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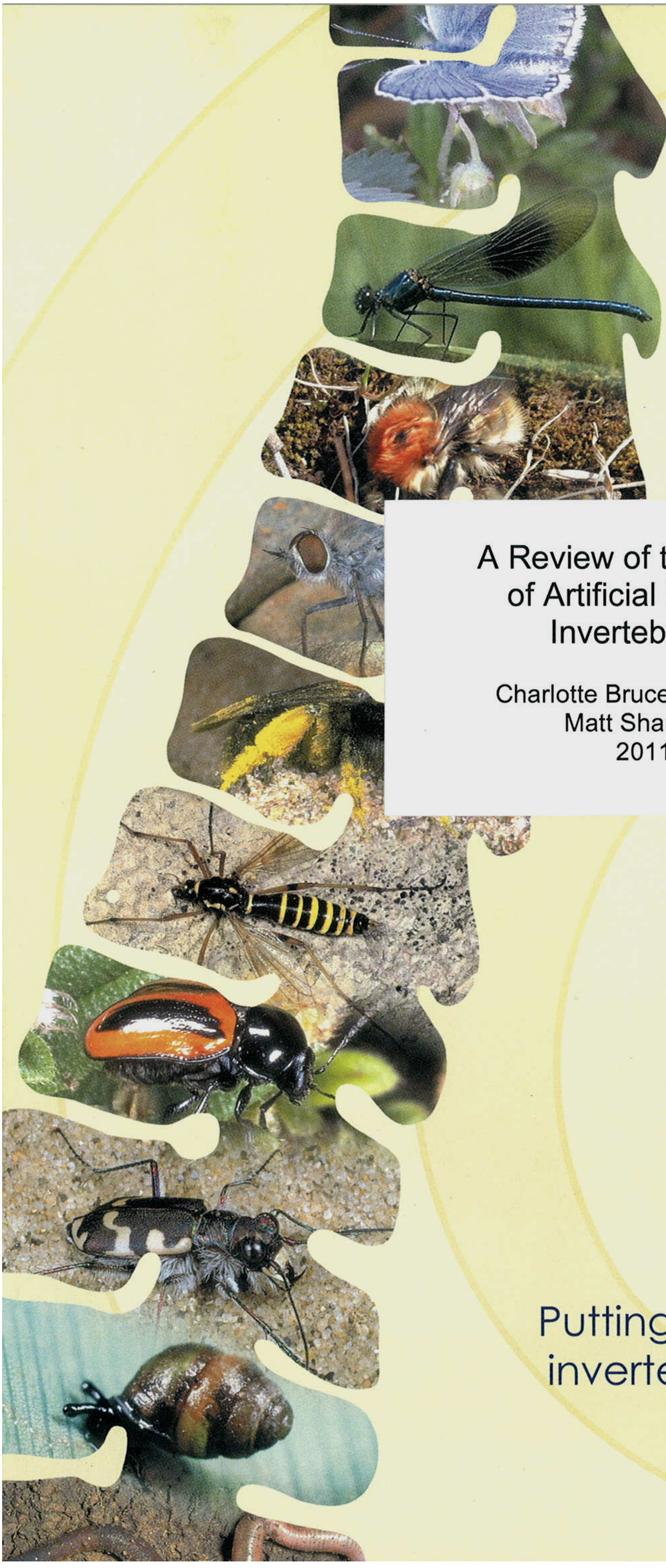
The Invertebrate Conservation Trust



A Review of the Impact of Artificial Light on Invertebrates

Charlotte Bruce-White and
Matt Shardlow
2011

Putting the backbone into invertebrate conservation

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Contents

1.0 Executive summary

This report reviews the available literature on how humans are changing the light environment and the impact that this has on insects and other invertebrates, makes recommendations and identifies several further research areas.

1.1 Conclusions

1. **Developments in lighting technology have led to major increases in the distribution and intensity of artificial light** in the past few decades and its growth is continuing largely unchecked.

2. **Artificial light has the potential to significantly disrupt ecosystems** and it has long been of concern to conservationists. It is widely observed that some invertebrates, such as moths, are attracted to artificial lights at night. In addition the polarisation of light by shiny surfaces is a significant problem as it attracts aquatic insects, particularly egg laying females, away from water, and reflected light has the potential to attract pollinators and impact on their populations, predators and pollination rates.

3. **Artificial light can significantly disrupt the natural light/dark patterns.** Many invertebrates depend on the natural rhythms of day-night and seasonal and lunar changes to light levels. As a result artificial lighting has several negative impacts on a wide range of invertebrates including disrupting their feeding, breeding and movement which may reduce and fragment populations.

4. **Invertebrates make up the majority of biodiversity on earth and are vital to ecosystems.** Many invertebrates are also listed as national priority species for conservation under the UK Biodiversity Action Plan (BAP). It is therefore important to minimise the impacts of artificial light on invertebrate populations.

5. **Action to reduce artificial light impacts is necessary and justified now.** Although further research is required to fully understand the impacts of artificial light on invertebrates and the environment as a whole, the precautionary principle applies and enough is known to take action now. This report makes several recommendations that would reduce and mitigate the negative effects that artificial light has on invertebrates.

1.2 Recommendations

1. **Lighting should be kept to a functional minimum in all areas.** Better designed lighting, in the right places and at the right times is needed rather than just increasing the amount and brightness of artificial light at night. Those involved in planning lighting schemes should always assess whether lighting is necessary and whether alternative solutions are available. If lighting is deemed necessary then it should be used only where and when it is needed. The number of lights and brightness/wattage should be kept to a minimum and, to avoid light spillage, lamps should not emit light at angles greater than 70°.

2. **Lights that emit a broad spectrum of light with a high UV component should be avoided.** The majority of insects and other invertebrates are most sensitive and responsive to the short wavelength end of the light spectrum.

3. **Some locations are particularly sensitive to light pollution and lighting schemes in these areas should be carefully planned to avoid negatively affecting invertebrates and the environment.** In particular, lighting should not be installed near ponds, lakes, rivers and the sea; areas of high conservation value; sites supporting particularly light-sensitive species of conservation significance (e.g. Glow worms and rare moths) and habitat used by protected species of invertebrate.

4. **Areas with natural or near-natural lighting regimes should be officially conserved.** Additional Dark Sky Preserve areas should be identified to complement the Galloway Forest Park Dark Sky Preserve. In these areas existing light pollution should be reduced and strict limits and constraints placed on any new lighting. New lighting in natural cave systems should not be permitted and lighting in show caves should be minimised.

5. **Light pollution from domestic security lighting would be reduced through awareness raising.** Many members of the public are not fully aware of the environmental impacts of lighting. Information on lighting types, installation and maintenance should be given before purchase to reduce the impact of these domestic lights. Retailers selling domestic security lighting should be properly trained and informed on the issues.

6. **Sources of polarised light pollution should be identified and reduced.** Light creation is not the only form of artificial light pollution. Artificial surfaces that reflect polarised light are attractive to aquatic insects. Insects attracted to hot dry surfaces can suffer a high mortality or undertake futile egg-laying. The use of **agricultural sheeting** in sensitive areas, particularly near open water, should be halted, or non-polarizing sheeting should be used where necessary. **Car parks** should be located far enough away from rivers and other waterbodies so that aquatic insects are not attracted to the cars for egg-laying. **Asphalt** road surfaces near waterbodies should be made non-polarising by incorporating a rough top layer or white granules that scatter light. New buildings should not include **glass** that produces horizontally polarised light. **Solar panels** should include a pattern of roughened or painted glass or a horizontal light blocking grid so that they are no longer attractive to aquatic invertebrates.

7. **Structures in the countryside, particularly in perilous situations such as wind farms, should not be painted with colours that attract insects.** Pollinating insects are attracted to surfaces of particular colours. Large structures painted yellow, white or pale grey are likely to divert pollinators away from flowers and also attract their predators. In the case of wind turbines this is likely to result in an increased mortality of insects, birds and bats.

8. **The potential impacts of light pollution on wildlife should be a routine consideration in the Environmental Impact Assessment process.** Risks should be eliminated or minimised wherever possible.

2.0 **Aims and objectives**

The aims for this report are to:

- Review the available literature on the impact of artificial emitted, polarised and reflected light on insects and other invertebrates and identify further research needed to address any knowledge gaps.

- Make recommendations to minimise any impacts of artificial light on invertebrates and develop a strategy for influencing planners, engineers and other stakeholders in their choice of lighting equipment and other materials.

- Raise awareness of the negative effects that artificial light poses to invertebrates and other wildlife.

3.0 **Introduction**

Humans have long been producing and manipulating light. Up until about 150 years ago all artificial light was produced by burning substances such as wood, candles, oil and gas. These are combustion-based forms of lighting that emit a broad spectrum of light but are very inefficient. The introduction of the electric filament lamp in the mid-19th century caused a revolution in lighting, allowing much brighter, more efficient light to be produced. Incandescent forms of lighting remained dominant until the 1930s but fluorescent lighting started to become more widespread in post-war Britain.

The dramatic development of lighting technology in recent decades has led to a massive increase in outdoor lighting both in Britain and on a global scale. The distribution and intensity of artificial lighting continues to increase with the growth in worldwide development. Urban and rural development brings with it road, security and amenity lighting that results in a significant change in the natural patterns of day and night in the environment. Associated artificial surfaces can polarise or reflect significant amounts of sunlight. These factors have created more direct exposure of wildlife to artificial light.

Concern about the impacts of artificial lighting on the environment have been growing in recent years and was recently summarised in the 2009 Royal Commission on Environmental Pollution report on Artificial Light in the Environment.

Artificial lighting has the potential to significantly disrupt ecosystems and it has long been of concern to conservationists[1]. The negative effects that lighting has on vertebrate animals, such as migrating birds, nesting sea turtles and bats have been well documented[2,3,4]. However, despite almost universal awareness that electric

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[1] Rich, C. & Longcore, T. (Eds). (2006) *Ecological Consequences of Artificial Night Lighting*. Washington, Island Press.
[2] Bruderer, B., Peter, D. & Steuri, T. (1999) Behaviour of migrating birds exposed to x-band radar and a bright light beam*. The Journal of Experimental Biology*, **202**, 1015–1022.
[3] Lorne, J.K. & Salmon, M. (2007) Effects of exposure to artificial lighting on orientation of hatching sea turtles on the beach and in the ocean. *Endangered species research*, **1**, 23–30.
[4] Kuijper, D.P.J., Schut, J., Van Dullemen, D., Toorman,H., Goossens, N., Ouwehand, J. & Limpens, H.J.G.A. (2008) Experimental evidence of light disturbance along the commuting routes of pond bats (*Myotis dasycneme*). *Vereniging voor Zoogdierkunde en Zoogdierbescherming*, **51**(1), 37–49.

lighting disturbs nocturnal invertebrates, little substantial scientific research has been conducted to assess the nature of these effects on nocturnal invertebrates.

