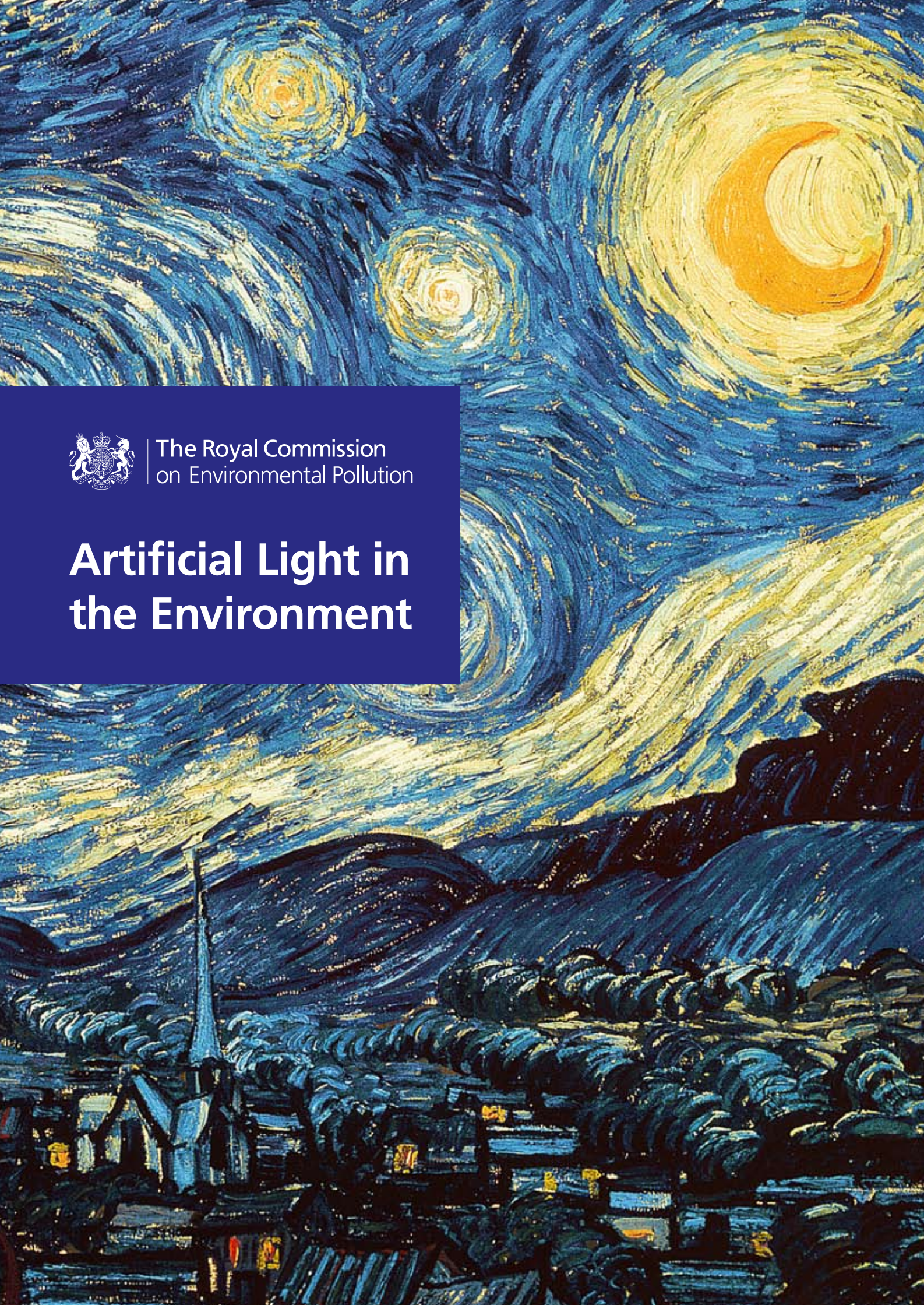

The Royal Commission
on Environmental Pollution

Artificial Light in the Environment

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Chapter 1

Introduction

There are two kinds of light – the glow that illuminates, and the glare that obscures.

James Thurber

1.1 Imagine a vista of outstanding natural beauty, to say nothing of historic and cultural significance, permanently obscured from public view by a cloud of non-toxic, but visually impenetrable, artificial vapour. Such a prospect seems unthinkable in Britain today. Yet we seem to tolerate the daily destruction of arguably the most culturally universal and historically pristine of natural vistas – the night sky, filled with constellations of stars, and planets and galaxies. The responsible pollutant, however, is not an impenetrable vapour, but the light that we so freely emit into our surroundings.

1.2 If inescapable visual pollution were the only effect of light in the wrong place it would be bad enough, but there are other consequences of the ubiquity of current outdoor lighting in towns and cities, along highways and in industrial locations. Light is one of the most potent agents interacting with biological systems. Responses to light include phototropism (movement or growth towards or away from light) and stimulation of hormone production, including the fine tuning of cyclical changes. That living organisms have evolved varying degrees of sensitivity to light should surely give us pause for thought as we pollute our night-time environment with it.

1.3 For the most part, light at night provides valuable benefits; it is something that we deliberately seek and can be an essential aid to safety. However, we consider the experience of light in the wrong place or at the wrong time as light pollution; the timing of illumination may be as important a factor as the actual level of light. Light pollution can take various forms, and may originate from both diffuse and point sources:

Glare: The excessive contrast between bright and dark areas in the field of view.

Light trespass: Unwanted light, for example from adjacent properties and activities.

Light clutter: The excessive grouping of lights, for example in roadside advertising which can prove a dangerous distraction to motorists.

Light profligacy: Over-illumination which wastes energy and money.

Sky glow: A combination of reflected and refracted light from the atmosphere. A major effect of sky glow at night is to reduce contrast in the sky. This is the most pervasive form of light pollution and can affect areas many miles from the original light source.

An absence of darkness: Artificial light makes experiencing natural night-time lighting conditions impossible in many parts of the country.

1.4 Over the last 150-200 years a huge change has taken place in the UK environment. The moon and stars are no longer the only major sources of light at night. Illumination of our streets and roads, our buildings and agricultural greenhouses, as well as other sites, now spills into the night. The consequences of this for wildlife and human health and wellbeing are largely unknown.

1.5 Wherever artificial light floods into the natural world there is the potential for some aspect of life and its rhythms – migration, reproduction, feeding – to be affected. For instance, man-made light is known to cause confusion to migrating birds, often with fatal outcomes. Exposure to artificial light, which simulates short nights, is known to induce early breeding in some species of birds. Another well-known example is the effect on the feeding behaviour of bats caused by insects clustering around outdoor light sources.

1.6 Human health problems have been associated with exposure to light at night inhibiting production of melatonin. The inhibition of the production of melatonin is associated with the incidence of certain breast cancers.[1] It should be emphasised that, so far, this possible effect has been confined to night shift workers exposed to high levels of indoor lighting; we do not deal with this effect further in our report where the focus is on light in the outdoor environment, but more recent work suggests changes in the nature of external lighting may mean this is more of an issue in the future.[i] However, the association between light at night and melatonin production is indicative of the largely unresearched effects that light can have on all organisms. Furthermore, people report negative health impacts from sleep disturbance due to light intrusion into their homes from road lamps that are left on all night.[2] They may also experience stress from unwelcome illumination, such as security lighting, spilling onto their property from that of their neighbours.

1.7 The Royal Commission's 26th report, *The Urban Environment,*[3] identified light pollution as a significant factor shaping local environmental quality, but did not consider it in any depth as it was outside the main focus of that report. The Commission has undertaken the present short study in recognition of the increasing pervasiveness of outdoor artificial light and concerns that its effects are becoming progressively more significant.

1.8 The loss of visual amenity represented by the obscuring of the night sky and the potential deleterious effects on photosensitive organisms are not the only issues raised by light pollution. Among the obvious consequences is the waste of energy and money associated with allowing light to escape upwards towards the sky when the purpose of most outdoor lighting is to enable people to go safely and securely about their business on the ground. Even the floodlighting of public buildings is better achieved when light is focused on the structure and not dissipated into the sky around it. Huge quantities of light are needlessly shone into space from cities around the world each year.[4] The carbon emissions associated with such energy profligacy must also be enormous. However, we do not dwell on the energy and climate change implications of light pollution in this report, as we regard these as part and parcel of wider problems that are already well recognised, although we touch on the issue where appropriate.[ii]

i There is some evidence to suggest that blue-enriched white light is very effective at keeping people alert throughout the day and in re-setting the body clock, so that we sleep better at night. See for example: van Bommell, W. (2006). The biological effect of lighting. *Lighting Journal*, **71**(1); and Donoff, E. (2009). Light's impact on health is playing a central role in design. *Lighting Journal*, **74**(1).

ii In 2006, lighting (predominantly interior lighting) accounted for around 20% of electricity consumption in the UK, with public lighting estimated to represent 1% of the total (personal communicaltion from Energy Statistics and Analysis, Department for Business, Enterprise and Regulatory Reform (BERR), now Business, Innovation and Skills (BIS), November 2007).

1.9 We have also chosen not to revisit the well-known deleterious effects of light pollution on astronomy. This topic was comprehensively covered by a 2003 report from the House of Commons Select Committee on Science and Technology (Box 1A).[5] We felt that we could not usefully add to the weight of that report, other than to note that the problem remains and to endorse the efforts of the Dark Sky Discovery Project[6] as part of the 2009 International Year of Astronomy.

BOX 1A LIGHT POLLUTION AND ASTRONOMY

The House of Commons Select Committee on Science and Technology published its report *Light Pollution and Astronomy* in 2003. The Committee concluded that the majority of professional astronomy now takes place outside of the UK due to the poor and unpredictable weather conditions of the British Isles, their hemispherical position and the continuing encroachment of light pollution on British skies.

The Committee emphasised the importance of the amateur astronomy community in the UK, which provides important observational data to professional astronomers. Amateur astronomical societies, along with professional astronomers based in the UK, are also instrumental in introducing young and future scientists to astronomy and physics through open days at observatories and by bringing mobile planetaria to schools and groups.

The report criticised the defeatist attitude and inconsistent approach shown by the Government toward light pollution and astronomy in the UK. It found that the response from local authorities to those seeking protection from light nuisance was uneven and usually unhelpful. The report provided recommendations on how light pollution can be controlled without reducing the levels of light needed for the safe illumination of urban and rural environments. In particular, the Committee called for a clear policy on the use of street lighting and for new planning guidance to cover light pollution. The Committee was persuaded that light trespass was both measurable and controllable and recommended that obtrusive light be made a statutory nuisance.

1.10 We believe that our inquiry into the effects of outdoor artificial light is timely. During the course of the study, we learned that 2.32 million of the United Kingdom's stock of 7.4 million road lights are scheduled to be replaced in the next two years because they are already well past their design life (over 30 years old).[7] This presents a real opportunity to ensure that replacements avoid some of the adverse effects of the current stock. The old lighting stock is predominantly low-pressure sodium vapour lighting which is monochromatic yellow/orange in colour. To meet the aesthetic preference for a more 'natural' colour of light, the old low-pressure sodium lights are being replaced by lights with a more natural colour: high-pressure sodium vapour, metal halide or even light-emitting diodes (LEDs). This replacement of lighting stock may also present further challenges. Whilst these newer lights are certainly more pleasant and may be better for human vision than the old monochromatic lights, they may have significantly different effects on the environment. As the light becomes more natural it is plausible that the natural world may respond to it more strongly.

1.11 Our report begins with a brief review of the rapid growth in the installation and use of artificial outdoor lighting over the past half century and the loss of visual amenity that has resulted (Chapter 2). We consider the social benefits and drawbacks of artificial lighting (Chapter 3) and the potential for deleterious effects on species and ecosystems (Chapter 4). In the report we make a distinction between the aesthetic impact of artificial light and the impact of light on organisms; in doing so the Commission has gleaned evidence from very different sources. This short report

is not however intended to be a comprehensive study of the biological effects of artificial light pollution on the environment; at present, the research base for such an assessment is lacking. We go on to provide a brief overview of opportunities for reducing the impacts of road lighting through technological improvements and better management (Chapter 5). We conclude (in Chapter 6) with a summary of recommendations.

