are examples such as the western Canary Islands (Tenerife and La Palma) where strict regulations allow only full cut-off luminaries (lights) in order to maintain a dark sky for their world famous astronomical observatories. Despite these regulations, tourists continue to visit the islands and the economy flourishes (Benn and Ellison, 1998).

In addition to regulations, it is important to develop programs that inform the public about the problem of light pollution. Some positive examples are brochures like "Die helle Not" in Austria (Tiroler Landesumweltanwalt, 2003) or activities like "Wieviele Sterne sehen wir noch?" in Austia (Posch et al., 2002) or "Night blight!" in England, (Campaign to Protect Rural England, 2003). Due to the growing worldwide concern about light pollution, in 1988 the International Dark Sky Association was founded to educate people about the problem and to develop methodologies to mitigate the effects of high levels of night lighting.

As a result of the UN Conference on Environment and Development - Rio de Janeiro, 1992 - a global programme for sustainable development was brought into being, the Agenda 21. In section II the main topics are the management of earth's resources, the protection of major biomes and conservation of biodiversity. It is recommended that all energy sources will need to be used in ways that respect the atmosphere, human health and the environment as a whole. As a consequence of Rio a 'Local Agenda 21' was established in Germany. It is used as a guideline for cities and regions to realise the ideas and recommendations of the global Agenda 21 on a local level. But unfortunately there is no mention of any link to the fact that light is wasted in huge dimensions dissipating energy and changing the night environment. In our opinion over lighting is recognised as modern component of atmospheric pollution. Therefore we recommend that the environmentally friendly use of artificial lighting should be a fixed part of strategies to promote sustainable development at all municipal levels. It contributes both to saving energy and conserves the diversity of organisms, especially of animals.

Summary

Artificial night lighting is increasingly affecting nature and ecosystems. Many groups of animals are affected directly or indirectly, especially birds and nocturnal insects. Our study in a rural landscape in Germany clearly demonstrates the importance of light quality for street lighting. The insect flight activity around high pressure sodium lights was reduced more than half in contrast to high pressure mercury lights. In the spirit of the comparative ecology theme of this book, there are numerous opportunities in the future for comparative studies of the affects of light pollution in cities on insects and other organisms because they all have very similar lighting fixtures, design and placement.

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