Invertebrates are animals that don't possess a backbone (vertebral column) and include everything from sponges (Porifera), jellyfish (Cnidaria), flatworms (Platyhelminthes), crustaceans, insects and spiders (Arthropoda) and snails (Mollusca). Invertebrates make up the majority of living species; they are hugely diverse and abundant and are vital to ecosystems[5]. Therefore it is important to understand and quantify the effects that artificial light has on invertebrate populations in order to assess the overall impacts on the ecosystems.

3.1 Light detection by invertebrates

Most animals are sensitive to light, and nearly all have some form of identifiable photoreceptors (light sensors). In the invertebrates there is a huge range in the complexity and capability of light-sensitive structures which range from simple nerve fibres of some sea urchins that respond to changes in light levels, to the complex compound eye of insects that detects light and is able to form images and the sophisticated eyes of jumping spiders that are able to focus images. Arthropods, molluscs and some worms have eyes that are extremely sensitive and they are perhaps most affected by changes in light.

Light and darkness are a major environmental influence in the lives of many animals, including invertebrates. Arthropods such as insects and crustaceans have compound eyes that are sensitive to a broad range of light. Most insects have a colour vision system that is based on three or four, sometimes five, types of colour receptor cells. Light wavelengths are measured in nanometres (nm) and most insects can perceive the spectral region from ultraviolet (UV) which has a short wavelength and high frequency (300 nm) to red which has a long wavelength and a low frequency (700 nm)[6]. UV light is used by terrestrial invertebrates in a variety of activities such as mate selection, navigation and foraging[7]. UV, green and blue light which have short wavelengths and high frequencies are best discriminated by insects, they are often much more sensitive to these wavelengths than humans are; while insects are generally insensitive to the red end of the spectrum. However, it is believed that some aquatic insects are more sensitive to red light than other invertebrates as it penetrates an unpolluted water column further than light with a shorter wavelength[8]. Some biting flies are also known to see infrared (>700nm) emitted from warm-blooded animals;

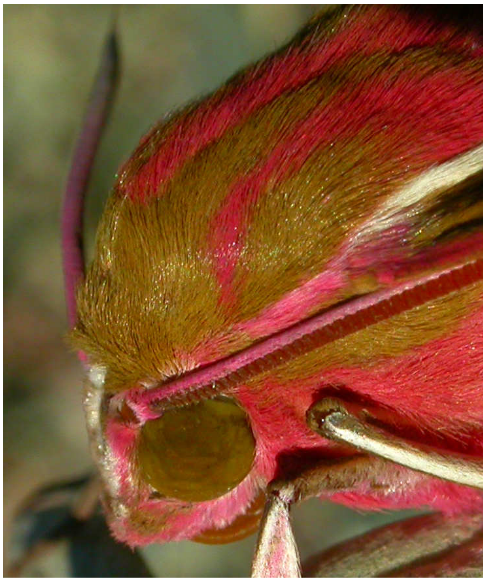

Figure 1. Elephant hawkmoth (*Deilephila elpenor*) © Nigel Jones

[5] Brusca, R.C. & Brusca, G.J. (2003) *Invertebrates* (2nd ed.), Massachusetts, Sinauer Associates.
[6] Arikawa, K., Inokuma, K. & Eguchi, E. (1987) Pentachromatic visual system in a butterfly. *Naturwissenschaften*, **74**, 297–298.
[7] Salcedo, E., Zheng, L., Phistry, M., Bagg, E.E. & Britt, S.G. (2003) Molecular basis for ultraviolet vision in invertebrates. *The Journal of Neuroscience*, **23**(34), 10873–10878.
[8] Heise, B.A. (1992) Sensitivity of mayfly nymphs to red light: implications for behavioural ecology. *Freshwater Biology*, **28**, 331–336

however in general insects are most strongly attracted to UV light and are least attracted to red light[9].

Some invertebrates can detect light at very low levels. For example nocturnal hawkmoths have large and sensitive superposition compound eyes. Their sensitive eyes allow them to see in colour even at very low light intensities that are roughly equivalent to starlight. Like humans, other insects with apposition eyes, such as bees, become colour-blind in dim light[10].

3.2 Light and invertebrate life-cycles

Many invertebrates depend on the natural rhythms of day–night and on seasonal and lunar changes in light levels to trigger vital stages in their life-cycles such as oviposition (egg-laying), emergence and diapause (hibernation). For example, some species of insects complete their lifecycle within a lunar cycle of 28 days. The presence or absence of moonlight provides a trigger for the beginning or end of each lifecycle. Some insects such as flying adult mayflies can become disorientated by artificial light and fail to successfully perform important aspects of their life-cycle[11]. It is likely that such disruption to essential life events would lead to local extinctions of species and a reduction in abundance and biodiversity.

4.0 Methodology

This report presents an overview of the impact of artificial night lighting on invertebrates. There has been anecdotal evidence about the deleterious effects of light pollution on invertebrates for many decades, but surprisingly little scientific data on the actual effects on species and populations exists. The majority of literature focuses on the effects of emitted light on night flying invertebrates, particularly moths. Literature on other groups of invertebrates and on polarised and reflected light is patchy. Although 'hard' data is limited, this report reviews a wide cross-section of available relevant literature and identifies where additional research is required. The literature used as supporting evidence in this report was found using web-based searches and from contacts with specific expertise. Most of the literature cited is from peer-reviewed publications providing a diverse selection of literature for the report. Both international and UK-based sources were utilised. The research in this report focuses predominantly on invertebrates but research on the effects of artificial light on other wildlife was also reviewed.

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9 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. *Pakistan Entomologist Journal*, **27**(1), 49–52.

10 Kelber, A., Balkenius, A. & Warrant, E.J. (2002) Scotopic colour vision in nocturnal hawkmoths. *Nature*, **419**, 922–925.

11 Nowinszky, L. (2004) Nocturnal illumination and night flying insects. *Journal of Applied Ecology and Environmental Research*, **2**(1), 17–52.

5.0 Potential impact on invertebrates

5.1 Attraction to artificial light

5.1.1 Attraction to emitted light

One of the most obvious effects of artificial lighting is that it attracts many nocturnal insects and some other invertebrates. Lighting attracts large numbers of a wide range of invertebrates but moths are perhaps best known for this behaviour[12]. Other groups drawn to artificial lights, include beetles, lacewings, aphids, caddisflies, crane-flies, midges, hoverflies, true flies, scorpionflies, damselflies and dragonflies, termites, butterflies, some diurnal jumping spiders, ant-lions, bush crickets and wasps[13,14,15]. UV, green and blue light which have short wavelengths and high frequencies are best discriminated by most insects and are highly attractive to them. Consequently, lights that emit little or no UV such as low pressure sodium lamps are least attractive to insects.

The distance that invertebrates are attracted to light varies greatly depending on other environmental factors and on the species. Moths are known to fly to light from distances varying from 3 to 130 m, but greater distances up to 500 m have been observed[16] and this may not be the upper limit. Attraction to artificial light has been utilised by entomologists for centuries as a way to survey and monitor moth and other invertebrate populations. Moth trapping is usually undertaken in a responsible manner. Many trappers will not run their traps in the same area on consecutive nights, in case the artificial light affects moth breeding and feeding behaviour. However, experiments conducted in Finland indicated that even the minimal amount of disturbance caused by moth traps could still lead to local extinctions of moths that have a very small population[17].

Figure 2. Insects attracted to light © Carl Monas

It is estimated that as many as a third of flying insects that are attracted to street lights will die as

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[12] Frank, K.D. (1988) Impact of outdoor lighting on moths: an assessment. *Journal of the Lepidopterists' Society*, **42**(2), 63–93.

[13] Eisenbeis, G. & Hassel, F. (2000) Zur Anziehung nachtaktiver Insekten durch Straßenlaternen – eine Studie kommunaler Beleuchtungseinrichtungen in der Agrarlandschaft Reinhessens [Attraction of nocturnal insects to street lights – a study of municipal lighting systems in a rural area of Rheinhessen (Germany)]. *Natur und Landschaft*, **75**, 145–156.

[14] Feltwell, J. (2010) Types of invertebrates attracted to artificial lighting. Personal Communication.

[15] Nakamura, T. & Yamashita, S. (1997) Phototactic behavior of nocturnal and diurnal spiders: negative and positive phototaxes. *Zoological Science*, **14**, 199–203.

[16] Frank, K.D. (2006) Effects of artificial night light on moths. *Ecological Consequences of Artificial Night Lighting* (eds C. Rich & T. Longcore), pp.345–364. Washington, Island Press.

[17] Väisänen, R. & Hublin, C. (1983) The effect of continuous light trapping on moth populations. A mark recapture experiment on *Hydraecia petasitis* (Lepidoptera, Noctuidae). *Notulae Entomologicae*, **63**, 187–191.

a result[18]. Insects can die or become injured when they collide with a hot lamp or they can become disorientated and exhausted making them more susceptible to predation. In some instances huge numbers of dead moths have been observed around outdoor lighting[19]. Certain species of fast-flying bats such as the Noctule (*Nyctalus noctula)* and Common pipistrelle (*Pipistrellus pipistrellus)* are known to feed on large numbers of insects that have been attracted to night lighting[20,21]. It has also been found that mercury vapour streetlights increase bat predation on moths because the lights interfere with the ability of moths to detect the ultrasonic sound bursts used by bats to locate prey[22].

Artificial lighting attracts other predators too. Moths and other invertebrates attracted to night lighting often rest on surfaces close to the light source during the day. Many invertebrate species use camouflage, but they may end up resting on an unsuitable background making them clearly visible to predators. It has been noted that birds soon learn to hunt for invertebrates resting on surfaces close to artificial light and amphibians and reptiles in some tropical areas will sit and wait to prey on invertebrates attracted to light[16]. It is thought that even Common toads (*Bufo bufo*) in Britain sometimes prey on flying insects attracted to street lamps at night[23]. Some nocturnal mammals such as hedgehogs and shrews will also eat invertebrates attracted to artificial lights[24]. The Bridge orbweaver (*Larinioides sclopetarius*) has an inborn preference to build its webs near artificial light. This behaviour might originate from the spider favouring hunting grounds near to water bodies which reflect moonlight[25]. This spider and several commoner spider species are able to take advantage of the attraction of flying insects to artificial lighting for their food supply.