Chapter 2

A Growing Sense of Loss

... I enjoyed being out there. ... Every element had something different about it but actually being out in the middle of nowhere, with the stars out, ... was just a fantastic place to be.

Prince Henry of Wales (Prince Harry) on his time in Afghanistan (2008)[8]

2.1 The sky at night has fascinated humans from the dawn of history. Myths and legends connected with the stars have played a significant role in European culture since the Greeks and Romans named the planets and constellations after their deities. Navigation by the stars was critical to the voyages of exploration which connected Europe to the rest of the world, as well as for the more mundane trading vessels that followed in the explorers' wake and were the foundation of Britain's strong maritime tradition. Folk weather forecasting practices often relied on conditions in the night sky. The sky full of stars has inspired poets, songwriters and artists for generations. But in 21st century Britain it is all but invisible. In the words of Marek Kukula, public astronomer at the Royal Observatory, Greenwich, in December 2008:[9]

> "This is a part of our heritage that we're losing. If we concreted over the countryside and bulldozed the forests, there would be an outcry, but this has sneaked up on us, and people don't realise what we are doing. The night sky is an amazing spectacle that 90% of the population doesn't get to see."

2.2 "People don't realise what we are doing" because the loss of the night skies has happened gradually over the course of the last century, particularly since the Second World War. A member of the public, now in her mid-eighties, lamented to one of our members how, in the Bristol suburbs in the 1930s:

> "Our dad used to take us girls out into the garden and show us all of the stars and teach us their names, but now you never see them. You would never know they were there."

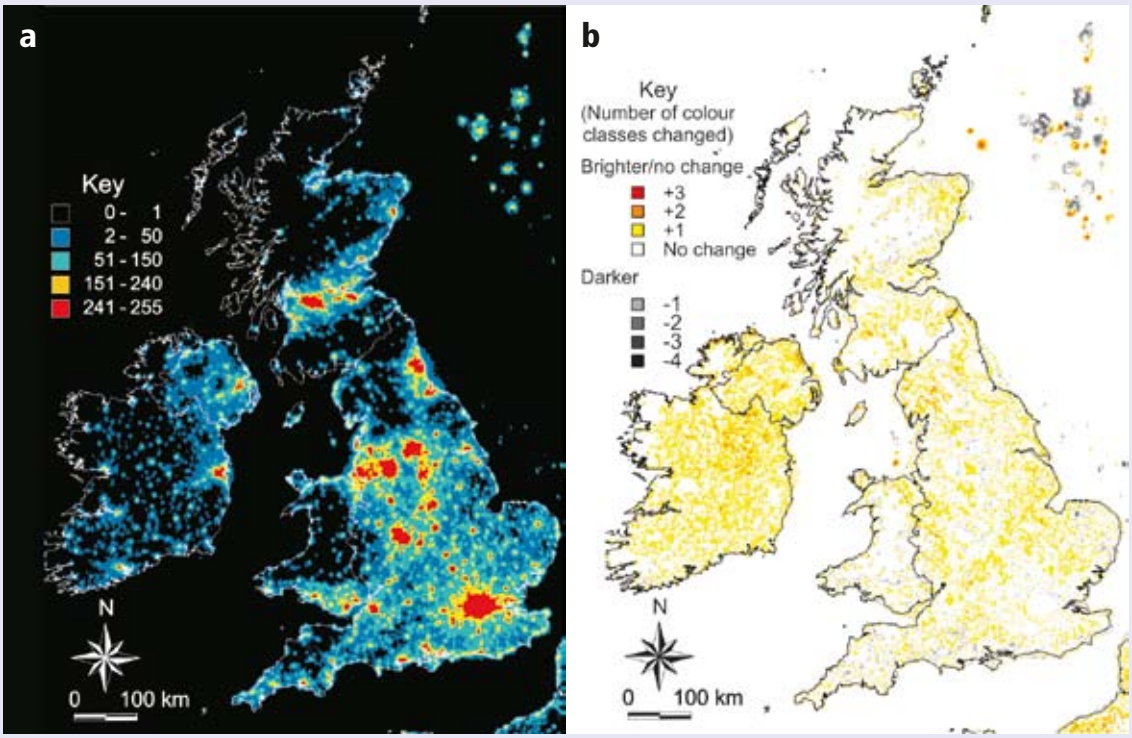
2.3 Light pollution is an important and avoidable consequence of poor lighting design, often exacerbated (especially in the case of floodlighting) by poor installation and maintenance. These factors result in light shining outwards and upwards into the sky where it is not wanted and where it often reflects off moisture and very fine particulate matter in the air giving rise to 'sky glow'.

2.4 Whilst poor lighting design is a major cause of light pollution, the sheer quantity of lighting installations in industrialised countries is a major problem, regardless of the quality of the scheme design. Even if every lighting installation were designed to the highest standards (in terms of downward cut-off and lack of light projected above the horizontal), considerable light pollution would still occur because of the effects of indirect reflection from road and building surfaces – all of which, unless they are completely matt black, have some degree of reflectance.[10]

2.5 Light in the wrong place has become one of the major unaddressed pollution problems in Britain today. Light pollution arises from a combination of extensive urban expansion and highway development, along with the provision of more and brighter road lighting, and is exacerbated in city centres by the proliferation of glass buildings from which light easily spills.

2.6 Figure 2-I below shows how in the seven years from 1993 to 2000 significant areas of the United Kingdom became more intensively lit at night. Many of the areas showing no significant increases in night light levels were areas which were already lit at a very high level in 1993. Other than these, the only areas showing no real increase in levels were in remote mountainous regions of Scotland and Wales. Outdoor lighting in the UK continues to grow at an estimated rate of about 3% per annum.[11]

FIGURE 2-I
Light at night[12]



(a) Map showing light levels at night in 1993.

(b) Change in light at night from 1993 to 2000. The change is shown with respect to the colour classes in (a). A point becoming brighter by 3 classes (+3), for example changing from dark blue to red in (a), is shown as red in (b). The maps show that almost every area in the UK has become brighter, particularly rural areas. Units are based on a scaled version of the percentage of land in the darkest category.

2.7 At least in North America it is possible to find locations sufficiently far from the sky glow of cities that the stars can be seen. In most of Africa a full moon still casts hard shadows. But, as Figure 2-I suggests, escape from the pervasive orange haze of urban outdoor lighting is virtually impossible in most of England and in many parts of the rest of the United Kingdom. Except on holiday, most of our population therefore seldom get to see a sky full of stars. And yet, as reported in the journal *Nature*:[13]

> "Without a direct view of the stars, mankind is cut-off from most of the Universe, deprived of any direct sense of its huge scale and our tiny place within it."

2.8 There are also signs of growing public recognition that something valuable is being lost. There is a Facebook group called 'Lights Off' which campaigns for the reduction of light pollution, and we know that marketing executives have determined that the view of the night sky can be a selling point for travel agents, as evidenced by the holiday company billboard on Reading Station asking "When was the last time you really counted the stars in an evening sky free of light pollution?" The creation of the Bortle Scale in 2001 codified the reduction of the view of the night sky (Box 2A).[14]

BOX 2A THE BORTLE SCALE

The darkness of the night sky is judged on what is called the Bortle Scale. This is a nine-level numeric scale that measures the night sky's and stars' brightness at a particular location. It quantifies the astronomical observability of celestial objects and the interference caused by light pollution and sky glow. John E. Bortle created the scale and published it in the February 2001 edition of *Sky & Telescope* magazine to help amateur astronomers compare the darkness of observation sites.

According to the Bortle Scale, night-time illumination over London ranks as a nine, while that over a remote desert may rank as one. Galloway Forest Park in Scotland scores around three on the scale, making its skies some of the darkest in Europe. Mount Nockalm in Austria is thought to be a 'Bortle one' sky.

2.9 Growing public interest in viewing the night sky unobscured by light pollution is also indicated by support for the registration of the 300 square mile Galloway Forest Park in southern Scotland as Europe's first official dark-sky park with the International Dark-Sky Association.[iii] Registering the park in Galloway is a British highlight of UNESCO's designation of 2009 as the International Year of Astronomy (IYA). Other UK National Parks, including Exmoor, the Brecon Beacons and the Peak District, are expected to follow suit. Additionally and complementary to this is the 'Starlight Reserve Concept' which was finalised at the UNESCO/International Association of Universities (IAU) meeting in March 2009, at which the Joint Nature Conservation Committee of the UK was a major participant. This initiative was designed as an international campaign in defence of the values associated with the night sky and the general right to observe the stars.[16]

2.10 The logic of dark-sky parks is appealing, but they need not be confined to remote areas where implementation is relatively easy; they can also play a role in areas closer to centres of population, even if these parks cannot attain the levels of pristine darkness of the more remote areas.

2.11 While most attention is paid to significant unlit areas in rural locations, there are also many low light areas in suburban locations which should be protected from light ingress, to counter the tendency to more light everywhere. We were aware of a case where a planning application to install floodlighting at a local tennis club in Surrey was rejected on the basis of maintaining an important low light area within a suburban location, to preserve darkness amenity. Such measures may also help to protect non-human species from the potential harmful effects of excessive light at night.

iii The International Dark-Sky Association is a member-based organisation, with its headquarters in the US and members in 70 countries, that seeks to preserve and protect the night-time environment and the heritage of dark skies through environmentally responsible lighting (http://www.darksky.org).

2.12 While we would welcome an expansion of dark-sky parks throughout the UK, it is interesting that as a nation we do not have a good understanding of the extent of such dark-sky areas. Even where it is not possible to meet the exacting standards required for international registration, **we recommend that those responsible for the management of existing National Parks and Areas of Outstanding Natural Beauty and the equivalent National Scenic Areas in Scotland seek to eliminate unnecessary outdoor light and to better design and manage that which cannot be eliminated, and also that efforts are made to retain or create dark skies over urban areas so that people in major centres of population may have access to the night sky**.

2.13 We have noted the loss of visual amenity of the night sky and the growth of light pollution since the Second World War. We believe that there is a serious problem of light pollution that needs to be addressed by controlling light out of place and by Government recognition of the value of a visually unpolluted night sky. In the following chapter we consider some of the specific benefits of outdoor illumination and the drawbacks that result when it is inappropriately or poorly implemented.

Chapter 3

Social Benefits and Drawbacks of Outdoor Lighting

More light! More light!

Dying words of Johann Wolfgang von Goethe

3.1 We recognise that there are benefits from night-time illumination outdoors. There is a demand for outdoor lighting for road safety, personal security against crime, and evening social and commercial activities. However, it is not at all clear that when it comes to outdoor lighting, more is necessarily better. Careful design to ensure appropriate light levels where it is really needed would seem to yield greater benefits.

Charles Dickens, *Barnaby Rudge: A Tale of the Riots of Eighty*

They were, one and all, from the broadest and best to the narrowest and least frequented, very dark. The oil and cotton lamps, though regularly trimmed twice or thrice in the long winter nights, burnt feebly at the best; and at a late hour, when they were unassisted by the lamps and candles in the shops, cast but a narrow track of doubtful light upon the footway, leaving the projecting doors and house-fronts in the deepest gloom. Many of the courts and lanes were left in total darkness; those of the meaner sort, where one glimmering light twinkled for a score of houses, being favoured in no slight degree. Even in these places, the inhabitants had often good reason for extinguishing their lamp as soon as it was lighted; and the watch being utterly inefficient and powerless to prevent them, they did so at their pleasure. Thus, in the lightest thoroughfares, there was at every turn some obscure and dangerous spot whither a thief might fly or shelter, and few would care to follow; and the city being belted round by fields, green lanes, waste grounds, and lonely roads, dividing it at that time from the suburbs that have joined it since, escape, even where the pursuit was hot, was rendered easy.

