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Potential ecological impacts of ground-mounted photovoltaic solar panels

An introduction and literature review

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1 Introduction

1.1 As the number of solar parks in the UK increases, there is growing interest in the interaction of wildlife with ground-mounted photovoltaic (PV) solar panels. To date, a relatively limited number of research papers have formed the basis for considerable discussion on the subject, and in some cases these have informed guidance relating to PV solar parks in the UK.

1.2 The aim of this document is to identify potential ecological issues of solar PV (as relevant to the UK), and identify current gaps in our knowledge. This review is an update to the original text published in January 2014 (Taylor *et al.*). Readily available papers on interactions between PV solar panels and ecological features including invertebrates, birds and bats have been collated in order to critically appraise the evidence base. Where apparent, conclusions are drawn on effects on local biodiversity.

Background

Solar PV in the UK

1.3 Solar PV is an important source of renewable energy in the UK, and one which is key to maintaining progress in the gradual transition from fossil fuels to other sources of power. In 2018 the Committee on Climate Change (CCC) issued a report to Parliament, which stated that solar photovoltaic systems had reached an installed capacity of 12.8 GW and accounted for 4% of UK energy generation in 2017. The report also stated that the expected installed capacity in 2020 would reach 13 GW.

1.4 This current and predicted capacity falls below the targets set by Government in May 2012. At that time the Government, announcing their updated renewable energy road map stated that up to 22GW of solar energy would be an achievable ambition by 2020 (DECC, 2012). The more modest growth in solar than anticipated in 2012 is likely to be due to the ending of subsidies for PV projects (Stoker, 2019).

1.5 There is likely to be a renaissance in the solar market in 2019, however. The Solar Trade Association said in late 2018 "Solar could soon be the cheapest form of electricity generation in the UK. A significant solar pipeline is widely expected to restart in the UK in 2019, assisted in the short term by developer needs to build out previously stalled projects and by a global module surplus. In the medium to longer term, the market outlook is supported by improved manufacturing efficiencies, higher gas price projections and the UK's growing need for clean generation capacity."

Solar Technologies in the UK

1.6 Solar energy can be utilised in a number of ways, including:

- Solar thermal systems – using solar energy to heat water or air which is then used to heat buildings.
- Concentrated solar systems – concentrating sunlight to superheat a fluid, which is then used to boil water, which in turn runs a generator and produces electricity.
- Photovoltaic (PV) systems – solar cells convert sunlight directly into electricity, by harnessing the current produced by electrons being knocked off the atoms of photosensitive materials such as Selenium.

1.7 In the UK the most common type of solar installations are PV systems, sometimes combined with thermal. A report released by the Committee on Climate Change in 2011 stated that concentrated solar systems are not suitable for use in the UK, as the technology requires intense sunlight and little cloud.

Assessing Solar Impacts on Biodiversity

1.8 The scope of any ecological assessment will depend on the type of development proposed and the method of construction. There are different ways of installing solar panels, and the ecological impacts of these vary. In the UK, photovoltaic/thermal solar panels can be installed in several forms (Li *et al*. 2013):

- Domestic – principally fixed on the roofs of domestic buildings. PV installations of this type can be as large as 4kW capacity.
- Building mounted – PV systems on commercial/non-residential typically range from 4kW to 100kW capacity, although larger buildings can accommodate larger arrays up to 5MW.
- Building Integrated – building materials that have a PV component built into them, such as roofing tiles.
- Ground-mounted – these generally supply power at a grid distribution level. They often span over a large area, with the land required for a 1MW fixed tilt array with security fencing currently being approximately 2.4 ha.

1.9 This review discusses some ecological considerations associated with the interaction of wildlife with ground-mounted PV panels. Ground-mounted PV panels have the potential to cause the highest impact on nature as they are installed on land which may have at least some value to wildlife. The other forms of installation are all reliant on built infrastructure, and are likely to be limited in their ecological impacts for this reason (Dale *et al*. 2011).

1.10 The potential impact of ground-mounted PV panels on ecological features has been the subject of media interest previously. Despite the occasional hiatus with regard to the findings of some studies and the production of industry guidance, there seems to be little empirical data on the subject. At times, it would also appear that the limited available research available has been stretched to address gaps in knowledge.

1.11 This article critically reviews the studies that have received the greatest amount of interest; these are principally concerned with aquatic invertebrates, birds, bats and effects on local biodiversity.

2 Research Review

Aquatic Invertebrates

Evidence of Invertebrate Attraction to PV Panels

2.1 At present there is limited evidence regarding the possible adverse effects that the presence of PV solar panels in the countryside could have on aquatic invertebrate populations. In 2010, Horvath *et al*. released a paper about the possible attractiveness of solar panels to aquatic invertebrates, from experiments conducted next to a river (from which the invertebrates emerged) in the Hungarian Duna-Ipoly National Park. The authors found that the homogenous black panels used in that particular study reflected horizontally polarized light at a higher percentage than water. It was postulated that the studied panels may therefore appear more attractive to aquatic insects than water bodies. As polarized light appears to be one of the most important sensory cues used by aquatic invertebrates when identifying water bodies, which may be used as egg-laying sites, artificial sources of highly polarised light could potentially impact aquatic invertebrate populations by inducing egg-laying in locations where survival is unlikely (Schwind, 1991; Horvath and Varju, 1997; Heinze, 2014).