Increased predation is not the only effect that attraction to artificial lighting has on invertebrates. Lighting can affect moths in many ways; it can disturb their flight, navigation, vision, migration, dispersal, egg-laying, mating, feeding and camouflage[12]. The combination of such wide-ranging effects could have a considerable impact. Two thirds of the 337 moth species with sufficient monitoring data to determine the population trend in Britain have decreased over the last 35 years. Light pollution has been identified as a possible contributing factor for the observed declines. However, it is difficult to separate the impacts of artificial lighting from other impacts of urban development such as loss of habitat and air pollution[26]. Further research is required to fully evaluate the problem.

Aquatic invertebrates are also influenced by artificial lighting. Riverflies are one of the most prominent of all the invertebrate groups affected. Riverflies include three orders of freshwater insects; stoneflies (Plecoptera), caddisflies (Trichoptera) and

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[18] Eisenbeis, G. (2006) Artificial night lighting and insects: attraction of insects to streetlamps in a rural setting in Germany. Ecological Consequences of Artificial Night Lighting (eds C. Rich & T. Longcore), pp. 345–364. Washington, Island Press.

[19] Feltwell, J.S.E. (1996) A hazard to moths on the Lozere Massif. *British Journal of Entomology Natural History*, **9**, 103-105.

[20] Blake, D., Hutson, A.M., Racey, P.A., Rydell, J. & Speakman, J.R. (1994) Use of lamplit roads by foraging bats in southern England. *Journal of Zoology* (London), **234**, 453–462.

[21] Rydell, J. (1992) Exploitation of insects around streetlamps by bats in Sweden. *Functional Ecology*, **6**, 744–750.

[22] Svensson, A.M. & Rydell, J. (1998) Mercury vapour lamps interfere with the bat defence of tympanate moths (*Operophtera* spp.; Geometridae). *Animal Behaviour*, **55**, 223–226.

[23] Baker, J. (1990) Toad aggregations under street lamps. *British Herpetological Society Bulletin*, **31**, 26–27.

[24] Outen, A.R. (2002) The ecological effects of road lighting. *Wildlife and Roads: The Ecological Impact* (eds B.R. Sherwood, D.F. Cutler & J.A. Burton), pp. 133–155. London, Imperial College Press.

[25] Milius, S. (1999) Nocturnal spider favors artificial lights. *Science News*, **155**(26), 407.

[26] Fox, R., Conrad, K.F., Parsons, M.S., Warren, M.S. & Woiwod, I.P. (2006) The state of Britain's larger moths. Butterfly Conservation and Rothamsted Research, Wareham, Dorset.

mayflies (Ephemeroptera). Riverflies and other aquatic invertebrates are a vital part of the freshwater ecosystem and are an important food source for birds, fish and other animals. It appears that the increasing intensity and distribution of lights across Britain is affecting riverfly breeding and survival[27]. Many riverflies depend on specific environmental cues for adult emergence and artificial lighting can interfere with these crucial cues. The larvae are generally repelled by light[8] but adult riverflies are attracted to artificial night lights and could become disoriented around them[28]. There are recorded incidents of high mortality of riverflies around light sources close to riverbanks. Such incidents have the potential to lure sufficient numbers of adult riverflies away from the water to cause population declines27[27].

Outside of the UK other species of freshwater invertebrates are known to be affected by artificial light. Populations of the Giant water bug (*Lethocerus deyrollei*) have declined dramatically in Korea and it has been designated as an endangered species by the Korean Ministry of Environment. The Giant water bug and other insects belonging to the genus *Lethocerus* are known to be attracted in large numbers to street lights during night dispersion flights. In artificially lit areas without water the Giant water bug can then die of dehydration. A study on Jeju Island found that artificial light sources might be critical in determining where Giant water bugs live in the landscape. In particular, it is speculated that the presence of artificial lights within a 1 km radius reduces the probability of inhabitation[29].

Many types of marine invertebrate, such as late-stage crab larvae, are attracted to artificial light[30]. Lights from the shore, boats and gas flares could disrupt marine invertebrates in the performance of activities vital to their life-cycles, such as feeding and breeding and make them more susceptible to predation. These invertebrates are important to the marine food chain and lighting around marinas and the shore must be minimised.

Electrocuting insect traps use light attraction to kill insects. They are widely used in food handling areas, and to some degree in homes, to control or eliminate unwanted flies. The traps contain a visual attractant, usually a UV bulb, and a high-voltage metal grid. Upon contact with the grid the insects are disintegrated by the high voltage. Scientific studies have shown that the disintegration of the fly results in the release of bacteria and viruses that were safely inside the fly, and hence present a likely increased risk of disease transmission to humans – directly and via foodstuffs. As a result glue board traps have been developed that operate at a lower voltage and stun the insect so that it falls onto a glue board and dies. We were unable to identify any research linking the use or efficacy of any electric insect traps to changes in population levels of insects or the killing of wild insects. It is very unlikely that indoor traps would damage the environment as they are generally placed in areas that are already fairly sterile and only a small fraction of the insect fauna is attracted indoors where they would be vulnerable. However, some traps are placed in stables and other more rural locations; there is some potential for these to affect wild insect populations, particularly if they are left running at night in an unenclosed space. We are aware of at least one instance of large electrocuting traps being placed outdoors

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[27] Macadam, C. (2009). Personal Communication.

[28] Rich, C. & Longcore, T. (2006) Synthesis. *Ecological Consequences of Artificial Night Lighting* (eds C. Rich & T. Longcore), pp. 345–364. Washington, Island Press.

[29] Choi, H., Kim, H. & Kim, J.G. (2009) Landscape analysis of the effects of artificial lighting around wetland habitats on the giant water bug *Lethocerus deyrollei* in Jeju Island. *Journal of Ecology and Field Biology*, **32** (2), 83–86.

[30] Porter, S.S., Eckert, G.L., Byron, C.J. & Fisher, J.L. (2008) Comparison of light traps and plankton tows for sampling Brachyuran crab larvae in an Alaskan fjord. *Journal of Crustacean Biology*, **28**(1), 175–179.

– to control mosquito populations at a sewage works. It seems almost inevitable that if these traps are effective in their desired objective of controlling populations of mosquitoes, they will also cause damage to local populations of a wide range of nocturnal insects.

5.1.2 ***Attraction to polarised light***

Polarised light pollution sources are also attractive to many invertebrates, including beetles, dragonflies and adult riverflies. Polarised light pollution is the process whereby light undergoes linear polarisation by reflecting off smooth surfaces or by scattering in the atmosphere or under water. Artificial lights are not necessarily part of this form of light pollution, but artificial lighting can make the situation worse.

Adult mayflies are attracted to sources of polarised light as in nature they indicate a water surface on which the insects can breed and lay eggs. Artificial sources of polarised light such as smooth dark building, cars, road surfaces and solar panels can attract mayflies in the same way; however, any eggs laid on such surfaces will not develop[31]. There are a total of 278 species of mayfly, stonefly and caddisfly in Britain, eight of which are UK Biodiversity Action Plan (UKBAP) priority species for conservation action. All but the most polluted rivers in Britain support mayfly populations, therefore artificial lighting and sources of polarised light pollution around all rivers should be minimised[27].

Figure 3. Drake mackerel mayfly (*Ephemera vulgata*) attracted to polarised light © me'nthedogs

Figure 4. Lesser silver water beetle (*Hydrochara caraboides*), an endangered beetle that is attracted to lay its egg on cars, especially red ones. The coating of the eggs is acidic and eats away the surface of the car's paint © Gyorgy Kriska

Other freshwater invertebrates are also attracted to artificial light, including aquatic beetles[18]. The Lesser silver water beetle (*Hydrochara caraboides*) is known to be attracted to polarised light pollution sources[32]. It is a UKBAP species, classed as endangered in Britain and is fully protected under Schedule 5 of the Wildlife and Countryside Act 1981 in England and Wales. It is possible that populations of this rare beetle could decline further due to the presence of artificial light and polarised light pollution near ditches and ponds where they are found.

[31] Horváth, 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.

[32] Kriska, G., Csabai, Z., Boda, P., Malik, P. & Horváth, G. (2006) Why do red and dark-coloured cars lure aquatic insects? The attraction of water insects to car paintwork explained by reflection–polarization signals. *Proceeding of the Royal Society*, **273**(1594), 1667–1671.

Large areas of plastic sheeting on arable fields are of particular concern as they have the potential to radiate large amounts of polarised light and thereby divert a large proportion of flying aquatic insects from water bodies; this has not been adequately researched.

5.1.3 ***Attraction to reflected light***

In addition to attraction to artificial and polarised light, light reflected off coloured artificial surfaces has the potential to impact on invertebrate populations. Some colours are very attractive to pollinating insects as they are strongly associated with flower colours. Yellow objects are attractive to diurnal pollinators while white or pale grey objects attract more insects at dusk[33]. Most attraction, for instance pollen beetles attracted to a yellow t-shirt, is likely to be very localised and, while the affected animals may waste some energy in futile activity, there is unlikely to be any significant ecological impact. However, there may be exceptions to this, large objects may attract many insects from a considerable distance; if combined with an increased risk of fatality then there could be significant ecological impacts. In particular a recent study has strongly suggested that pale grey wind turbines have the potential to attract insects at dusk and the suggestion is that this could in turn attract increased numbers of their predators, resulting in increased fatality of bats and possibly birds as well[34,33].

5.2 **Repulsion from light**

Many invertebrates are known to be repelled by light; examples are some species of earwigs, cockroaches, woodlice, earthworms and scorpions[35,36]. Investigating repulsion to light is more difficult than studying attraction to light: there is less available information and it is often hard to draw sound conclusions. As artificial lighting increases in both distribution and intensity there are fewer suitable places for these sensitive invertebrates to survive and reproduce. It is highly probable that increased light levels will damage the survival prospects of invertebrates that inhabit dark areas[37].

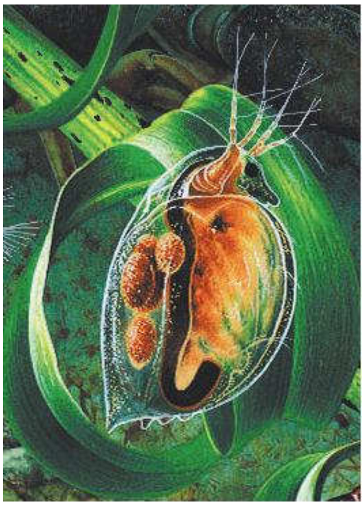

Figure 5. Common water flea (*Daphnia pulex*) © Ian Jackson

Zooplankton are a diverse group of small organisms that live in seas, oceans and fresh water bodies. They migrate from the depths of the water to the surface to feed under cover of darkness which helps them avoid predation from animals such as fish. However, light pollution prevents small zooplankton invertebrates such as *Daphnia* (also known as water fleas) in fresh water lakes from migrating upwards at night. As a result night-time activity near the surface

[33] Long, C.V., Flint, J.A. & Lepper, P.A. (2010) Insect attraction to wind turbines: does colour play a role? European Journal of Wildlife Research, Online First September 2010.
[34] Young, D.P. Jr., Erickson, P., Strickland, M.D., Good, R.E. & Sernka, K.J. (2003) Comparison of Avian Responses to UV-Light-Reflective Paint on Wind Turbines Subcontract Report July 1999 – December 2000. Colorado National Renewable Energy Laboratory, Colorado.
[35] Camp, E.A. & Gaffin, D.D. (1999) Escape behavior mediated by negative phototaxis in the scorpion *Paruroctonus utahensis* (Scorpiones, Vaejovidae). *The Journal of Arachnology*, **27**, 679–684.
[36] Hassall, M., Zimmer, M. & Loureiro, S. (2005) Questions and possible new directions for research into the biology of terrestrial isopods. *European Journal of Soil Biology*, **41**, 57–61.
[37] Feltwell, J. (2003) Light pollution – are we still in the dark? Buglife, Action Update 3.

is reduced and the *Daphnia* do not graze on the algae in the upper part of the water column. This could lead to an algal bloom in freshwater sources near urban areas which would considerably lower water quality[38].