Writing in 1840 about conditions in 1780

3.2 For example, evidence from the Department for Transport[17] states that the Highways Agency has concluded that the accident reduction from lighting motorway links (that is, between junctions) is of the order of 10%,[iv] and so may not be justified in cost–benefit terms. Logically, application of these findings should automatically lower the level of lighting required for motorways and help reduce the impact of lighting on the countryside. However, recent studies by the Department for Transport in relation to other roads suggest that such straightforward relationships are obscured by a large number of other factors.[18] The latest international guidance from the International Commission on Illumination (CIE)[19] suggests that the highest level of lighting should be on roads where pedestrians and vehicles meet. This again should automatically lower the level of lighting

iv Studies conducted in the 1950s (taking into account all types of road) suggested road lighting could lead to reductions of some 30% in night-time accident rates (evidence from the Department for Transport, January 2008). The difference in figures from the 1950s compared to the more recent Highways Agency data reflects in part the inferior road standards of the time as well as the lower performance of the lighting that was installed in vehicles half a century ago.

required for motorways and help reduce the impact of lighting on the countryside. The use of the new lower benefit figures when assessing future plans for installation and replacement of road lighting schemes could have a significant impact on the extent to which future roads are lit.[20]

3.3 We note that from April 2009 the Highways Agency has turned off lighting after midnight for five hours on sections of the M4 and M5 which have a good safety record and low levels of night-time traffic, primarily to cut energy use and carbon dioxide production.[21] We welcome such initiatives and hope to see their wider uptake by the Agency and other highway authorities.

3.4 With respect to crime, the view of the Home Office, based on a review of studies undertaken on its behalf by Farrington and Welsh,[22] is that crime levels are reduced after lighting is improved in, or provided to, an area.[23] The improvement was especially noticeable if targeted on high crime areas, with the greatest benefits being seen in areas where lighting was part of a wider strategy of uplift (for example, the removal of litter, graffiti, etc.). However, since the reduction applies to both day and night-time crime levels, the beneficial effect may be as much due to an increase in community pride (and associated improvements in informal social control) resulting from public investment in infrastructure as it is to the improvements in lighting *per se*. These studies concluded that improved lighting should be included as one element in crime reduction programmes, and we saw one such plan in evidence from Hampshire County Council.[24]

3.5 **We recommend that the highways authorities and local authorities reassess the lighting of roads against potential road safety and crime reduction benefits**. This reassessment should include consideration of the loss of visual amenity of the night sky, which may be experienced some considerable distance from the road, as well as potential negative impacts on the immediately adjacent natural environment (which will be discussed in Chapter 4). In some areas, reassessment may lead to the withdrawal of lighting where there is no clear safety benefit.

3.6 Private lighting of external space is a growing cause for concern. There have been significant increases over the years in the use of security lighting, which is now a feature of many private houses and commercial buildings, and in floodlighting of sports grounds, which has spread from professional to amateur level. Both can be obtrusive. We have seen the assertion that security lighting can, if badly designed, actually aid criminals by creating glare, which encourages passers-by to look away, and deep shadows in which to hide.[25] Lower levels of more uniform lighting may be more beneficial to both crime prevention and the environment than high-powered security lights. **We recommend that the sale of all new external lighting and floodlighting is accompanied by best practice advice, in order to help installers to aim them correctly, so as to avoid light nuisance and minimise light pollution**.

3.7 In addition to considerations of road safety and crime, light at night also enables people to engage in an extensive range of evening and night-time activities that would otherwise be difficult, if not impossible. Outdoor illumination undoubtedly provides enhanced practical opportunities for the social use of public spaces at night as well as helping to define the characteristic identities of urban areas, as a short walk from the floodlit buildings of the Houses of Parliament and Westminster Abbey to the advertising displays of Piccadilly Circus shows.

3.8 In the commercial districts of big cities, a significant contribution to light pollution results from leaving office lights on overnight. While this can help to visually define particular buildings or districts at night, this is not the purpose for which office lights were designed and results in excessive spill over and upwards reflection to the sky. Careful design can minimise these effects and when not in use office lighting (like any other) should be dimmed or switched off.

3.9 The Commission actually received relatively little evidence about direct light spillage from urban buildings, perhaps because it is seen as an integral part of the urban nightscape and its contribution to sky glow is much less than that of road lighting and light from buildings. However, there have been complaints about the lighting of greenhouses in rural areas.[26] There is at least one precedent, in relation to a rural greenhouse at Jealott's Hill, Berkshire, where planning permission has taken into account the need to reduce light spillage by including conditions relating to the control of light escaping at night and the hours of illumination of external lighting for footpaths surrounding the greenhouse.[27]

3.10 Light is one of the factors covered in Government Planning Policy Statements (PPS1 and PPS23; see Box 3A)[28] and the impact of artificial light from developments has to be investigated in the preparation of an environmental statement under Environmental Impact Assessment Regulations. We therefore particularly regret the fact that the Government undertaking in 2004 to produce an annex to PPS23 on the topic of light appears to have been withdrawn. **We recommend that there should be explicit consideration of light in planning policy. We recommend that planning guidance includes a presumption against the provision of artificial light in some areas where it may have a negative impact on species of concern** (see Chapter 4). **We also recommend that guidance is expanded specifically to enable local authorities to assess the likely ecological impacts of changes to the amount and quality of artificial light. Similar guidance should be provided by the Devolved Administrations**.

BOX 3A PLANNING POLICY STATEMENTS

Planning Policy Statement (PPS) 1: *Delivering Sustainable Development*, paragraph 20, states:

"Development plan policies should take account of environmental issues such as: – mitigation of the effects of, and adaptation to, climate change through the reduction of greenhouse gas emissions and the use of renewable energy; air quality and pollution; land contamination; the protection of groundwater from contamination; and noise and ***light pollution***."

Annex A of PPS23: *Planning and Pollution Control,* Matters for Consideration in Preparing Local Development Documents and Taking Decisions on Individual Planning Applications, states:

"The following matters (not in any order of importance) should be considered in the preparation of development plan documents and may also be material in the consideration of individual planning applications where pollution considerations arise:

... the need to limit and, where possible, reduce the adverse impact of ***light pollution***, e.g. on local amenity, rural tranquillity and nature conservation."

3.11 Not all illumination of buildings is unintended. There are schemes to enhance the nightscape through floodlighting of monuments, buildings or areas of aesthetic or historic interest. We recognise that in the right place, such lighting, including advertising lights, can contribute to the spirit of a particular environment. The use of light in advertising is significant and has a long history. Neon lighting was first used at the Chicago World Fair in 1893 – the lights then were used to spell out the names of famous scientists. The growing use of light-emitting diodes (LEDs) in lighting in advertising poses a potential challenge due to their high light intensities and the distracting effect of rapidly changing images.[29]

3.12 We have also heard that some large buildings are now clad with LED systems – some of which feature digital displays or dynamic facades – to illuminate the whole building at night.[30] This is a new development which may require specific regulation given the obtrusive nature of such

large buildings. Lasers, searchlights and beams of light projected onto buildings are regarded as advertisements under the Town and Country Planning (Control of Advertisement) (England) Regulations 2007,[31] but it is not obvious to the Commission whether this regulation is subtle enough to take into account different types of lights (for example LEDs), or whether it covers instances of adverts being projected onto buildings.

3.13 We have seen lighting designs that focus on specific details of buildings, rather than blanket floodlighting, which are both visually more effective and result in less light pollution. There seems to be plenty of room for improvement in monumental lighting schemes, which need to be carefully planned and must take account of the wishes of the local community and users.

3.14 Different areas create their own characteristic identity. However, the aesthetic qualities of external lighting need to be developed through an explicit process which we believe can best be addressed at a local level through the development of lighting master plans, which has already happened in some UK cities (Box 3B).

BOX 3B LIGHTING MASTER PLANS[32,33]

The purpose of a strategic lighting master plan is to design, in a co-ordinated manner, all lighting within a delineated urban area, so as to avoid arbitrary and unco-ordinated lighting initiatives which waste considerable sums of money and have very little net visual effect on the night-time appearance of the relevant area. City lighting master plans are drawn up by specialist lighting engineers and are implemented by local or unitary authorities. The process of master planning for a town or city involves analysis of the town or city's characteristics. The focus is on prioritising the visual experience of the city for the pedestrian, improving the variety and quality of the lit scene to a level above and beyond base lighting.

In the UK, local authorities tend to have divided responsibilities for public lighting – the local authority will be responsible for amenity lighting and sometimes the illumination of side streets, with the county council or Highways Agency taking on all the lighting of major highways and through routes.

The success of a lighting master plan depends to a large extent on the support that the local council has for the plan – in terms of ability and willingness to implement it in its entirety, and sufficient financial resources. Only in larger metropolitan unitary authorities is the local council responsible for all aspects of public lighting. In such cases the local authority can take on board proposals for changing street and highway lighting, and implement them without reference to other bodies, making achievement of the lighting plan much easier.

Such plans have been implemented in a number of cities throughout the UK, including Edinburgh, Leeds, Coventry, Liverpool and Belfast.

3.15 Because we consider that more explicit recognition needs to be given to the visual and wider societal impacts of artificial lighting, particularly in urban areas, **we recommend that local authorities should develop a lighting master plan in consultation with their local communities, professional lighting designers and their own public lighting engineers.** Due consideration of lighting will be managed by different levels of government in different regions of the UK. Local authorities may consider lighting not just from the visual amenity perspective, but also when they come to consider reducing their carbon footprints. We understand that the International Commission on Illumination (CIE) is due to publish a guide to master planning in the near future, specifically aimed at those in public administration.

3.16 Although the temptation has been for local authorities to provide more, brighter lighting, the CIE recommends brightness limits for vertical surfaces which are much lower than some of the luminance levels found in urban centres today,[34] but these CIE recommendations have no statutory force in the UK. New York City already implements such planning accordance for the central areas of Manhattan.

3.17 The fact that light is regarded as pollution in certain circumstances suggests that it is unwelcome to at least some of those perceiving it at a particular time and place. In fact, the Government has recognised light as a potential source of nuisance in the common law, and also as a statutory nuisance on which local authorities have powers to act.

3.18 The Clean Neighbourhoods and Environment Act 2005 (England and Wales) amended the Environmental Protection Act 1990 to bring artificial light from premises under the statutory nuisance regime as from 6 April 2006. However there are exemptions for airports, public service vehicle operating centres, harbours, goods vehicle operating centres, railway premises, lighthouses, tramways premises, prisons, bus stations and associated facilities, and premises occupied for defence purposes. Similar, but more recent, provisions enacted in Scotland under the Public Health etc. (Scotland) Act 2008 are more extensive, applying not only to premises but also to 'stationary objects' including road lighting, with exemptions relating only to lighthouses and premises occupied for defence purposes. The defence of using 'best practicable means' to prevent or counteract the effects of the nuisance applies across the board in Scotland, but only to industrial, trade, business and sports facilities in England. As the legislation is relatively new, it is unclear at the present time which approach will prove to be most effective.[v] **We recommend that the Government departments responsible for light nuisance legislation in England and Wales, and Scotland keep the legislation under review**.

3.19 Because light at night has brought undisputable benefits, its use has expanded to the point where it has become inescapable, even in rural areas distant from major centres of population. However, it is clear to us that better lighting is not synonymous with more lighting – a point we will expand upon in Chapter 5. Poor lighting practices have a negative impact on the visual amenity of the night sky and have unproven benefits, possibly even negative impacts, on road safety and personal security. They may also have negative impacts on ecosystems and wildlife that we have barely begun to comprehend. It is to the potential damage that light at night may be causing to the natural world that we now turn.

v It is worth noting that accompanying guidance was published in early 2009 in England (by Defra), Wales (by the Welsh Assembly Government) and Scotland (by the Scottish Government) on '*Statutory nuisance from insects and artificial light*', aimed specifically at local authorities.

Chapter 4

Impacts of Light Pollution on Organisms and Ecosystems

The sea-bird wheeling round it, with the din
of wings and winds and solitary cries,
Blinded and maddened by the light within,
Dashes himself against the glare, and dies.