Macro-invertebrate species such as some aquatic midge larvae and shrimps exhibit pronounced avoidance of even dim light. This behaviour is possibly a way in which they protect themselves from predation by fish which select for larger prey as light levels decrease. Artificial light can confine these species to cold, deep waters where food is less abundant and where their growth is slow, which could reduce their populations[39].

It is possible that invertebrates that are repelled by light will not use large areas that are illuminated by artificial lighting. The proliferation of such 'no-go' areas through an increase in outdoor lighting could lead to the fragmentation of habitats, and isolation of populations. Small isolated populations might not be viable in the long term, which could ultimately lead to local extinctions and reduce gene flow between populations.

Light which has short wavelengths and high frequencies such as UV, blue and green light is best discriminated by invertebrates and hence the most attractive. While high and low pressure sodium lamps are less attractive to invertebrates than some other lamp types because they emit little or no UV light, some observations suggest that normal flight behaviour of insects is completely inhibited in the general area of sodium lamps. So, although sodium lamps are less attractive to some invertebrates, sodium lamps can still affect the behaviour of others, particularly those that are repelled or inhibited by their light[40].

5.3 Other negative impacts of artificial lighting

5.3.1 ***Dormancy***

Invertebrate development from egg to adult is often interrupted by a period of dormancy when conditions become unsuitable, such as in very high or low temperatures or during drought. Dormancy can occur in summer (aestivation) or in winter (hibernation), and may involve quiescence or diapause. Quiescence is when development is halted or slowed as a direct response to unfavourable conditions and development immediately continues when conditions become more favourable. Diapause, in contrast, involves arrested development combined with adaptive physiological changes and development does not necessarily continue when conditions become more favourable but will only continue when particular physiological stimuli are triggered[41].

Many invertebrates in temperate climates such as insects, spiders, millipedes and woodlice undergo a period of diapause which enables them to survive when

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[38] Moore, M.V., Pierce, S.M., Walsh, H.M., Kvalvik, S.K. & Lim, J.D. (2000) Urban light pollution alters the diel vertical migration of Daphnia. *Verhandlungen des Internationalen Verein Limnologie*, **27**, 779–782.

[39] Moore, M.V., Kohler, S.J. & Cheers, M.S. (2006) Artificial light at night in freshwater habitats and its potential ecological effects. *Ecological Consequences of Artificial Night Lighting* (eds C. Rich & T. Longcore), pp. 345–364. Washington, Island Press.

[40] Uffen, R. (1994) Report of East Region meeting, Nottingham University, 13th November 1993. *Antenna*, **18**, 80–81.

[41] Gullan, P.J. & Cranston, P.S. (2005) *The Insects: An Outline of Entomology* (3rd ed.). Oxford, Blackwell Publishing.

environmental conditions become unsuitable[42,43,44,45]. Day length (photoperiod) is the primary environmental stimulus involved in the regulation of their life cycles and it is significant in diapause because alteration in day length predicts much about the future seasonal environmental conditions. Photoperiod is a far more reliable environmental cue than temperature which can vary significantly from day to day. Insects can detect changes in day and night length, often quite accurately, through brain receptors rather than using eyes. Experiments have shown that extending day length using artificial light prevents European corn borer larvae (*Ostrinia nubilalis*) and Codling moth larvae (*Cydia pomonella*) from entering diapause[46]. In such circumstances non-diapausing invertebrates would not survive the extreme conditions of winter. This would have a significant effect on invertebrate populations and could even cause local extinction quite quickly in an area.

*5.3.2 **Migration***

Changing the natural day–night cycles of invertebrates can affect dispersal and migration. Disruption of the circadian clock (the 24-hour rhythm) of Monarch butterflies (*Danaus plexippus*) using artificial light has been shown to interfere with their orientation direction during migration[47].

It is also likely that artificial lighting could affect invertebrate migration and movement on a more local scale too, interfering with local dispersal and metapopulation connections.

Some flying insects are attracted to the lights around sea and air ports. These insects may rest on planes or boats and be transported to other regions and countries where they can become a pest[48]. This form of artificial migration is important both in economic and environmental terms.

*5.3.3 **Changes in activity levels***

Artificial light at night has the potential to confuse invertebrates and change their natural levels of activity at night. Artificial light could also change the speed of development in invertebrates.

A high general level of illumination at night caused by artificial lighting can cause night flying insects to cease flying and settle as if it was sunrise. This prevents insects from performing normal nightly activities such as feeding and breeding.

It has been found that Corn earworm moth (*Helicoverpa zea*) activity in a bioclimatic chamber was suppressed by light intensities as low as 0.1 lux (less than a fifth of full

[42] Tauber, M.J. & Tauber, C.A. (1970) Photoperiodic induction and termination of diapause in an insect: response to changing day lengths. *Science*, **167**, 170.
[43] Schaefer, M. (1987) Life cycles and diapause. *Ecophysiology of Spiders* (ed W. Nentwig), pp. 331–347. Berlin, Springer-Verlag.
[44] Mocquard, J.P., Juchault, P. & Souty-Grosset, C. (1989) The role of environmental factors (temperature and photoperiod) in the reproduction of the terrestrial isopod *Armadillidium vulgare* (Latreille, 1804). *Monitore Zoologico Italiano Monografia*, **4**, 455–475.
[45] David, J.F., Geoffroy, J.J. & Célérier, M.L. (2003) First evidence for photoperiodic regulation of the life cycle in a millipede species, *Polydesmus angustus* (Diplopoda: Polydesmidae). *Journal of Zoology*, **260**, 111–116.
[46] Hayes, D.K., Sullivan, W.N., Oliver, M.Z. & Schechter, M.S. (1970) Photoperiod manipulation of insect diapause: A method of pest control? *Science*, **169**(3943), 382–383.
[47] Froy, O., Gotter, A.L., Casselman, A.L. & Reppert, S.M. (2003) Illuminating the circadian clock in monarch butterfly migration. *Science*, **300**(5623), 1216–1217.
[48] Wallner, W.E., Humble, L.M., Levin, R.E., Baranchikov, Y.N. & Cardé, R.T. (1995) Response of adult lymantriid moths to illuminations devices in the Russian Far East. *Journal of Economic Entomology*, **88**(2), 337–342.

moonlight) and that field oviposition rates were significantly reduced at times of full moon[49].

A study looking at Speckled wood butterfly larvae (*Pararge aegeria*) showed that a higher growth rate associated with a longer photoperiod (as would be caused by artificial light) resulted in significantly higher predation on the butterfly larvae from the primary parasitoid species[50]. It appears that artificial light can affect growth rate and can also affect the natural predator–prey balance, which could benefit a few species while possibly negatively impacting many more.

Many diurnal (day active) invertebrates such as butterflies have larvae that feed at night, a behaviour which helps them avoid predation. British butterfly caterpillars that feed at night include Wall brown (*Lasiommata megera*) and Grayling (*Hipparchia semele*) which are listed as priority species in the UK Biodiversity Action Plan (UKBAP). Other night feeding species include Scotch argus (*Erebia aethiops*), Meadow brown (*Maniola jurtina*), Marbled white (*Melanargia galathea*) and Ringlet (*Aphantopus hyperantus*)[51]. It is likely that artificial lighting will impact on the behaviour of night feeding larvae and will either make them much more susceptible to predation or inhibit their feeding.

The larvae of riverflies and some other freshwater species exhibit a nocturnal pattern of movement called stream drift. Stream insects and crustaceans hide amongst substrate during the day, but at night they will detach themselves and drift downstream eventually reattaching themselves to the substrate. This allows movement to areas with less competition or better foraging. By moving only at night they avoid predation from fish. Stream drift is cued by low light intensity; higher light levels, such as during a full moon (0.5-1 lux in clear conditions), can suppress stream drift. Artificial light spill can produce light levels far higher than the light level recorded under full moon, so it is likely that artificial light cast onto streams will prevent a significant amount of invertebrate stream drift. A reduction in stream drift could reduce species populations, inhibit dispersal to new areas and have other wider implications for steam ecosystems[38].

In cave systems beyond the entrance zone there is no natural light; specialised species live in these permanently dark zones. In the UK there are several species of springtail, crustaceans and spiders that only occur in dark caves. The introduction of artificial lighting into these areas, as is often associated with public access, dramatically changes cave ecology, enabling generalist species to invade the cave and out-compete the specialist species.

On the other hand, light pollution can result in diurnally active species becoming more active at night. Necrophilous flies do not normally lay eggs at night, but will do so if an area is illuminated by artificial light[52] and artificial nocturnal moonlight has a

[49] Nemec, S.J. (1971) Effects of lunar phases on light-trap collections and populations of bollworm moths. *Journal of Economic Entomology*, **64,** 860-864.
[50] Gotthard, K. (2000) Increased risk of predation as a cost of high growth rate: an experimental test in a butterfly. *Journal of Animal Ecology*, **69**(5), 896–902.
[51] Lewington, R. (2003). *Pocket Guide to the Butterflies of Great Britain and Ireland*. Gillingham, British Wildlife Publishing.
[52] Baldridge, R.S., Wallace, S.G. & Kirkpatrick. (2006) Investigation of nocturnal oviposition by necrophilous flies in Central Texas. *Journal of Forensic Sciences*, **51**(1), 125–126.

twofold influence on fruit flies: it shifts the circadian clock, and it increases nocturnal activity independently of the clock, making them become nocturnal[53].

5.3.4 Disruption of bioluminescent behaviour

Beetles of the family Lampyridae, which include fireflies and glow-worms, produce light (bioluminescence) to attract mates and prey[54]. The Glow-worm (*Lampyris noctiluca*) is the commonest species of Lampyridae in Europe; this species is nocturnal and the flightless females produce a bioluminescence glow to attract flying males. There is some evidence that Glow-worms are declining in Britain and light pollution may be one of several contributory factors[55].