Extract from *The Lighthouse* by Henry Wadsworth Longfellow

4.1 The intensity, spectral quality, duration and periodicity of exposure to light affect the biochemistry, physiology and behaviour of organisms. In plants, the presence of light-sensitive chemicals provides the basis for photosynthetic activity. Light is also an important environmental modulator of growth rates and growth patterns for which changes can have profound consequences at the level of the individual plant. Many micro-organisms and a wide variety of animals ranging from protozoans to higher vertebrates perceive light – the ability may range from basic light perception to full visual imaging. More complex animals have the ability to form images from information gleaned using their light receptor systems.

4.2 In general, the term 'light' describes that part of the electromagnetic radiation spectrum that is visible to humans. Other species have different spectral sensitivities; many insects, for example, are able to detect ultraviolet light, which is electromagnetic radiation of a wavelength that is too short for the human eye to perceive. Some species have a high sensitivity to a narrow band of radiation within their spectral range. The sort of differences that exist are shown in Box 4A which compares the visual capabilities of the human eye with that of the elephant hawk-moth.[35]

4.3 Natural light intensity varies during the day–night (diurnal) cycle, the lunar cycle and the seasonal cycle. Organisms have evolved to respond to these periodic changes in light levels in ways that control or modulate movement, feeding, mating, emergence, seasonal breeding, migration, hibernation and dormancy, and in plants, flowering and vegetative growth, and the direction of growth.

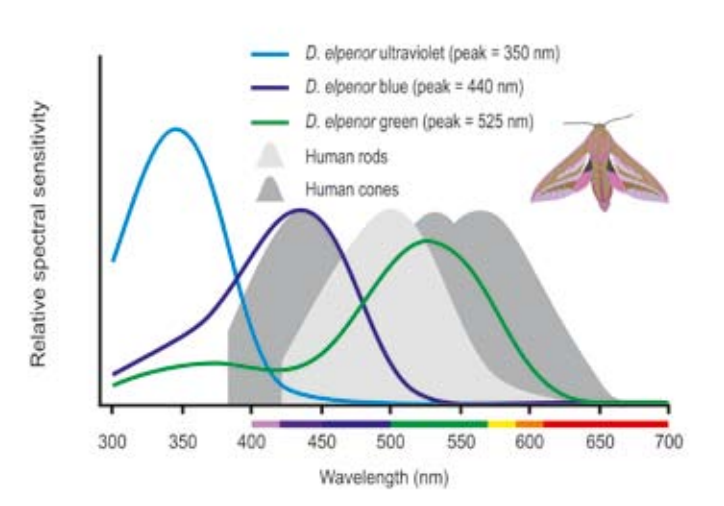
4.4 Given the effects of light on living organisms, it is plausible, and even probable, that introduction of artificial light into the natural light regime will disturb the normal routines of many plants and animals.

4.5 Plants are sensitive to different intensities and wavelengths of light. Red light induces most of the key stages in the life cycle of flowering plants from germination, through shoot and leaf development and flowering, to the onset of dormancy in those species that have a dormant phase. Phototropism, the tendency of plants to grow towards light, is induced by blue light. Day length is an important regulator of flowering in some temperate angiosperms, although the response to this photoperiodism is not the same in all species. Some, such as spinach, radish and sugar beet, flower on long days but not short ones (long-day plants), whereas others, such as chrysanthemums,

rice and poinsettias, flower on short days but not long ones (short-day plants). Flowering in other plants, such as tomato, are not affected by day length. It is also a critical factor in determining the onset of dormant phases in trees.[36]

BOX 4A VISUAL CAPABILITIES OF THE ELEPHANT HAWK-MOTH

The elephant hawk-moth, *Deilephila elpenor*, which is widespread throughout the British Isles, is frequently used as a model organism in investigations of insect eyesight. Like humans, it has trichromatic colour vision, a trait it shares with the majority of insect species which have been studied. Its visual pigments have different sensitivities to ours, as shown in the figure below.



D. elpenor is highly sensitive to ultraviolet light and insensitive to red light. Typical sensitivities of human cones are shown here in aggregate. The hawk-moth sensitivities are shown as if each pigment exhibited the same level of response overall (the same area under each curve). This emphasises the relative sensitivity of each pigment compared to the others at each wavelength. Human pigment sensitivities indicate the wavelength of peak sensitivity in each case.

D. elpenor can apparently perceive colour when illumination is very low (equivalent to starlight). In contrast, human vision under these conditions cannot detect colours. Recent studies have demonstrated that these moths exhibit a degree of colour constancy; like humans they perceive colours as being the same under quite different types (spectra) of illumination.

4.6 Information regarding the light sensitivity of invertebrates (which comprise more than 95% of the animal species currently in existence) is still patchy.[37] Their photoreceptors are highly diverse, ranging from the simple nerve fibres of some sea urchins that respond to changes in light levels, to the compound eye of insects, extremely complex structures for detecting light and forming images. Vertebrates have two types of light-sensitive cells in their eyes: *rods* which work in dim light but with low acuity and are most sensitive to blue/green light with a wavelength of 496 nm; and various types of *cones*, which tend to be well supplied with nerve connections and can therefore deliver sharp colour vision across the visual spectrum. Not surprisingly, the proportions of rods and cones correlate broadly with the lifestyle of animals. The eyes of nocturnal mammals have a greater preponderance of rods than cones whereas the eyes of diurnal mammals are rich in cones. But the differences between species are more subtle than this, which suggests that there has been strong evolutionary pressure for adaptation to particular light regimes.

4.7 Our knowledge of the biological effects of light comes from laboratory-based studies and field observations of a narrow range of species. This work reveals four main types of effect induced by light. Light pollution could potentially impact on each of these with consequences that might be significant for the spatial and temporal distributions of populations. The four main types of effect are:

- *Attraction to light*. Many species of invertebrates and vertebrates will move towards a light source. One advantage of this sort of response is that it can enhance foraging behaviour. Light also acts as a directional navigational signal used to guide animals, for example, crabs moving about on the seashore.
- *Avoidance of light*. Many species show the opposite behaviour. Thus, when there is bright moonlight, small nocturnal mammals tend to move about less, restrict their foraging range and feed for a shorter time than when the sky is overcast. The main advantage of keeping out of the light is generally thought to be the avoidance of predation.
- *Photoperiodism*. As was noted earlier, many aspects of physiology and behaviour are influenced by day–night or circadian rhythms. Where species show seasonality in their behaviour, such as annual migrations or periods of dormancy, day length is a mediating factor. These changes enable the individual concerned to avoid unfavourable conditions.
- *Spectral quality*. Species have evolved to function under particular light regimes and both their ability to receive light stimuli and respond to them are finely tuned to particular qualities of the visual spectrum. This is particularly apparent in plants, where different photoreceptors are stimulated by different wavelengths of light.

4.8 There is no doubt that organisms respond to artificial as well as natural sources of light. In laboratory experiments investigators have manipulated light stimuli using artificial illumination and have observed a wide range of effects.[38] However, there is much less evidence of how plants and animals respond to artificial light in the wild, where changes to the normal lighting regime may be far less dramatic than in laboratory situations. Where research has been carried out, it has tended to focus on the types of response that are well known from anecdotal evidence, like the attraction of insects and bats to road lighting. There is, however, some evidence for all the main groups of vertebrates.[39]

4.9 It has been known for over a century that some birds are attracted to lights at night. Powerful lighting on lighthouses and on tall buildings can act as a 'super stimulus' causing birds to fly towards the structure. Those that are not killed by collision may nevertheless waste considerable time and energy flying around and around a fixed point, limiting their chance of survival and reproduction. On occasion, hundreds, even thousands, of migrating birds can be killed on a single night.

4.10 In North America there have been several initiatives, such as that of the National Audubon Society in New York and the Toronto Fatal Light Awareness Program,[40] which have led to several cities in the US and Canada reducing the light from skyscrapers at night during migration season and saving millions of birds from dying due to disorientation. If the lights in office blocks can be switched off overnight during bird migrations with no apparent loss of utility to businesses or to citizens, we are forced to wonder why they are not turned off throughout the year.

4.11 Bats are often cited in the literature on artificial night lighting, particularly in relation to road lighting. Nearly all insectivorous bats feed at night. Some species congregate around road lights because of the high numbers of flying insects they attract, rather than as a direct response to the light itself. On the face of it, road lighting in this instance is beneficial to the bats because it provides additional feeding points, although it may also increase the risk of predation, by raptors and domestic cats. However, not all species of bat show the same feeding behaviour. Some species feed by quartering along hedgerows and between trees taking insects on the wing as they move. For these species, road lighting offers no benefits. Recent experiments which artificially illuminated the flight paths of bats showed that they avoided such areas, with potentially harmful effects on distribution and foraging behaviour.[41]

4.12 Many species of frogs and toads also gather around the base of road lights where they feed on insects.[42] Whether there is direct attraction to the light itself is unclear. Amphibians typically have excellent nocturnal vision with exceptionally sensitive photoreceptors. If these are exposed to artificial light at high intensities, pigment 'bleaching' can cause temporary blindness just as it does in humans when moving from sunlight to indoors. However, the visual impairment is likely to last far longer because it may take several hours for amphibian pigments to return to a dark-adapted state.[43]

4.13 We have seen that, depending on circumstances, the response of individual organisms to light may be favourable or unfavourable. A more difficult question to answer is whether artificial light pollution is having significant consequences at the population and ecosystem levels, and whether such impacts constitute damage. This is difficult to address for two reasons – the nature of light as a pollutant and the practical challenges encountered when performing studies.

4.14 Unlike chemical pollutants, light (including artificial light) is not inherently toxic, although it may cause injury and have pathological implications.[44] Any effect of artificial light at the ecosystem level is likely to be subtle and may well result from the indirect consequences of a change in lighting regime rather than the presence of artificial light itself. This makes it difficult to identify artificial light as a culprit when environmental damage is observed and makes the design of field experiments to investigate the impacts of artificial lighting at a population level challenging and costly to set up (but see 4.11 above). A study exploiting artificial road lighting was able to show a small but significant negative impact on breeding black-tailed godwits.[45] Box 4B[46] illustrates a clearer-cut ecological change, but unlike the field experiments cited in 4.11, the causal link to artificial lighting is only circumstantial.

BOX 4B COMPETITION BETWEEN TWO SPECIES OF BATS

There is circumstantial evidence to suggest that the presence of road lighting might alter the competitive balance between species of bat that do and do not feed around road lights. The lesser horseshoe bat (*Rhinolophus hipposideros*) became extinct in several mountain valleys in Switzerland (but still occurs in Britain) after road lighting was installed there. This species does not feed around road lights. The decline in the lesser horseshoe bat coincided with an influx of large numbers of pipistrelle bats (*Pipistrellus pipistrellus*), a species which is known to feed around road lights. The two species are of similar size and feed on the same kinds of insects so it is possible that local extinctions might have been caused by the competitive exclusion. It should be noted, however, that the lesser horseshoe bat was already in serious decline across its range and there are undoubtedly other factors involved in its demise.