Figure 6. Glow-worm (*Lampyris noctiluca*) © John Horne

There have been anecdotal reports that male Glow-worms are attracted to artificial lighting at night. A laboratory study showed that males respond to certain wavelengths of light. They have been found to be attracted to lights in the green to orange part of the spectrum but inhibited by blue and ultraviolet light[56]. Many artificial lights produce wavelengths that would be attractive to male Glow-worms. However, it is not known if artificial lighting significantly affects the breeding, mating success and population levels of Glow-worms in field conditions. The distances over which males are attracted to lights or how they judge the size of a light source is also not fully understood. It is also thought, but not yet proven, that the efficiency with which males can detect female bioluminescence is reduced when the background environment is highly illuminated by artificial lighting.

Female Glow-worms generally do not start glowing until light levels have dropped below a certain point[57]. Artificial light might prevent the stimulus that female Glow-worms require to initiate glowing, or it might reduce the amount of time that they would naturally glow in a night which would then decrease the chance of a successful mating. Interestingly, there have been anecdotal observations of female Glow-worms displaying under street lamps though this might simply be because females are attracted to open areas where they are more visible to males. In addition, glowing activity usually only starts above a certain ambient temperature; which happens only after warm days and before the night-time temperature drops too low.

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[53] Kempinger, L., Dittmann, R., Rieger, D. & Helfrich-Förster, C. (2009) The nocturnal activity of fruit flies exposed to artificial moonlight is partly caused by direct light effects on the activity level that bypass the endogenous clock. *Chronobiology International*, **26**, 151-166.

[54] Lloyd, J.E. (2006) Stray light, fireflies, and fireflyers. *Ecological Consequences of Artificial Night Lighting* (eds C. Rich & T. Longcore), pp. 345–364. Washington, Island Press.

[55] Crowson, R.A. (1981) *The Biology of Coleoptera*. New York, Academic Press.

[56] Booth, D., Stewart, A.J.A. & Osorio, D. (2004) Colour vision in the glow-worm *Lampyris noctiluca* (L.) (Coleoptera: Lampyridae): evidence for a green-blue chromatic mechanism. *Journal of Experimental Biology*, **207**, 2373–2378.

[57] Dreisg, H. (1971) Control of the glowing of *Lampyris noctiluca* in the field (Coleoptera: Lampyridae). *Journal of Zoology*, **165**, 229–244.

Artificial light has the potential to affect some of the basic functioning of Glow-worms and other Lampyridae. However, most evidence is anecdotal and more field and laboratory experiments are required to determine Glow-worm population trends and determine any negative effects that artificial lighting might have on them.

*5.3.5 **Nectaring and pollination***

Many flowers are pollinated at night, mostly by moths. Moths require both visual and olfactory floral stimuli in order to locate and feed on flowers[58]. Unlike humans and bats, moths have colour vision at low light intensity. Crepuscular insects are most attracted to white flowers that have low ultraviolet reflectivity[59,60]. Moon and starlight are significantly long wavelength shifted and hence red flowers are bright against green leaves. Light pollution has many spectral peaks and hence will affect the apparent colour and contrast of flowers at dusk and night. There is a clear possibility for the pollination rates of flowers that are adapted to nocturnal pollination to be affected by emitted light pollution[60]. As moths may use colour to identify mates and rivals this activity may also be affected. There have been no studies published investigating the impacts of the colour of light pollution on the pollinating behaviour of insects.

6.0 **Review of the use of artificial lighting**

Artificial night lighting is used for a number of reasons in both rural and urban areas. Lighting is used for security, safety and amenity, and to enable nocturnal recreational or work activity. Significant sources of light pollution include sports facilities, commerce, retail, agriculture, buildings, monuments, mineral extraction, airports, sea ports, roads, streets, junctions, pedestrian paths and parking areas[61].

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[58] Raguso, R.A. & Willis, M.A. (2005) Synergy between visual and olfactory cues in nectar feeding by wild hawkmoths, Manduca sexta. *Animal Behaviour*, **69**, 407–418.

[59] White, R. H., Stevenson, R.D., Bennett, R.R. & Cutler, D.E. (1994) Wavelength and the role of ultraviolet vision in the feeding behaviour of hawkmoths. *Biotropica*, **26(4),** 427-435.

[60] Johnsen, S., Kelber, A., Warrant, E., Sweeney, A.M., Widder, E.A., Lee, R.L. Jr & Hernández-Andrés, J. (2006) Crepuscular and nocturnal illumination and its effects on color perception by the nocturnal hawkmoth Deilephila elpenor. *The Journal of Experimental Biology*, **209,** 789-800.

[61] Department for Communities and Local Government. (1997) *Lighting in the Countryside: Towards Good Practice*. London, The Stationery Office.

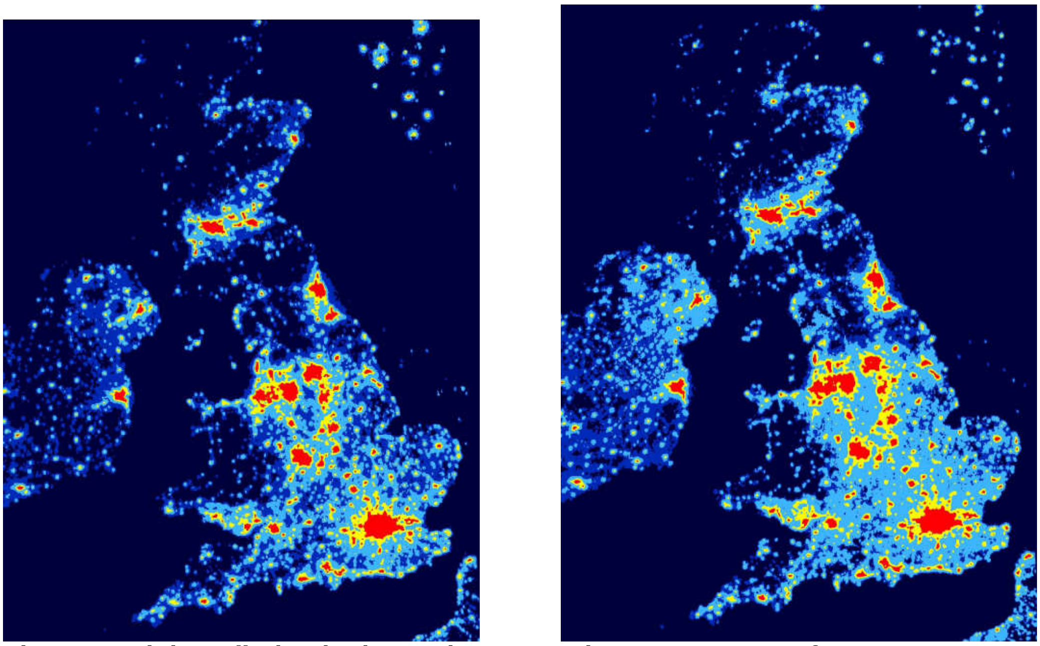

Figure 7. Light pollution in the UK in 1993 and 2000, courtesy of CPRE.

As shown in Figure 7 there has been a significant increase in the general light pollution from lighting in the UK. The growth in the use of artificial light at night is expected to continue. In their 2009 report into the problem the Royal Commission on Environmental Pollution highlighted that over 2.3 million of the United Kingdom's 7.4 million road lights were scheduled to be replaced over the next couple of years. It is likely that the prevalent yellow low-pressure sodium vapour lighting will be replaced by a broader spectrum lights that enable humans to discern colours, but which are of greater concern than yellow lights in terms of risk to invertebrate populations and wildlife.

6.1 Units of measurement

The lux is the derived SI unit of illuminance and luminous emittance. It is the unit used by nearly all lighting designers, lighting engineers, and environmental regulators to measure light. However, this measurement places emphasis on the wavelengths most visible to the human eye and largely ignores wavelengths which are outside human vision but which are visible to other species. High pressure sodium lights, for instance, will attract moths because they emit UV wavelengths, while low pressure sodium lights of the same intensity, but which don't produce UV light, are far less likely to attract moths[21].

6.2 Types of lamps

There are a wide range of different lamps available which perform differently and can therefore be used for a variety of applications.

There are two main types of electric lamp: lamps that emit light by heating a tungsten filament until it glows (incandescent lamps) and lamps that work through an electric gas discharge (fluorescent lamps as well as those described as low and high pressure discharge lamps). However, incandescent lamps are less commonly used for outdoor lighting and the most inefficient varieties are in the process of being phased out in the EU[62]. Sodium vapour lamps are most commonly used for street lighting in the UK, but there are several other varieties of lamps that are also used for night lighting.

Low pressure sodium vapour lamps, also known as sodium oxide lamps (SOX), emit light at one wavelength in the yellow part of the spectrum in which humans are particularly sensitive. They produce an orange glow which appears bright to humans but has a low overall brightness. These lamps emit no UV light and so they attract, and probably repel, the fewest number of invertebrates when compared to other types of electric light source. In addition, they are also one of the most energy-efficient of all commercial sources and they interfere less with astronomical observations than other types of lighting. However, they have several disadvantages. They produce monochromatic light, so they are usually unsuitable if human colour vision is required. High colour rendering can be important in residential and shopping areas but is less likely to be important in industrial areas. At higher wattage the lamps are too large to install in many fixtures, for example a 135-W lamp is 77 cm long and a 180-W lamp is 112 cm long. Their large size makes it difficult to focus the light from these lamps and they contribute to unattractive orange 'skyglow' and can produce a general higher level of illumination. However, if reflective full cut-off shielding is fitted to SOX lamps then light spillage can be greatly reduced[18].

High pressure sodium vapour lamps (SON) emit a moderate band of long wavelengths including a small UV component; this makes them more attractive, and probably more repellent, to invertebrates than SOX lighting. They appear pale pinkish-yellow to humans and are popular as street lighting because they produce reasonably good colour light. They generally have a longer lifespan than SOX lamps, are medium-sized and are moderately energy-efficient[18]. High pressure sodium lamps are much more compact than low pressure sodium lamps. Their smaller size makes it easier to control the direction of light by using a reflector which improves overall efficiency and reduces light spill[63]. They are commonly used for road lighting, for floodlighting and industrial interior lighting[64]. SON lamps have been slowly replacing SOX lamps in recent years because they produce colour light which is more acceptable to people while still being highly efficient.

'White' SON lamps are a variation of the high pressure sodium vapour lamps. They have a higher pressure than the typical SON lamp and closely resemble the colour of an incandescent light making them popular in cafes and restaurants. However, they have a larger UV component, have a shorter life and are less energy-efficient than the typical SON lamps[65].