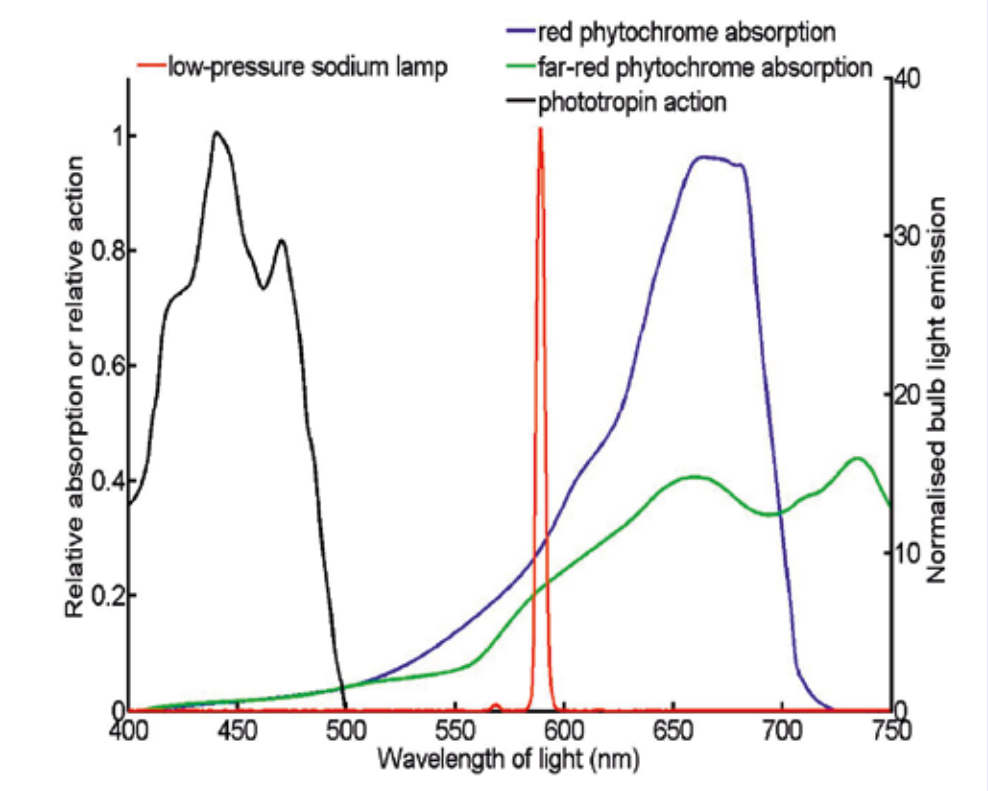
4.15 There is very little information of any sort regarding the effects of light pollution on plants in natural ecosystems. Given the complexity of their photoreceptor systems, this is somewhat surprising. It may be that responses are quite localised so that effects do not show up at the population level. For example, trees near to road lights may retain some or all of their leaves when those further away lose theirs.[47] In extreme cases, only those parts of a plant nearest the light source may be affected. Laboratory experiments indicate that the sensitivity of plants to artificial lighting varies from species to species and even within a species.

4.16 The type of artificial lighting is likely to be a critical factor in determining how a plant responds because the spectral profile of different light sources varies. This is illustrated in Figure 4-I[48] where it can be seen that the activity absorption spectra of some plant photoreceptors overlap only slightly with the emission spectrum for low-pressure sodium lighting. On the other hand, it has been reported that plane trees exposed to high-pressure sodium vapour lighting showed rapid and late-season growth followed by severe winter dieback compared to trees screened from the lights. It has also been observed that continuous artificial lighting depresses chlorophyll formation and stimulates the expansion of leaves resulting in elevated sensitivity of the plants to chemical pollution.[49] Similarly, Box 4A shows that the wavelength of low-pressure sodium lamps (at around 590 nm) lies outside the elephant hawk-moth's field of sensitivity. There are however new types of lighting with different wavelengths coming on-stream (see Figure 5-II) which may have considerable impact on species such as this.

FIGURE 4-I

The relative absorption of plant pigments relative to emissions from low-pressure sodium lamps

The figure shows three main classes of plant pigments, found in varying combinations in all flowering plants, and their ability to absorb light of different wavelengths.



4.17 Light intensity strongly influences the behaviour of freshwater and marine animals. Daily migration in zooplankton, where the animals move down through the water column during the hours of daylight and return to nearer the surface at night, is believed to have evolved as a means of avoiding predation. It is hypothesised that artificial light in the environment could disrupt organisms such as zooplankton, with further consequences for species higher up the food-chain.[50]

4.18 Many species of marine invertebrates synchronise their spawning behaviour by responding to phases in the annual and lunar cycles. These responses are finely attuned so that spawning may only occur on one or two nights of the year.[51] There have been few investigations of how artificial light might affect such behaviour. If sky glow increases background illumination to the extent that changes in the strength of the moonlight stimulus become masked, this would disrupt the synchronised response and lead to breeding failure.

4.19 Amongst terrestrial invertebrates, most attention has been paid to the attraction of night-flying moths to road lighting. Flying insects are generally most attracted to shorter wavelengths of light and so particularly favour mercury vapour lights. It has been estimated that high-pressure sodium lamps, by contrast, attract between 20-60% of the number of insects attracted to mercury lamps; low-pressure sodium lamps are even less attractive (see Chapter 5).[52] Low-pressure sodium lighting may cause a different sort of problem for insect populations. It can inhibit flight behaviour in moths and concern has been expressed that its widespread use may effectively be sterilising large areas for nocturnal flying insects.[53]

4.20 Several bird species become active under artificial light. For example, the robin can be induced to sing, forage and feed its young under artificial lighting. Usually the robin, like most songbirds, is diurnal, beginning the day with a dawn chorus, ending it with a less intense dusk chorus and foraging in between. Under artificial lighting, however, the robin begins singing much earlier than unlit counterparts on the same day and there are reports of birds occasionally singing throughout the night. Recent research indicates that robins do not always exploit available food resources at night, even if it is possible for them to do so. While a robin with an artificially-lit territory would, therefore, be likely to be active for longer periods than is normal, it does not seem to lose body mass even though its energy expenditure is greater and it is not feeding at night.[54]

4.21 Further evidence that artificial light can influence animals in natural ecosystems can be gleaned from the ways in which humans have exploited the effects of light on living organisms over the centuries, long before there was any scientific understanding of the processes involved. That some fish and shellfish are attracted to artificial light at night provides the basis for night-fishing using lanterns. In modern times artificial lighting in greenhouses has been used both to extend and change the flowering season of a wide variety of plants.

4.22 In this chapter we have briefly illustrated some of the diverse ways in which organisms exhibit sensitivity to light and the kinds of disturbances that the introduction of artificial light can cause. Given the importance of light as an environmental factor it is surprising that there is not more evidence of ecological effects arising from light pollution. It is important to note, however, that a lack of evidence of significant effects is not the same as evidence of no significant effects. Where anecdotal evidence exists, it mainly concerns charismatic groups of animals, such as birds and sea turtles, and these species have been the subjects of the limited ecological research that has been carried out. We know comparatively little about the photobiology and ecology of most of the species in the UK that are likely to be affected by light pollution because they tend to be nocturnal, difficult to study and seldom observed. We do know, however, that many species are in

decline (not least a wide variety of UK moths),[55] some to the point of becoming threatened or even endangered. Habitat degradation and chemical pollution are often cited as causing biodiversity loss but it is plausible that artificial light could also be a contributory factor.

4.23 The paucity of information on the ecological effects of artificial light across species and habitats is well illustrated by the quotations in Box 4C.[56] In its report, *Light Pollution and Astronomy*,[57] the House of Commons Select Committee on Science and Technology referred to earlier government guidance in *Lighting in the Countryside: Towards Good Practice*[58] which concluded that light pollution could have adverse ecological effects on insect populations, particularly moths and glow worms, nocturnal mammals and plants, and that the behavioural patterns of birds could be severely damaged.

BOX 4C PAUCITY OF INFORMATION ON THE ECOLOGICAL EFFECTS OF ARTIFICIAL LIGHTING

Although anecdotal reports of the effects of artificial lights are common in the literature on frog natural history, ... there have been few direct experimental studies of the effects of artificial night lighting on anurans. The few studies reported in the literature demonstrate that anurans are sensitive and responsive to artificial night lighting. [p193]

... few studies, or even anecdotal reports, document the effects of artificial night lighting on mammals in the wild. [p19]

Bats have long been observed feeding on insects attracted to artificial light sources. ... it seems possible or even likely that lights indirectly influence the survival and reproductive performance, and hence the conservation status, of both bats and insects. [pp43-44]

Globally, cumulative natural ... and anthropogenic changes ... are having profound, long-term effects on the Earth's ecosystems ... The proliferation of artificial light throughout the biosphere could act in synergistic and unknown ways with these other large-scale environmental changes.

Direct information on negative consequences of artificial lights in free-ranging reptiles (other than sea turtles) is not readily available. Several studies suggest, however, that such adverse effects may indeed exist. ... Considerable information now exists to support the contention that artificial lighting affects the activity of some ... reptiles, but the nature of the effects is species specific and hard to predict.

Few studies have addressed the effect of artificial night lighting on salamander populations in the field or over long periods of time, ... [p243]

Despite the well-known and profound influence of light on the behaviour of aquatic organisms, ... little research has addressed the consequences of human disruption of ... illumination. [pp257-258] ... Disruption of [the] natural lighting regime may have significant consequences for species richness and community composition [among fish]. [p270]

... adverse effects of street lighting on insects theoretically could have serious ecological consequences. [p281]

Few studies have systematically examined the effects of artificial lighting on moths, and none has measured effects on moth populations. [p306]

From our initial findings, coupled with the existing literature, we conclude that artificial night lighting may alter the spatial distribution, diel movements, ... demography, and overwintering success of some freshwater organisms. [p380]

... except for two articles ... no rigorous studies have examined effects of artificial night lighting on plants in conditions approaching their natural environment. [p390]

4.24 Despite the pleas for more research and the recommendations for that research made by the editors of and contributors to the book *Ecological Consequences of Artificial Night Lighting* (Box 4C), we have not found many more references to add to those in that volume. We share the editors' concerns and endorse their recommendations but conclude that without central government direction, it is unlikely that there will be firm scientific evidence in the near future on whether or not pollution from artificial lighting has serious ecological consequences.

4.25 The evidence that the Commission has received on the subject leads us to conclude that there are insufficient data on the ecological consequences of artificial light in the environment. A more fundamental concern that the Commission holds is that insufficient research is being conducted to allow us to obtain such information. **We recommend 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 the effects of both existing and proposed lighting technologies on biological systems**.

4.26 However, while further research is clearly required, we believe that there is already sufficient information available to generate concern regarding the potential adverse ecological impact of artificial lighting schemes. In the next chapter we consider some of the technical aspects of road lighting provision and opportunities for reducing its negative impacts on both natural ecosystems and human communities.

Chapter 5

Road Lighting Technology: An Opportunity and a Challenge

Less is more.

Mies van der Rohe

5.1 It seems highly likely that the use of outdoor artificial lighting will continue to grow in tandem with the demand for new infrastructure associated with increases in population, economic growth and new technological opportunities. The evidence we have seen suggests that the main focus of concern in most areas is the road lighting provided by public authorities. The evidence we received during this study suggests that there is now a general recognition that outdoor lighting should be designed not only to provide light where and when it is needed in an energy-efficient manner, but also to minimise or prevent the problems that can arise from stray light. By far the largest part of external lighting outside city centres is public road lighting.

5.2 Road lighting should be installed in such a way that the benefits are achieved with the least escape of light in directions where it is not useful or is positively damaging. This is illustrated in Figure 5-I. The light needs to be sited correctly at the right height. The protective case around the light source, known as the *luminaire*, should be designed to direct the light where it is needed. It is inevitable that some light will be reflected back from lit surfaces; the amount of reflected light may not be negligible when taken over large areas and the elimination of all sky glow may not be possible. However, with careful choice of technology and proper installation, light pollution can be minimised. The Institution of Lighting Engineers is one of the organisations providing guidance on how to reduce obtrusive light.[59]

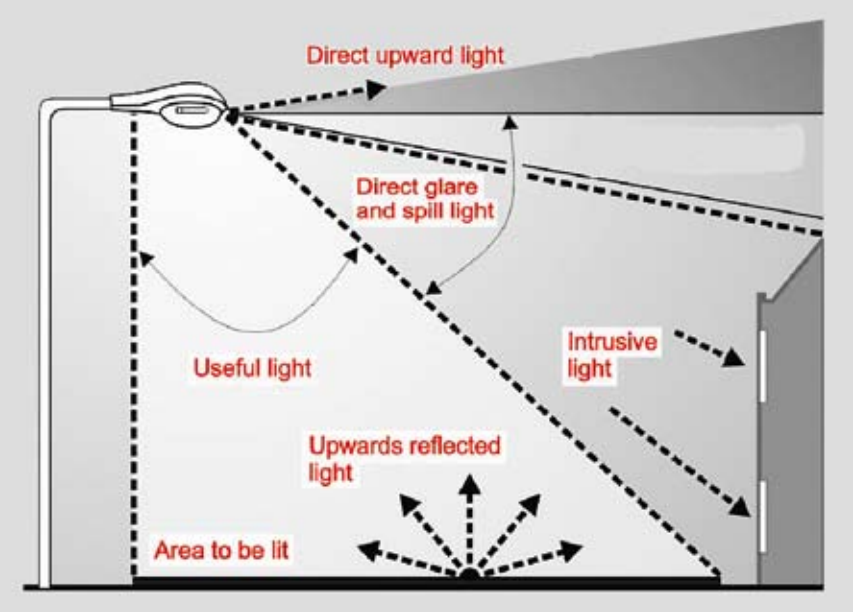
5.3 The Illuminating Engineering Society of North America (IESNA) has introduced a classification system for luminaires to highlight those that minimise light pollution (especially sky glow).[60] Full cut-off luminaires produce very little light pollution since no light is allowed to scatter upwards above the horizontal; some classifications allow light to be scattered above or at the horizontal, whereas all other designs are classified as 'non-cut-off' luminaires.