Mercury vapour lamps emit light quite evenly over a broad spectrum, including a larger component of UV light to which insects are particularly sensitive. Some invertebrates can be attracted to mercury lamps in large numbers[65]. Mercury vapour lamps are very energy-inefficient. They were used for illuminating road signs and industrial lighting but they are becoming rarer in the UK; they are not used in new

[62] Loe, D. (2003) Energy efficiency in lighting – an overview. [online] London, Carbon Trust. Available from: http://www.cibse.org/pdfs/energylight.pdf [Accessed 30 Oct 2009].
[63] Emery, M. (2008) The effects of street lighting on bats. Basingstoke, Urbis Lighting Ltd.
[64] Forster, R. (2001) *Lighting Industry Federation Limited Lamp Guide 2001* (4th ed). London, Lighting Industry Federation Limited.
[65] Williams, C. (2009) Bats and lighting in the UK – Bats and the Built Environment Series. London, The Bat Conservation Trust.

developments and are due to be phased out for street, office and industry uses in the EU by 2015[66].

Metal halide lamps are compact and powerful and can produce a clean white light that shows good colour rendition. They are also energy-efficient and have a long lifespan. Metal halide lamps are frequently used in commercial interiors, industry and floodlighting. They emit much less UV light than mercury vapour lamps but produce more than high pressure sodium lamps and they are still attractive to invertebrates[63].

Light-emitting diode (LED) lamps are a relatively new technology and have only recently been considered for commercial outdoor lighting. They are extremely diverse; they are compact, long-lived and very efficient, produce a narrow beam and provide instant light[64]. LED wavelength, and therefore their colour, can vary from the near-infrared, through visible to near-ultraviolet light. White LED lamps have a broad spectrum of light. Their wavelength peaks at 450 nm and they therefore emit much more blue light than high-pressure sodium lamps. Red, yellow and amber LED lamps each have a specific, narrower spectrum and have peak wavelengths between 590 and 660 nm, which is less attractive to invertebrates[67].

Compact fluorescent lamps are also known as energy-saving lights. Many have been designed to replace incandescent light as compact fluorescent lamps are more energy-efficient. Most compact fluorescent lamps produce a white light with good colour rendition and they emit some UV light as well[65].

Tungsten halogen is a form of incandescent lamp. They have a variety of uses including for entertainment lighting, in medical technology, for airfield lighting and in many other industrial applications. Tungsten halogen lamps are not used for new street-lighting schemes but they are commonly used for domestic security lighting[65]. They produce a bright white light with excellent colour rendition with a UV component. Incandescent lamps attract fewer insects than mercury vapour lamps but they still attract more than low pressure sodium lamps[18].

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[66] OSRAM. (2008) EU directive – street, office and industry lighting, [online] München, OSRAM. Available from: http://www.osram.com/osram_com/Consumer/Home_Lighting/Alternatives_to_light_bulbs/EU_directive_-_street%2c_office_and_industry_lighting/index.html [Accessed 27 Oct 2009].

[67] Hewes, J. (2009) Light emitting diodes (LEDs). [online]. London, The Electronic Club. Available from: http://www.kpsec.freeuk.com/components/led.htm [Accessed 17 Nov 2009].

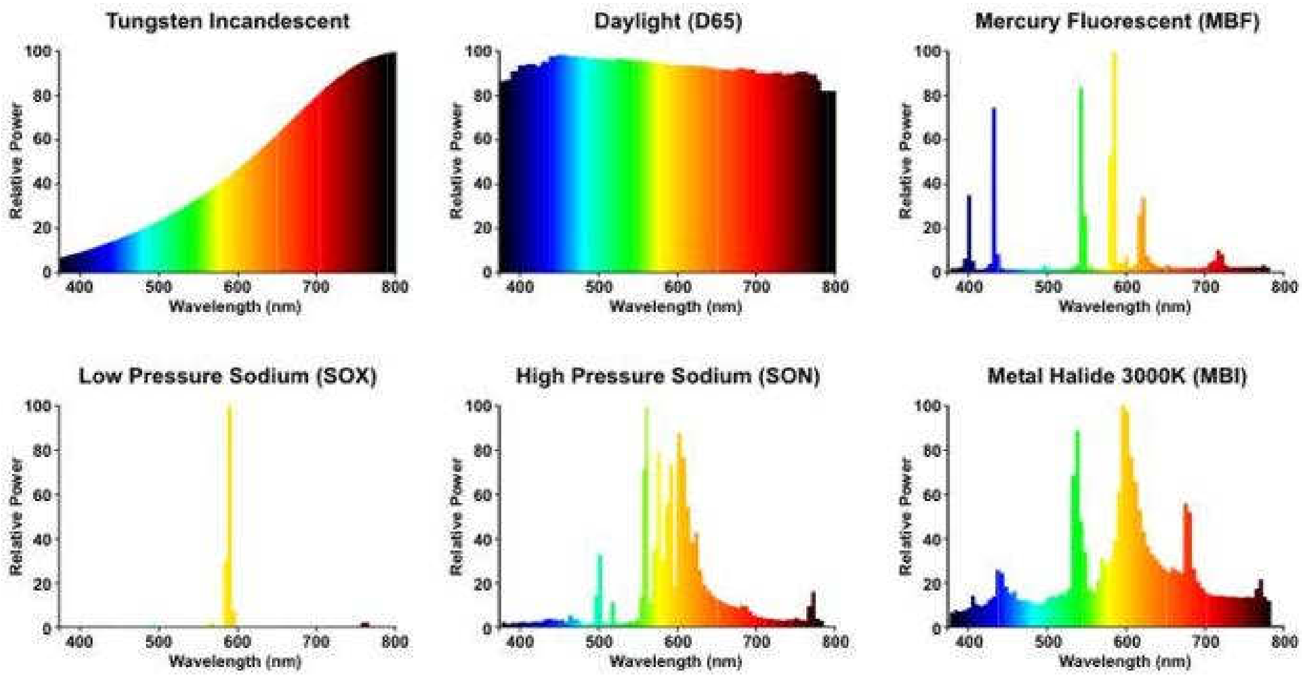

Figure 8. Spectral power distributions of various light sources[68]

6.3 Luminaires

The unit into which the lamp is fitted is called a luminaire and all luminaires in the UK must conform to set European standards. A great variety of outdoor lighting luminaires are available with different optical systems and light distribution characteristics. The range of luminaires exists because the function of different lights varies widely. For example, street lights can vary from lighting small single carriageway roads that are only 6 m wide, to much larger four-lane motorways that can be more than 20 m across. The luminaires are designed to emit as much light as possible where it is required. However, as diverse outdoor areas have different lighting requirements, the amount of light spill from luminaires varies.

A reduction of light spill from luminaires in street lighting can be achieved by cutting out the light emitted from the luminaires at angles greater than 70° from the vertical plane. Light emitted at angles greater than 70° will be wasted and spill out to surrounding areas that don't need illuminating. Using a flat glass protector rather than a curved glass protector can prevent light from being dispersed upwards and sideways. Accessories in the structure of the luminaire such as shields, hoods and louvres can also be used to reduce light spill[62].

7.0 Recommendations and considerations to avoid, minimise, or mitigate the impacts of light pollution on wildlife

The application of the precautionary principle, as set out in the EU Communication from the Commission on the Precautionary Principle (2000), is relevant to artificial

[68] Hooker, J.D. (2003) Spectral properties of sodium discharge. [online]. UK, Lamptech. Available from: http://www.lamptech.co.uk/Documents/SO2%20Spectral.htm [Accessed 12 Mar 2010].

light. There are reasonable grounds for concern that the effects of artificial light on the environment may be damaging and hence there is a need to minimise the risk of environmental damage.

All public bodies must consider the impact artificial light will have on biodiversity in the area. In England and Wales the Natural Environment and Rural Communities (NERC) Act 2006 came into force on 1 October 2006. Section 40 of the Act requires all public bodies to have regard to biodiversity conservation when carrying out their functions. The Nature Conservation (Scotland) Act 2004 came into force on 29 November 2004 and places a duty on every public body to further the conservation of biodiversity in Scotland. These duties are commonly referred to as the 'biodiversity duties'. Many invertebrates are listed as national priority species for conservation under the UK Biodiversity Action Plan (UKBAP) and are hence protected by the NERC Act.

7.1 **Light and Environmental Impact Assessments**

The potential for light pollution from a development (emitted and polarised particularly, but in the case of large structures reflected as well) should be considered at the scoping stage of the Environmental Impact Assessment process. Light spill onto wildlife habitats should be avoided altogether where possible, but when not possible the impact should be considered as being likely to be significant and should be fully assessed in the Environmental Statement.

The Environmental Statement should include a survey of species of conservation significance (e.g. Red Data Book listed species and UK Biodiversity Action Plan listed species) that may be sensitive to light. The scope of the survey will vary depending on location and habitats likely to be affected, but may include moths, Glow-worms, other beetles and aquatic invertebrates. An experienced entomological consultant would be able to provide advice on the scope of the surveys. In addition the Environmental Statement should include a visible light spill map that is clear and easy to interpret (i.e. shaded lux isolines (isophotes) that go at least as low as 0.5 lux), a comparable UV light spill map and, where relevant, a similar map of polarised light effects. A lighting plan should be provided that details the location, type, wavelength emittance and shielding of lights. The text of the Environmental Statement should detail areas of possible light pollution impact on invertebrates and explain how these impacts will be avoided, minimised and/or mitigated or compensated for. The aim should be for at least no net increase in light pollution on wildlife habitats.

When assessing the likely significance of impacts planners should bear in mind that light levels as low as 0.1 lux have been shown to affect invertebrate activity; that constant light pollution at or above the equivalent of full moon light (0.5-1 lux) can be expected to have a profound effect on many invertebrates; that insects can be attracted to an unshielded light source from a distance of at least 500 m; and that UV light pollution will have an even bigger impact that visible light. The impacts of polarised light have not yet been adequately gauged in terms of intensities and distances, but polarised light sources within 500 m of water bodies, or that reflect light into that vicinity are of the greatest concern. Exposed surfaces that are white, pale grey or yellow are most likely to attract pollinating insects.

In England the 'Planning Policy Statement 23: Planning and Pollution Control' states the need to limit and, where possible, reduce the adverse impact of light pollution during the planning process.

7.2 **Assess the need for lighting**

Artificial lighting has many benefits for people but it can also adversely affect humans and other organisms. Better designed lighting, in the right places and at the right times, is needed, rather than just increasing the amount and brightness of artificial light at night. Lighting is perceived as good for reducing crime and accidents but this is not always the case. Studies suggest that lighting can reduce road accidents at junctions where pedestrians and traffic meet, but it does not necessarily reduce accident levels on motorways when compared to daylight conditions. Badly designed lighting can produce glare - the excessive contrast between bright and dark areas in the field of view - which can aid rather than reduce criminal activity[69].