5.4 Correct positioning of luminaires is important; in a survey of 73 environmental health officers conducted in 2004, 50 (69%) said they would ask for existing luminaires to be redirected when faced with a problem of obtrusive light. Only 19 (26%) would ask the owner to switch to a different luminaire.[61]

5.5 As mentioned in Chapter 1, of 7.4 million road light fittings in the United Kingdom, 2.32 million lighting columns will be more than 30 years old by 2010. Given that the design lifespan of most of these was 25 years, we face a substantial programme of replacement. This provides an opportunity, but one which needs to be exercised carefully in order to ensure that the benefits of new technology are captured without creating adverse consequences. To make best use of luminaires which avoid or minimise the amount of light diverted upwards it is important to position lights on posts of adequate height if uniform luminance is to be achieved. **We recommend that the authorities responsible should carry out replacement programmes for road lighting in a way that explicitly minimises the negative impacts of stray light**.

FIGURE 5-I
Useful and wasted illumination from a road lamp.[62]

The figure shows that the type and amount of light produced by the road lamp depends on the luminaire.



5.6 As described in Chapter 3, we recognise that lighting of public space has benefits and is perceived by many in society to have advantages which outweigh the negative impacts. But it is equally clear that, through the relatively simple mechanism of directing light more accurately to where it is needed, improved technology can be used to deliver those benefits while at the same time minimising adverse side-effects. The technologies to do this already exist and should be incorporated in all new road lighting and replacement lighting. For example, we were told that new lighting technologies can provide an equivalent level of visibility at lower levels of light than older systems, such as low-pressure sodium lights, which have narrower ranges of wavelengths, and that the new systems can be far more accurately directed at the surfaces to be illuminated.[63] **We recommend that lighting standards should require the provision of light at an intensity no greater than the minimum necessary to deliver the intended benefits and that the light should be directed at only those areas which are intended to be illuminated**.

5.7 The benefits and the drawbacks of artificial light depend on where and when it occurs, but also on its strength and colour. Natural daylight is normally referred to as white, although its exact nature depends on time of day and year, and cloud cover. Light energy is distributed over a wide range of wavelengths, from the infrared through to the ultraviolet. At normal daylight levels of lighting, the human eye is able to see light with wavelengths from about violet (380 nm) up to red (750 nm) and the level of natural light in this range is roughly uniform. At low levels of light, such as natural outdoor conditions at night, the human eye is essentially monochromatic. Incandescent artificial lights (filament bulbs) give light which is spread over all the visible wavelengths with some bias towards the longer (red) end. Different kinds of lights have different spectral compositions, as shown in Box 5A and Figure 5-II.

BOX 5A CHARACTERISTICS OF SOME COMMON UK ROAD LIGHTS COMPARED TO INCANDESCENT BULBS AND WHITE LIGHT-EMITTING DIODES (LEDs)[64]

Type of light	Low-pressure sodium (LPS or SOX)	High-pressure sodium (HPS or SON)	Compact fluorescent	Metal halide	Incandescent	White light-emitting diode (LED)
Colour of light	yellow/ orange	pinkish/ amber-white	warm white	bluish-white/ white	yellow/white	white
Ultraviolet radiation (%)	0	0.3	0.5-1	2-7	0-0.2	0
Colour rendering index (CRI)[1]	0[2]	25 (up to 85 for white SON)	82	65-87	100	>60[3]
Efficiency (lumens per Watt)	80-200	90-130 (30-45 for white SON)	67-87	60-120	8-25	60-80
Approximate number of luminaires (in millions) and percentage of total (in brackets)	3.454 (44%)	3.181 (41%)	1.193 (15%)	≈0 (growing) (≈0%)	NA	NA

Notes

1. A measure of the light source's ability to reproduce colours faithfully in comparison with an ideal or natural light source. Higher values are better.
2. Perceptibly monochromatic light: it actually emits light of two main wavelengths (589.0 and 589.6 nm).
3. 'White' LEDs have a CRI of >60 by definition.

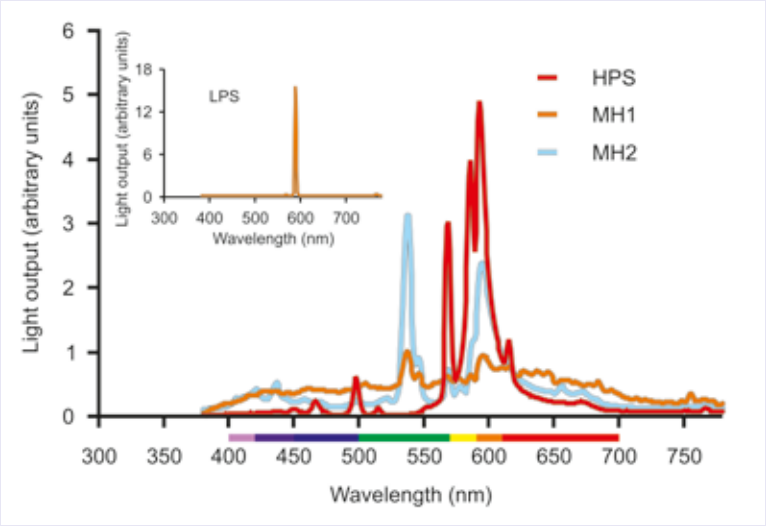
5.8 The colour and character of light can be represented by its spectrum, which shows intensity of output plotted against the wavelength. Various spectra from artificial light sources are shown in Figure 5-II. As Box 5A shows, the most numerous type of road light is the low-pressure sodium light. This is the familiar light with a pronounced yellow/orange colour, the spectrum for which is shown in Figure 5-II(a) where it appears as a line (actually two lines close together) at about 590 nm. Because the light from low-pressure sodium is at a single wavelength it does not permit any colour rendering, which reduces the human ability to discriminate objects.

5.9 Because of the undesirable absence of colour rendering with low-pressure sodium lights, there has been a shift to other light sources. Most significant is the growth in the number of high-pressure sodium lights (HPS) which have several peaks in the spectrum and allow some perception of colour. This spectrum is also shown in Figure 5-II(a). The compact fluorescent light (CFL) gives quite good colour rendering (Figure 5-II(b)), as do the newer metal halide lights (MH1 and MH2 in Figure 5-II(a)) which are now being installed in large numbers where colour and brightness are important. The new white light-emitting diodes (LEDs) can give good colour rendering but remain expensive and are still only being installed on a trial basis or in special circumstances. The LED is compact and can be highly directional, thus aiming light more precisely where it is wanted.

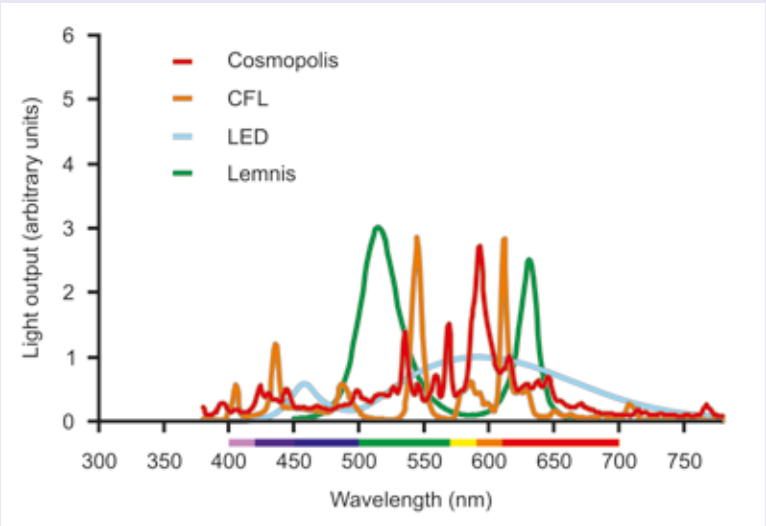
FIGURE 5-II
Road light emission spectra[65]

Spectra are scaled so that the overall amount of light from each source is the same for the wavelengths depicted (those roughly equivalent to visible light). Different sources have very different emission profiles. They may therefore appear very different to human observers and will have different effects on flora and fauna.

(a) Metal halide and sodium lamps. HPS = high-pressure sodium; MH1 = metal halide (Master Colour); MH2 = metal halide (Master City White). Low-pressure sodium lamps (LPS (inset)) produce almost monochromatic light. When scaled as here, their peak emission is just over four and a half times higher than the highest emission at a given wavelength for any of the other lamps shown.



(b) Cosmopolis, compact fluorescent and light-emitting diode (LED) lamps. Cosmopolis = Cosmopolis metal halide 'white' lamp; CFL = compact fluorescent lamp; LED = Osram Golden Dragon warm white LED (as used for road lighting in Banff, Canada); Lemnis = Lemnis prototype LED road light.



5.10 As explained in Chapter 4, many biological effects depend on exposure to quite specific wavelengths of light. If new lighting systems expose organisms to new wavelengths for the first time, we might see the emergence of previously unobserved impacts. Some of the newer lighting sources produce a wider spectrum of visible light, which may be harmful to non-human life forms that were previously unable to detect the spectra emitted by low-pressure sodium lights. We have received no evidence that this possibility has been taken into account in designing and implementing new street lighting technologies. **We recommend that, before replacement road lights using broader**

wavelength technologies are widely introduced, particularly in rural areas, the Department for Environment, Food and Rural Affairs (Defra) and the Department for Transport should commission a systematic investigation of their impact on natural systems.

5.11 Although traditional low-pressure sodium lighting is a very energy-efficient system, it is rather inflexible and works best when the lights are left full on during the period of darkness. It does not, therefore, lend itself to reducing unwanted illumination by ensuring that public spaces are only lit when required, with the lights turned off or dimmed at other times. Almost by accident, the inherent efficiency but inflexibility of the traditional system has created an expectation that road lighting will remain on throughout the hours of darkness, even when few people are using roads or public spaces. Attempts have been made by a number of local authorities, including Powys and Hampshire, to turn off road lights or reduce lighting after a certain hour. Evidence from a trial in Hampshire is that the public are not generally content with a complete turn-off in many areas but are willing to accept dimming.[66] In Powys, reaction to turning off some but not all lights in quieter areas in September 2008 was again mixed, with one individual paying for the lights to stay on in his village.[67]

5.12 Dimming, preferably using a centralised management system (CMS),[vi] is one way of reducing unnecessary illumination. In the past, dimming was generally achieved by simply switching off a fraction of the lights. This saves energy, but the lack of uniformity within a group of lamps can be hazardous because dangers may not be seen in the dark regions. The dimming technologies now available for lights other than low-pressure sodium avoid this problem. Depending on the method employed, dimming can also reduce energy demand by 40% and maintenance costs by 50%.[68] Although centralised management systems can be more expensive to install, the payback time can be as little as 4-5 years.[69]

5.13 Some more innovative approaches to dimming have been applied elsewhere. For example, in some parts of Portugal,[70] road lighting in quieter roads is activated by movement, so enabling lighting to be switched on only when there is someone there to benefit. In the German village of Doerentrup, road lights are being switched off at night to save energy and reduce carbon emissions but local residents can use their mobile phones to switch them back on again for short periods of time if they are needed.[71] We are not aware of any installations along these lines in the United Kingdom, but it is another potential option. One possible disadvantage, however, might be an increase in disturbance, as the sudden activation of lights against a dark background might be more intrusive than a continuous light for those who have problems sleeping or more disruptive to foraging nocturnal mammals or to birds. However, this option could be appropriate in some areas and might merit further consideration.

5.14 Artificial light should only be used at times when the benefits are needed. **We recommend that local authorities and others responsible for the provision of road lighting should pay careful attention to the outcome of the trials currently underway to examine the impact of reducing or turning off lighting in quieter areas where there is unlikely to be any significant use of the roads by pedestrians or road traffic; and that they should consider what lessons they can draw from them to help minimise negative impacts.**

vi A centralised management system (CMS) has the capability to switch on or off and dim road lights remotely, depending on the conditions or time of night, and to monitor and report on energy consumption and equipment faults and failures via wireless digital links. Some experts claim up to 40% energy saving is possible using these systems (personal communication from Carl Gardner, Institution of Lighting Engineers).

5.15 In conclusion, we believe that there are significant opportunities for the reduction of light pollution through the design, installation, maintenance and operation of road lighting and other outdoor lighting systems which can and should be pursued without delay. However, we also urge caution in relation to the widespread adoption of newer light sources in the absence of research into the possibility that they will have more adverse effects on plants and wildlife than the existing low-pressure sodium lights.

Chapter 6

Conclusions and Recommendations

6.1 We have examined the explosive growth in outdoor lighting in the UK since the Second World War and the resulting loss of visual amenity of the night sky due to light pollution, particularly sky glow. We believe that access to the natural beauty of the night sky is every bit as important as the preservation of other aspects of natural beauty which society routinely seeks to protect for the enjoyment of its citizens and for posterity.

6.2 We are also concerned that we simply do not know enough about the biological impacts of light pollution on plants and wildlife, particularly at the population and ecosystem levels. In many cases scientists have barely begun to look. Humans, and most other animals and plants, have evolved in an environment which has alternating periods of light and darkness, both within each day and, outside the tropics, between seasons. This has important consequences for the ways in which organisms behave in the environment and for certain processes within organisms and ecosystems. The disruption of normal light patterns can therefore have significant effects.

6.3 However, because of the general perception of light as a natural and benign phenomenon, it is sometimes difficult for people to understand its negative effects. This may be one reason for the apparent general indifference to the potential negative impacts of light in the environment when any other anthropogenic effect having the same impact would have long been subject to more rigorous scrutiny and control.

6.4 To rapidly redress the lack of access to the night sky for the population of the UK, **we recommend that those responsible for the management of existing National Parks and Areas of Outstanding Natural Beauty and the equivalent National Scenic Areas in Scotland seek to eliminate unnecessary outdoor light and to better design and manage that which cannot be eliminated, and also that efforts are made to retain or create dark skies over urban areas so that people in major centres of population may have access to the night sky (2.12)**.

6.5 Much light pollution comes from road lighting. While we recognise that road lights can reduce road accidents and increase people's sense of security, we have found that the magnitude of claimed benefits are either smaller than previously thought (accidents) or equivocal (crime reduction), and in any case these goals are not necessarily associated with higher levels of illumination. Smarter lighting rather than more lighting is the key. We recognise that lighting arrangements can be important in providing people with a sense of place, but inappropriate lighting causes unnecessary stress to people, to plants and to animals. **We recommend that the highways authorities and local authorities reassess the lighting of roads against potential road safety and crime reduction benefits (3.5)**.

6.6 Private lighting of external space is a growing cause for concern. **We recommend that the sale of all new external lighting and floodlighting is accompanied by best practice advice, in order to help installers to aim them correctly, so as to avoid light nuisance and minimise light pollution (3.6)**.

6.7 Light is one of the factors covered in Government Planning Policy Statements (PPS1 and PPS23) and the impact of artificial light from developments has to be investigated in the preparation of an environmental statement under Environmental Impact Assessment Regulations. **We recommend that there should be explicit consideration of light in planning policy. We recommend that planning guidance includes a presumption against the provision of artificial light in some areas where it may have a negative impact on species of concern. We also recommend that guidance is expanded specifically to enable local authorities to assess the likely ecological impacts of changes to the amount and quality of artificial light. Similar guidance should be provided by the Devolved Administrations (3.10)**.

6.8 Because we consider that more explicit recognition needs to be given to the visual and wider societal impacts of artificial lighting, particularly in urban areas, **we recommend that local authorities should develop a lighting master plan in consultation with their local communities, professional lighting designers, and their own public lighting engineers (3.15)**.

6.9 The principal protection that individuals have against the intrusion of light upon their lives at night is regulation on statutory nuisance. The Government has recognised legislation is necessary to tackle light nuisance, but different approaches to enforcing this legislation have been adopted in England and Wales as compared to Scotland. Whereas in Scotland exemptions from statutory nuisance apply only to lighthouses and premises used for defence purposes, the equivalent legislation in England and Wales exempts a very wide range of facilities. As the legislation is relatively new, it is unclear at the present time which approach will prove to be most effective. **We recommend that the Government departments responsible for light nuisance legislation in England and Wales, and Scotland keep the legislation under review (3.18)**.

6.10 In the course of our study, we have been convinced that artificial light can have significant effects on the natural environment. Many of these effects have been investigated at the level of the individual organism, but it is not clear how significant these impacts are at the population or ecosystem level. Impacts could either be direct, for instance in relation to some species of bats where light could significantly reduce their foraging area, or indirect, such as those cases where increased light levels at night allow day-time predators to extend their range to include night-time species. **We recommend 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 the effects of both existing and proposed lighting technologies on biological systems (4.25)**.

6.11 There are around 7.4 million road lights in the United Kingdom of which about 2.32 million are nearly 30 years old. Given that their design lifespan was 25 years, we face a substantial programme of replacement. This provides an opportunity, but one which needs to be exercised carefully in order to ensure that the benefits of new technology are captured without creating adverse consequences. **We recommend that the authorities responsible should carry out replacement programmes for road lighting in a way that explicitly minimises the negative impacts of stray light (5.5)**.

6.12 We recognise that lighting of public space has benefits and is perceived by many in society to have advantages which outweigh the negative impacts. But it is equally clear that improved technology can deliver those benefits while minimising unwanted side-effects. The technologies to do this already exist. **We recommend that lighting standards should require the provision of**

light at an intensity no greater than the minimum necessary to deliver the intended benefits and that the light should be directed at only those areas which are intended to be illuminated (5.6).

6.13 It seems very probable that the impacts of much artificial road lighting have fortuitously been minimised by the fact that the majority of lighting used to date has a very restricted spectrum at around 590 nm, the wavelength of orange light. This may have led to a smaller impact on the natural environment because receptor systems in some organisms happen not to detect that particular wavelength. The use of more modern technologies with a much broader wavelength spectrum could lead to significant changes in the impact of artificial light on natural systems. **We recommend that, before replacement road lights using broader wavelength technologies are widely introduced, particularly in rural areas, the Department for Environment, Food and Rural Affairs (Defra) and the Department for Transport should commission a systematic investigation of their impact on natural systems (5.10)**.

6.14 Artificial light should only be used at times when the benefits are needed. **We recommend that local authorities and others responsible for the provision of road lighting should pay careful attention to the outcome of the trials currently underway to examine the impact of reducing or turning off lighting in quieter areas where there is unlikely to be any significant use of the roads by pedestrians or road traffic; and that they should consider what lessons they can draw from them to help minimise negative impacts (5.14)**.

6.15 Finally, at present, none of these issues appear to have any natural locus within Government, with different departments considering different aspects and some key departments such as transport explicitly not considering impacts on the natural environment. Light has been the poor relation for too long; Government needs to accept the fact that light, like noise and chemicals, in the wrong quantity, in the wrong place and at the wrong time can cause problems and must be addressed explicitly in policy development. **We recommend that Defra and equivalent bodies elsewhere in the UK take the lead in co-ordinating interdepartmental activity on artificial light**.

6.16 In closing, we emphasise that while research into and monitoring of the biological effects of light pollution on human wellbeing and natural ecosystems are desirable, this may not be an issue which requires greater scientific confidence to justify corrective action. We are convinced of the plausibility of the argument that light in the wrong place and at the wrong time can disturb the lives of organisms, potentially with adverse ecological effects. Considered alongside the indisputable loss of the visual amenity of the night sky, the Royal Commission considers that there is sufficient reason to take action to reduce light pollution without waiting for the results of scientific inquiry into biological impacts, which should focus on research that could inform the design of new lighting technologies and installation practices.

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Appendix A

Background to the Commission's Report on Artificial Light in the Environment

Rationale for and Scope of the Study

A1 This topic was selected in recognition of the increasingly pervasive nature of artificial light, and hence of its effects. Natural light plays a fundamental role in the biology of organisms. Artificial light has the potential to disrupt the biology of many species. The study follows on from the Commission's March 2007 report on the *Urban Environment* where light was identified as an important issue in determining local environmental quality.

A2 A major review of light pollution and astronomy was published by the House of Commons Select Committee on Science and Technology in 2003. Our study did not therefore consider the effects of artificial light on astronomy. It is however fitting that 2009, the year of publication of the Commission's report, is the International Year of Astronomy.

Announcement of the Study and Invitation to Submit Evidence

A3 The Commission launched the call for information and evidence, in order to help define the scope of the report, on 14th December 2007 with a closing date of 18th January 2008. The invitation was sent to a number of organisations and was also placed on the Commission's website. The subject of environmental man-made light includes several major themes, each of which prompted a series of example questions to which consultees were invited to respond:

Aesthetic effects

- Artificial light can enhance monuments or locales in different ways (for example, York Minster and Piccadilly Circus). Is it possible to identify the circumstances where man-made light provides an enhanced aesthetic?
- Conversely, are there cases where artificial lighting is aesthetically damaging?

Effects on the natural world

Artificial light affects a wide diversity of species in many different ways both individually and perhaps at the population level.

- What are the effects on flora and fauna?

Human health effects

Various health effects have been ascribed to man-made lighting. For example, it has been suggested that one possible consequence of artificially extended day length is the suppression of melatonin production which might in turn lead to an enhanced risk of various forms of cancer.

- Is there evidence for effects on human health of environmental artificial light (as opposed to indoor illumination)?
- If there is, what are the effects, and what are their likely impacts?

Benefits including reduced crime and accidents

Well-sited street lighting can prevent both crime and accidents. In contrast, poorly planned facilities can exacerbate both these problems.

- What is the relationship between lighting and crime/accidents?

Energy use

Figures from the Department for Business, Enterprise and Regulatory Reform (now the Department for Business, Innovation and Skills) suggest that approximately 20% of the total final consumption of electricity in the UK in 2006 was for lighting (including interior lighting). Poorly designed lighting can lead to significant amounts of energy being wasted, whilst new technologies offer opportunities for energy savings.

- Is energy currently being wasted through artificial outdoor lighting and if so how much?
- Are there significant energy savings to be made from implementing new technology or by controlling lights in a particular way (e.g. movement activated lights)

A4 This report was drafted between February 2008 and October 2009. The organisations or individuals who provided information or otherwise gave assistance are listed below. In some case, indicated by an asterisk *, meetings were held with Commission Members so that particular issues could be discussed.