When planning a new development (which may or may not require an Environmental Impact Assessment) or re-evaluating an old lighting scheme the first thing that should be considered is whether lighting is really necessary. Instead of assuming that light is automatically necessary, promoters of lighting schemes should consider if:

- the development could function without artificial night lighting;
- the benefits of lighting outweigh any negative effects of lighting in a world that is required to use less energy, and is faced with rising energy costs, the cost/benefit of lighting is becoming a serious issue;
- there are alternatives to lighting; better security methods such as strong fencing can be more effective than lighting, for example.

If it is determined that lighting is necessary for a development, then several aspects of the lighting scheme must be considered to reduce the impact on invertebrates and the environment. The location and design of a lighting scheme are of particular importance.

7.3 **Minimise the impacts of lighting**

Lighting schemes should be developed after careful site appraisal, including where required, environmental impact assessments. Developments must comply with Health and Safety regulations but, where possible, this should not be to the detriment of wildlife. Minimising the impact of lighting is important in all locations – in cities, villages and rural areas. Installing the right kind of lamp and luminaire in the right location is very important in minimising the impact of lighting. Some of the most important habitats for invertebrates and wildlife are in or close to cities (such as brownfield sites along the Thames Estuary) so lighting must be considered in urban areas.

In addition light pollution can also be created outside the planning system, including by the activities and behaviour of individuals. Measures as simple as closing curtains and turning off lights in unoccupied rooms will reduce light pollution. The following points are key to reducing the impact of emitted light pollution.

- The brightness/wattage of the lamp. A lower brightness/wattage should reduce the impact lighting has on invertebrates in areas close to the light source. For example, high power (300/500-W) lamps are not necessary for domestic security lighting and will produce too much glare, reducing security.

[69] The Royal Commission on Environmental Pollution. (2009) *Artificial Light in the Environment*. London, The Stationery Office.

A lower power 150-W lamp should be adequate. Street and road lamps can also be fitted with dimmer switches so that their brightness is reduced when fewer pedestrians and vehicles are active. Motion detectors can be used to turn lights off completely when there is no human activity nearby; this system works particularly effectively with LED lighting as this can provide instant light as required.

- The number of lights used. Minimising the number of lights on a development will lower the overall levels of light pollution and reduce the impact that lighting will have on wildlife. An area should not be over-illuminated, it is best to only use as many lights as necessary.

- The wavelengths the lamp produces. The majority of insects and other invertebrates are most visually sensitive to the short wavelength end of the light spectrum. Therefore lamps with longer wavelengths are likely to have less effect on them (i.e. red, yellow and orange light). Lights that emit a broad spectrum of light with a high UV component should be avoided. If lighting is necessary, then low pressure sodium lamps or narrow spectrum LED lights that incorporate full cut-off shielding are preferable. This is because they produce light at one wavelength, usually in the yellow part of the spectrum in which humans are particularly sensitive, but emit no UV light. Ultraviolet-absorbing filters or glass can also be used on lamps that emit UV light. Full cut-off shielding must also be used as this directs light and prevents light spillage. Mercury vapour is most likely to have the greatest impact on invertebrates and should be avoided. Metal halide and tungsten halogen lamps can also have a negative impact on invertebrates and they too should be avoided where possible.

- Colour rendition. Connected to the issue of wavelength is the consideration of having lights that produce good colour rendition. If colour rendition is not required low pressure sodium lamps with full cut-off shielding, which produce an orange monochromic light, should be used. However, if colour rendition is required high pressure sodium lamps with shielding should be used as they emit less UV light than many other types of lamps. There is also the potential for the development of new lamps that would have minimal impact on invertebrates but still provide good colour. A lamp that provides optimal illumination and colour rendition for human vision while having minimal impact on invertebrates and other wildlife is needed. Specially designed lamps for coastal areas where marine turtles nest have been developed and such technology could be applied to invertebrates and other light sensitive wildlife.

- The direction in which light shines. Most lights should be pointed towards the ground to illuminate the way for pedestrians and vehicles and away from natural habitats such as hedgerows, trees, water bodies and grassland. Light that spills sideways and upwards is unnecessary and will attract flying invertebrates from a greater distance. Globe luminaires and other luminaires that emit light at angles greater than 70° should n ot be used. Shielding can be fixed to new and existing lights to prevent light spillage. Barriers can be placed around lamps to prevent them from spilling light into surround areas (e.g. man-made barriers or tree planting). The height the lamp is mounted is also important for directing light. A higher mounting height has the advantage that it allows light to be directed downwards. On the other hand a shorter mounting height means a less powerful lamp can be used to illuminate an area. The emission of light from skylights should also be considered; in factories, warehouses, offices and new-build houses, such windows should be equipped with blinds or shields; where possible these should close automatically at night.

- The period of lighting. The timing when lights are switched on and off should be carefully considered. Many lights could be switched off between midnight and 5 a.m. when few people are active. In particular all decorative and advertising lighting should be switched off during these times. Security lighting should have motion-sensor switches to keep lighting off when it is not required. They should be kept on the minimum time-setting and sensors which can be tripped by road and footway users or large animals should be avoided.

- Sensitive locations. Is the lighting in or near an area of conservation value, such as Special Areas of Conservation (SAC), Sites of Special Scientific Interest (SSSI), National Parks and Areas of Outstanding Natural Beauty, or areas where rare and specially protected invertebrates are found? Avoid lighting in these areas. Aquatic invertebrates, such as riverflies in streams and rivers, and marine invertebrates living close to the sea shore and marinas, are particularly sensitive to light pollution. Lighting adjacent to waterbodies should be absolutely minimised and any lighting that is needed should be carefully shielded to prevent it from shining directly on the water surface.

- Responsible moth trapping. Moth traps should not be routinely run in one location on consecutive nights, except where required for the scientific monitoring of populations. Moth trapping in the close vicinity of the breeding locations of rare species that occur at low density should only be carried out on a small proportion of the nights in the relevant flight period/s. Released moths should be given the highest possible chance of survival; preferably by being kept in cool shady conditions and then released at dusk, or otherwise released in long grass or other cover and not on lawns or other exposed surfaces, thus minimising bird predation. Collecting limited number of specimens contributes to scientific understanding of ecosystem health and dynamics but should comply with the 'Code of Conduct for Collecting Insects and other Invertebrates'[70].

- Electrocuting or stunning insect traps. These should not be placed in rural locations, such as stables, and left running at night in an unenclosed space. Large electrocuting traps placed outdoors are very likely to damage populations of invertebrates and should only be installed as a last resort to prevent a serious public health risk.

7.4 **Minimise polarised light pollution**

Sources of polarised light pollution should be identified and diminished, and further research into the issue should be undertaken. The use of agricultural sheeting and large areas of solar panelling in sensitive areas, particularly near water-bodies, should be limited, or sources of polarized light should be broken up by adding non-polarizing patterns, areas or grids that block horizontal light. This approach, specifically using white borders and white grates has been shown to prevent insects

[70] Invertebrate Link (2000) A Code of Conduct for Collecting Insects and other Invertebrates. *British Journal of Entomology and Natural History*, **15**, 1-6.

being attracted to solar panels[71]. Car parks should be located far enough away from rivers and other waterbodies so that aquatic insects are not attracted to the cars for egg-laying. Asphalt road surfaces near waterbodies should not be smooth and dark. Asphalt can be made non-polarising by incorporating a rough top layer or white granules that scatter light[72]. New buildings should not include glass that produces horizontally polarised light.

7.5 Don't paint large structures with colours that attract pollinators

As a precaution large structures in the countryside, particularly in perilous situations such as wind farms, should not be painted with colours that attract insects. It is well known that many pollinating insects are attracted to surfaces of a particular colour. In particular, day flying insects are most attracted to yellow surfaces, and white or pale grey surfaces attract evening and nocturnal insects. Structures painted with these colours are likely to divert pollinators away from flowers and also attract their predators. In the case of wind turbines this is likely to result in an increased mortality of insects, birds and bats. More research is required to determine the likely magnitude of the effect and if high UV reflectivity can reduce attractiveness.

7.6 Conserve and create areas with natural light regimes

At present our understanding of the extent to which artificial lighting has an effect on invertebrates and the wider environment is poor. Some invertebrates, such as those with superposition eyes (e.g. hawkmoths) are sensitive to even very low light levels. While reducing artificial light and changing lamp types is often beneficial; it is recommended that places with natural or near-natural light regimes should be conserved and created. Galloway Forest Park in southern Scotland became Europe's first official Dark Sky Preserve with the International Dark-Sky Association in 2009. It is increasingly important that there is more official protection of areas with natural light regimes. Where possible additional Dark Sky Preserve areas should be identified to complement the Galloway Forest Park Dark Sky Preserve. In these areas existing light pollution should be reduced and strict limits and constraints placed on any new lighting.

Artificial lighting should not be installed in natural cave systems. In existing show caves every effort must be made to minimise the amount of time that lighting is on and lamps with a narrow light range between yellow and red should always be used in all areas where colour perception is not necessary.

Lighting necessity should be considered and it kept to a functional minimum in all areas. However, certain locations are likely to be particularly sensitive and artificial lighting in these areas should be carefully planned, reduced or, ideally, totally removed to avoid negatively affecting invertebrates and the environment.

- Conserve existing areas with natural light regimes and aim to further reduce artificial light levels from the surrounding locations. These areas should be designated as Dark Sky Preserves.

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[71] Horváth, G., Blahó, M., Egri, A., Kriska, G., Seres, I. & Robertson, B. (2010) Reducing the maladaptive attractiveness of solar panels to polarotactic insects. Conservation Biology, **24(6)** 1644–1653,

[72] Horváth, G., Kriska, G., Malik, P., Hegedüs, R., Neumann, L., Åkesson, 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? New York, Nova Science Publishers Inc.

- Create new areas with natural light regimes. Avoid lighting and reduce/eliminate general light levels in and near areas of known conservation value. This would include areas where Red Data Book listed and UK Biodiversity Action Plan (UKBAP) species with localised distributions are found, Special Areas of Conservation (SAC), Sites of Special Scientific Interest (SSSI), National Parks and Areas of Outstanding Natural Beauty. Areas that are of conservation value and are home to rare invertebrates and other wildlife include urban settings as well as suburban and rural habitats. Steps should be actively taken to reduce light levels in these areas with the aim that these locations could eventually be designated as Dark Sky Preserves.

7.7 Raise public awareness

The general public should be made more aware of the issues of artificial light pollution and the environment. The public can then understand and support positive changes made by public bodies to lighting schemes, and light polarisation or reflection effects.