Government Departments

Communities and Local Government
Department for Culture, Media and Sport
Department for Environment, Food and Rural Affairs
Department for Transport
Department of Environment, Northern Ireland
The Home Office
The Scottish Government
Welsh Assembly Government

Other Organisations

Abacus Lighting
Bat Conservation Trust
British Astronomical Association's Campaign for Dark Skies
Buglife
British Trust for Ornithology
Butterfly Conservation
CSS (formerly the County Surveyors' Society)
Chartered Institute of Environmental Health
Campaign for National Parks

Cresswell Associates (for the Institute of Ecology and Environmental Management)
Directorate General, Enterprise and Industry, European Commission
Environmental Protection UK
Environmental Change Institute, Oxford University
EU NumeLiTe Consortium
Forestry Commission
General Lighthouse Authorities
Happold Lighting, Buro Happold Ltd
Health Council of the Netherlands
Health Protection Agency
Highways Agency
Institute of Ecology and Environmental Management
Institute of Photonics, University of Strathclyde, Glasgow
International Commission on Illumination (CIE)
Lighting Industry Federation Ltd
The Lighting Research Center, US
London Assembly
Mouchel Ltd
Natural Environment Research Council
Parliamentary Office of Science and Technology
Philips lighting
Planning Officers Society
Royal Entomological Society
Royal Society for the Prevention of Accidents
Royal Society for the Protection of Birds
Royal Society of Edinburgh
Royal Town Planning Institute
Scottish Environment Protection Agency
Scottish Natural Heritage
South Lanarkshire Council
TFC Group
The Urban Wildlands Group

Individuals

Peter Boyce
Alastair Burn
Ray Cassar, Usk Astronomical Society
Dr David Chesmore, Senior Lecturer, Department of Electronics, University of York
Pierantonio Cinzano
Barry Clark, Astronomical Society of Victoria, Australia
Graham Cliff, LightPollution.org.uk
Dave Coatham
Karen Imparato Cotton, Bird Collisions Campaign Manager, American Bird Conservancy
Steve Dagnall, AEA Technology
Matthew Eagles
Professor David Farrington, Professor of Psychological Criminology, University of Cambridge
Steve Fotios, Sheffield University
Alison Fure
Carl Gardner*, Institution of Lighting Engineers

Andreas Hänel, Museum am Schölerberg, Osnabrück, Germany
Rita Harrold, Illuminating Engineering Society of North America
Professor Denis Henshaw, Professor of Physics , Bristol University
Jenik Hollan
John Hopkins, Natural England
Keith Scott Jamieson, Centre for Environmental Policy, Imperial College
Dr Sönke Johnsen, Duke University, North Carolina, US
Professor Michael Kalloniatis, Auckland University, New Zealand
John S. Lewis
Travis Longcore, Urban Wildlands Group
Robert Lucas, Manchester University
Dr Paul Marchant, Leeds Metropolitan University
Francesca Morrison, Richmond-upon-Thames Borough Council
Ilga Nielsen
Alan Outen, formerly of Hertfordshire Biological Records Centre
Steven Owens, UK Co-ordinator, International Year of Astronomy 2009
Ian Panton
Nigel Parry, Institution of Lighting Engineers
Professor Peter J. Pearson, Professor of Energy and Environmental Studies, Imperial College
Dr Alex Pollard*, University of Cardiff
Alison Quant*, Hampshire County Council
Nigel Pollard, NEP lighting Consultancy
Alex Rann, Natural England
Peter Raynham, The Bartlett School of Graduate Studies, University College London
Helen Read, British Myriapod Isopod Group
John Rooymans, Lemnis Lighting Company
Professor Yvonne Rydin, University College London
Wim Schmidt, Sotto le stelle (a lighting company), the Netherlands
Duco Schreuder, the Netherlands
Alistair Scott
Dr Alan Stewart
Hans Tetteroo, Shell
Oliver Tickell
Simon Tilleard, London Climate Change Agency
Reginald R. Wilson, the International Dark-Sky Association
Councillor Sylvia Wright, Essington, South Staffordshire

Commissioned work

A5 The Commission is grateful to Martin Morgan-Taylor, Principal Lecturer in Law at De Montfort University, Leicester, for providing information on security lighting, and UK and international legislation.

Appendix B

Members of the Commission

Sir John Lawton (Chairman) CBE

- President, Council of the British Ecological Society, 2005-2007
- Chief Executive, Natural Environment Research Council, 1999-2005
- Director (and founder), Natural Environment Research Council Centre for Population Biology at Imperial College, Silwood Park, 1989-1999
- Member, Royal Commission on Environmental Pollution, 1996-1999
- Lecturer, Senior Lecturer, Reader, Professor of Biology, University of York, 1972-1989
- Demonstrator in Animal Ecology, Department of Zoology, University of Oxford, 1968-1971
- Chairman, Royal Society for the Protection of Birds, 1993-1998
- Vice-President, Royal Society for the Protection of Birds, 1999-
- Past Vice-President, British Trust for Ornithology, 1999-2007
- Trustee, WWF-UK, 2002-2008; Fellow of WWF-UK, 2008-
- Foreign Associate, US National Academy of Sciences, 2008-
- Foreign Honorary Member, American Academy of Arts and Sciences, 2008-

Professor Michael Depledge

- Professor of Environment and Human Health, Peninsula Medical School, Universities of Exeter and Plymouth, 2006-
- Keeley Visiting Fellow, Wadham College, University of Oxford, 2006-
- Honorary Visiting Professor, Department of Zoology, University of Oxford
- Senior Science Advisor, Plymouth Marine Laboratory, 2005-2007
- Chief Scientific Advisor, Environment Agency of England and Wales, 2002-2006
- Vice-Chairman, Science Advisory Committee, European Commission, DG-Research, 2006-
- Former Board Member, Natural England, 2006-2009
- Council Member, Natural Environment Research Council, 2003-2006
- Honorary Professor, School of Earth Sciences and Engineering, Imperial College, 2002-
- Honorary Visiting Scientist, School of Public Health, Harvard University, USA, 2000-2003

Dr Ian Graham-Bryce CBE

- Principal Emeritus, University of Dundee
- Chairman, East Malling Trust for Horticultural Research
- Principal and Vice-Chancellor, University of Dundee, 1994-2000

- Convener, Committee of Scottish Higher Education Principals, 1998-2000
- President, Scottish Association for Marine Science, 2000-2004; and currently Honorary Vice-President
- President, British Crop Protection Council, 1996-2000
- Council Member, Natural Environment Research Council, 1989-1996
- Head, Environmental Affairs Division, Shell International, 1986-1994
- President, Association of Applied Biologists, 1988-1989
- Director, East Malling Research Station, 1979-1986
- President, Society of Chemical Industry, 1982-1984

Professor Jeffrey Jowell QC

- Professor of Law, University College London
- UK's Member on the Council of Europe's Commission for Democracy Through Law ("The Venice Commission")
- Chair, British Waterways Ombudsman Committee
- Former non-executive Director of the Office of Rail Regulation
- Practising barrister

Professor Maria Lee

- Professor of Law, University College London
- Member of the London Sustainable Development Commission
- Member of the academic panel of the barristers' chambers Francis Taylor Buildings

Professor Peter Liss CBE

- Professor of Environmental Sciences, University of East Anglia, 1985-
- Chair, Scientific Committee of the International Geosphere – Biosphere Programme (IGBP), 1993-1997
- Chair, International Scientific Steering Committee for Surface Ocean – Lower Atmosphere Study (SOLAS), 2002-2007
- Council Member, Natural Environment Research Council, 1990-1995
- Independent Member, Inter-Agency Committee on Marine Science and Technology, 2000-2008
- Chair, Royal Society Global Environmental Research Committee, 2007-
- Council Member, Marine Biological Association of the UK
- Chair, Higher Education Funding Council's Research Assessment Exercise Panel in Earth and Environmental Sciences, 2001
- Guest Professor, Ocean University of Qingdao, China

- President, Challenger Society for Marine Science, 2006-2008
- Chair, European Research Council Advanced Grants Panel in Earth System Science, 2008-

Professor Peter Matthews obe

- Board Member, Port of London Authority, 2006-
- Chair, Northern Ireland Authority for Energy Regulation, 2006-2007
- Chair, Northern Ireland Authority for Utility Regulation, 2007-
- Board of the Environment Agency and Chair of its Audit Committee, 2000-2006
- Former Deputy Managing Director for Anglian Water International
- Past President of the European Water Association, Chartered Institution of Water and Environmental Management and Past Chair of the Society for the Environment
- Served on the Board of Anglia Ruskin University

Professor Judith Petts

- Pro-Vice-Chancellor (Research and Knowledge Transfer), University of Birmingham, 2008-
- Head, School of Geography, Earth and Environmental Sciences, University of Birmingham, 2002-2007
- Chair of Environmental Risk Management, University of Birmingham, 1999-
- Member, Engineering and Physical Sciences Research Council Societal Issues Panel, 2007
- Council Member, National Environment Research Council, 2000-2006
- Member, Environmental Advisory Board, Veolia Environmental, 1999-
- Member, Royal Society Science in Society Group, 2005-2008
- Member, Higher Education Funding Council's Research Assessment Exercise Panel in Geography and Environmental Studies, 2005-
- Member, Office of Science and Innovation Sciencewise Strategy Group, 2004-2008
- Member, Environmental Advisory Group, Onyx Environmental Plc, 1999-
- Former Specialist Advisor House of Commons Environment, Transport and Regional Affairs Committee and House of Lords Sub-Committee
- Member, Council of the Institute of Environmental Assessment, 1990-2000

Professor Steve Rayner

- Director, James Martin Institute for Science and Civilization, Professor of Science and Civilization, Saïd Business School, University of Oxford, and Professorial Fellow of Keble College
- Professor of Environment and Public Affairs, Columbia University, USA, 1999-2003
- Chief Scientist, Pacific Northwest National Laboratory, USA, 1996-1999
- Director, Economic and Social Research Council Science in Society Programme, 2001-2007
- Member, Intergovernmental Panel on Climate Change
- Past President of the Sociology and Social Policy Section of the British Association

Dr Michael Roberts CBE

- Ministerial appointee to the Veterinary Residues Committee and a Non-Executive Director of the Defra-sponsored National Non-Food Crops Centre (NNFCC)
- Chief Executive of the Department for Environment for Food and Rural Affairs (Defra) Central Science Laboratory, 2001-2008
- Former Director of the Natural Environment Research Council's (NERC) Institute of Terrestrial Ecology (ITE)
- Former Director of NERC's Centre for Ecology and Hydrology (CEH)
- Member of the Yorkshire and Humber Science and Innovation Council, 2005-2008

Professor Joanne Scott

- Professor of European Law, and Vice-Dean for International Links, at the Faculty of Laws, University College London
- Member of the editorial boards of the Journal of Environmental Law and the Journal of International Economic Law
- Visiting Professor at Columbia Law School
- Former Visiting Professor at Harvard and Georgetown Law Schools

Professor Lynda Warren

- Emeritus Professor of Environmental Law, University of Aberystwyth
- Deputy Chair, Joint Nature Conservation Committee
- Member, Committee on Radioactive Waste Management
- Board Member, British Geological Survey
- Board Member, Environment Agency, 2000-2006
- Chair, Wales Coastal and Maritime Partnership
- Chair, Salmon and Freshwater Fisheries Review, 1998-2000
- Former Member, Radioactive Waste Management Advisory Committee, 1994-2003
- Former Member, Countryside Council for Wales, 1991-2003
- Trustee, Field Studies Council
- Trustee, Wildlife Trust of South and West Wales
- Former Trustee, WWF-UK

Professor Gordon MacKerron (Economic Advisor to the Commission)

- Currently Director, Sussex Energy Group, SPRU (Science and Technology Policy Research), University of Sussex
- Chair of the Committee on Radioactive Waste Management, 2003-

- From June to December 2001: secondment to the PIU, Cabinet Office, as Deputy leader of the UK Government's Energy Review team
- Chair, Energy Panel, DTI/OST Technology Foresight Programme, 1995-1998

Members of the Commission involved in the report but no longer serving as Commissioners

Professor Janet Sprent
Professor Susan Owens
Professor Stephen Holgate
Professor Paul Ekins
Mr John Speirs
Professor Nick Cumpsty

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