Raising awareness will also help reduce light pollution from private residences. Most artificial light produced in Britain comes from industry and housing developments and from road and street lighting. Local authorities and the planning system have a major part to play in reducing the environmental impact of artificial light, but members of the public also should be aware of the issue. Domestic lighting is mostly outside of planning control, but it too can cause problems to the environment. Most domestic security lighting is purchased by members of the public who are not fully aware of the environmental impacts of lighting. Information on lighting types, installation and maintenance should be given before purchase to reduce the impact of these domestic lights. Retailers selling domestic security lighting should be properly trained and informed on the issues. Similarly there is currently low awareness of the negative impacts of solar panel associated light polarisation on aquatic life and the readily implementable solutions to this threat.

8.0 Further research requirements

This report has highlighted what is known about the biological impacts of artificial light on invertebrates. However, we still know very little about the effects artificial light has on invertebrates, particularly at population and ecosystem level. Indeed in the 2006 paper ‘The identification of 100 ecological questions of high policy relevance in the UK’[73] one of the questions prioritised was “What are the effects of light pollution from built development and road lights on wildlife behaviour, mortality and demography?”. There has been little progress in answering this question since 2006. The 2009 Royal Commission on Environmental Pollution report on ‘Artificial Light in the Environment’ recommends “that the Natural Environment Research Council, with input from other agencies, leads a pilot programme of directed research to explore the impacts of artificial light on populations and ecosystems, and to clarify

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[73] Sutherland, W.J., Armstrong-Brown, S., Armsworth, P.R., Brereton, T., Brickland, J., Campbell, C.D., Chamberlain, D.E., Cooke, A.I., Dulvy, N.K., Dusic, N.R., Fitton, M., Freckleton, R.P., Godfray, H.C.J., Grout, N., Harvey, H.J., Hedley, C., Hopkins, J.J., Kift, N.B., Kirby, J., Kunin, W.E., MacDonald, D.W., Marker, B., Naura, M., Neale, A.R., Oliver, T., Osborn, D., Pullin, A.S., Shardlow, M.E.A., Showler, D.A., Smith, P.L., Smithers, R.J., Solandt, J-L., Spencer, J., Spray, C.J., Thomas, C.D., Thompson, J., Webb, S.E., Yalden, D.W., Watkinson, A.R (2006). The identification of 100 ecological questions of high policy relevance in the UK. *Journal of Applied Ecology*, **43**(4).

the effects of both existing and proposed lighting technologies on biological systems". It appears that this programme has not been implemented and indeed that NERC has not funded any research into light pollution in the last decade. Research on the issue should be implemented to develop our understanding and enable the minimisation and mitigation of negative effects of artificial light on invertebrate populations.

The following research priorities have been identified:

- Information on invertebrate sensitivity to light of different wavelengths is still limited and patchy. What level of illumination produced by artificial light causes no ecological impacts to invertebrates? Further fundamental research on the light sensitivity of a wide range of invertebrate taxa is required.
- Is artificial light to blame, or partly to blame, for the long-term declines in moths, riverflies and other invertebrates in the UK? If so, what are the mechanisms and how can they be ameliorated?
- What are the impacts of light pollution on Glow-worm populations?
- What are the impacts of light pollution on populations of light-averse invertebrates?
- Do artificial sources of polarised light cause population level effects on flying aquatic invertebrates?
- Does artificial light affect the ability of moths to detect flowers and reduce the pollination rates and population levels of moth pollinated plants?
- To what extent do artificial light sources act as barriers to the movement of invertebrates through the countryside and urban areas?
- Over what distances do artificial light sources affect the behaviour of moths and other night-flying insects?
- Can wind turbines be painted in colours that reduce their attractiveness to invertebrates, impacts on invertebrate populations, and thereby fatalities of their predators (bats and birds)? In particular the effect of high UV reflective pale paints should be investigated.

9.0 **Conclusion**

Invertebrates make up the majority of biodiversity and they are vital to ecosystems. Artificial light in the wrong place at the wrong time adversely affects the life cycles and survival invertebrates. This could have knock on effects at a population level, contributing to declines and extinctions of species.

Artificial light has the potential to significantly disrupt ecosystems and it has long been of concern to conservationists. It is widely observed that some invertebrates, such as moths, are attracted to artificial lights at night. Artificial lighting can significantly disrupt the natural light/dark patterns. Many invertebrates depend on the natural rhythms of day-night and seasonal and lunar changes to light levels. As a result artificial lighting has several negative impacts on a wide range of invertebrates, including disrupting their feeding, breeding and movement, which may reduce and fragment populations. In addition the polarisation of light by shiny surfaces is a significant problem as it attracts aquatic insects, particularly egg laying females away from water and reflected light has the potential to attract pollinators and impact on their populations, predators and pollination rates.

Because invertebrates are so fundamentally important to healthy ecosystems and because declines and threats mean that many species are already listed as national priority species for conservation under the UK Biodiversity Action Plan (UKBAP), it is imperative that avoidable threats to their well being are avoided.

Action to reduce artificial light impacts is necessary and justified now. Although further research is required to fully understand the impacts of artificial light on invertebrates and the environment as a whole, the precautionary principle applies and enough is known to take action now. This report makes several recommendations that would reduce and mitigate the negative effects that artificial light has on invertebrates.

Local authorities and Government departments must take a lead on reducing the impact of artificial light. The environmental impact of light for new developments must be more prevalent in the planning process and more routinely part of the Environmental Impact Assessment process. Public bodies have a ‘biodiversity duty’ under the NERC Act 2006 and Nature Conservation (Scotland) Act 2004 and must consider the impact that lighting, polarisation and reflection will have on biodiversity.

Light pollution levels should be generally reduced everywhere. However, it is particularly important that areas that currently have low lighting levels and areas that are important for wildlife should be identified and progress to become Dark Sky Preserves.

Established lighting schemes should also be reconsidered to reduce their impact on the environment. In addition, the issue of artificial light and its environmental impacts on invertebrates and other wildlife should be given a greater public profile.

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11.0 Appendices

11.1 Further reading

Department for Communities and Local Government. (1997). *Lighting in the Countryside: Towards Good Practice.* London: The Stationery Office.

Department for Environment, Food and Rural Affairs. (2006). *Assessment of the Problem of Light Pollution from Security and Decorative Lighting*. Horsted Keynes: Temple.

Horváth, G., Blahó, M., Egri, A., Kriska, G., Seres, I. & Robertson, B. (2010) Reducing the maladaptive attractiveness of solar panels to polarotactic insects. *Conservation Biology*, 24(6) 1644–1653,

Horváth, G., Kriska, G., Malik, P., Hegedüs, R., Neumann, L., Åkesson, 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?* New York, Nova Science Publishers Inc.

Office of the Deputy Prime Minister. (2004). *Planning Policy Statement 23: Planning and Pollution Control*. London: The Stationery Office.

Rich, C., & Longcore, T. (Eds). (2006). *Ecological Consequences of Artificial Night Lighting.* Washington: Island Press.

The Institution of Lighting Engineers. (2005). *Guidance Notes for the Reduction of Obtrusive Light*. Rugby: The Institution of Lighting Engineers.

The Royal Commission on Environmental Pollution. (2009). *Artificial Light in the Environment*. London: The Stationery Office.

The Scottish Executive. (2007). *Controlling Light Pollution and Reducing Light Energy Consumption*. Edinburgh: The Scottish Executive Publications.

The Institution of Lighting Engineers. (2005). *The Outdoor Lighting Guide*. Rugby: The Institution of Lighting Engineers.

Williams, C. (2009). *Bats and Lighting in the UK*. London: The Bat Conservation Trust.

11.2 Legal protection of invertebrates

Wildlife and Countryside Act 1981

Many of Britain's wild plants and animals are legally protected. The main law dealing with this is the Wildlife and Countryside Act, which was passed in 1981. This act was amended by the Countryside and Rights of Way Act 2000, which covers England and Wales but not Scotland. Wild birds and certain other wild animals (including some invertebrates) are legally protected. A schedule (Schedule 5) in the Wildlife and Countryside Act lists the animals other than birds that qualify for protection.

In Northern Ireland the Wildlife and Countryside Act is transposed by the Wildlife (Northern Ireland) Order 1985. With regard to the protection of species, this is very similar to the Wildlife and Countryside Act.

Habitat Protection
Most threatened animals cannot be properly protected without conservation of their habitats. There are legal provisions for the protection and management of areas where threatened species occur.

- Sites of Special Scientific Interest (SSSIs), National Nature Reserves and Marine Nature Reserves are selected and protected under British law because they are examples of important habitats and often contain rare invertebrates.

- Special Areas of Conservation (SACs) are chosen under the Habitats Directive for other animals and plants requiring habitat protection in Europe as a whole. Among these species are the Stag beetle (*Lucanus cervus*) and White clawed crayfish (*Austropotamobius pallipes*).

- Other areas in the UK are designated under the Ramsar Convention, a worldwide agreement on the conservation of wetlands.

Habitat Action Plans have been drawn up for priority habitats under the UK Biodiversity Action Plan.

International statutes
The UK is bound by international legislation on species protection. The 1992 Habitats Directive covers all the countries of the European Union. Under these Directives, strict protection (very similar to provisions under the Wildlife and Countryside Act) is required for a large number of plant and animal species. For another group of animals and plants listed in the Habitats Directive, conservation measures are required if killing or taking from the wild poses a threat to these species.

The UK has signed up to other international agreements on wildlife protection

- The Bern Convention covers the states in the Council of Europe. It gives protection to threatened plants, animals and habitats and regulates the exploitation of certain species.

- CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) regulates international trade in threatened animals and plants.

- The United Nations Convention on Biological Diversity, which was drawn up at the Earth Summit in Rio de Janeiro in 1992, requires this country to take action to conserve its threatened species and habitats. As a result, the UK Biodiversity Action Plan has been drawn up and this includes practical measures for the conservation of many of Britain's rare and declining species.

'Biodiversity duty'
In England and Wales the Natural Environment and Rural Communities (NERC) Act 2006 came into force on 1 October 2006. Section 40 of the Act requires all public

bodies to have regard to biodiversity conservation when carrying out their functions. The Nature Conservation (Scotland) Act 2004 came into force on 29 November 2004 and places a duty on every public body to further the conservation of biodiversity in Scotland. These duties are commonly referred to as the ‘biodiversity duties’. Many invertebrates are listed as national priority species for conservation under the UK Biodiversity Action Plan (UKBAP) and are hence protected by the NERC Act.

Invertebrates make up the majority of living species in Britain and globally, therefore invertebrates are hugely important for biodiversity. Artificial lighting could be a factor in invertebrate population declines so artificial lighting might be reducing biodiversity in general. Public bodies must consider artificial lighting in relation to their ‘biodiversity duty’.