2.2 In the paper by Horvath *et al*. (2010) experiments were carried out to test the attractiveness of solar panels to mayflies, caddis flies, dolichopodids, and tabanids. The experiment found some evidence that mayflies (Ephemeroptera), stoneflies (Trichoptera), dolichopodid dipterans, and tabanid flies (Tabanidae) were attracted to solar panels and did exhibit egg-laying behaviour above solar panels more often than above surfaces with lower degrees of polarisation. Specific counts of eggs on solar panels were not undertaken during this experiment and it was assumed by the authors of the paper that eggs were laid following observation of egg-laying behaviours.

2.3 The research investigated the attractiveness of panels that reflect highly polarised light rather than their ecological impacts. The results of the research led the authors to the conclusion that some consideration would be appropriate in the siting and design of solar panels where important populations of aquatic invertebrates are likely to be present locally. This recommendation was quoted in a European Commission news alert (European Commission, 2011) and in a briefing note released by the RSPB (RSPB, 2011).

2.4 Farkas *et al.* (2016) looked at sensitivity to polarised light in two mayfly species, *Ephoron virgo* and *Caenis robusta*[1], at three sites in Hungary. These species were chosen as they belong to different families and occur in different habitat types; the larvae of *E. virgo* develop only in rivers, while *C. robusta* larvae occur in streams, still waters and rivers. Similarly to the studies mentioned above, horizontally polarised light was much more attractive than vertically polarised light or unpolarised light. A key observation during this study was that the shadow and reflection of riparian vegetation at the edges of water bodies reflect weak, vertically polarised light; flying mayflies use this stimulus to avoid the edges and remain continuously above the water surface. If the mayflies were not to use this stimulus, they might lay their eggs on the muddy substrate at the edge of the waterbody, which is not suitable for the development of their larvae.

2.5 A study in Budapest by Egri *et al.* (2016) investigated the sensitivity of the springtail *Podura aquatica* to polarised light. The study found that horizontally polarised light was most attractive to *P. aquatica* and vertically polarised light least attractive. Unpolarised stimulus elicited moderate attraction. A key finding of the study was that horizontally polarised light was more attractive than unpolarised light, even when the polarised stimulus was ten times dimmer. This behaviour in other Collembola species has been studied (Shaller, 1972; Salmon & Ponge, 1998; Dromph, 2003; Fox *et al.* 2007), and the results show that only species living on water surfaces/plants are attracted to horizontally polarised light. The majority of springtails are found in soil, therefore horizontally polarised light indicates inappropriate habitat and is avoided (Egri *et al.* 2016). The life cycle of *P. aquatica* is strongly water-dependent, so attraction to horizontally polarized light reflected from solar panels could result in significant population level effects if they are chosen over water-bodies.

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[1] *C. robusta* are also found in the UK, with the majority of records from the South East of England (The Riverfly Partnership http://www.riverflies.org/caenis-robusta-anglers-curse).

2.6 The potential attraction of invertebrates to highly polarised reflected light occurs with many man-made surfaces, such as, asphalt roads, parked cars and glass buildings (Kriska *et al.,* 1998; Wildermuth, 1998; Kriska *et al.,* 2006; Kriska *et al.*, 2008). It would therefore be difficult in some locations, without very careful experimental design, to determine if population changes were due to polarised light from a solar park or other man-made features. Furthermore, in order to assess the impacts of a solar park, other variables affecting aquatic invertebrates would also need to be monitored and taken into account, such as the water quality of existing water bodies, which can have substantial effects on invertebrate species populations and diversity (Sundermann *et al.,* 2013).

2.7 It is unclear whether impact susceptibility varies between still water and fast flowing water species although it could be hypothesised that the likelihood of an ecological effect occurring (if one does occur), would be greater in close proximity to still and slow-moving water habitat as the solar array may superficially appear to be a slow moving or standing water-body as oppose to a riverine habitat.

Reducing Invertebrate Attraction to Solar PV Panels

2.8 Horvath *et al.* (2010) noted that for polarising surfaces that were broken by a white border or grid, the occurrence of egg laying behaviours was reduced. The study found that "*The highly and horizontally polarising surfaces that had non-polarising, white cell borders were 10- to 26-fold less attractive to insects than the same panels without white partitions*". Moreover, the polarisation of light by these broken surfaces appeared from the results to be less than water. As most existing and proposed solar parks in the UK employ grid-formed panels with anti-reflective films it is likely that the reflection of polarised light from these surfaces is already substantially reduced.

2.9 It has been suggested that anti-reflective coatings (ARCs) reduce the amount of polarised light pollution (PLP) that they reflect, and thereby their attractiveness to aquatic insects. Szaz *et al.* (2016), working in Hungary, investigated the attractiveness of panels with ARCs compared to uncoated panels. The responses of populations of mayflies (Ephemeroptera), horseflies (Tabanidae) and non-biting midges (Chironomidae) were considered. The study used artificial test surfaces which mimicked the optical properties of coated and uncoated solar panels. These surfaces were tested for their polarisation properties from all angles of view and in sunny and overcast conditions. Coated and sunlit solar panels were strong sources of horizontally polarised light only when the sun was ahead and behind, while uncoated panels exhibited high levels of horizontally polarised light from all angles. Under overcast skies, both the coated and uncoated panels reflected moderate levels of horizontally-polarised light.

2.10 The results revealed that horseflies showed a reduced attraction to coated panels, there was no difference in attractiveness of coated and uncoated panels to midges, and mayflies actually showed a preference for coated panels under overcast skies. These results led the authors to conclude that ARCs are most likely to benefit aquatic insects under sunny skies, for example in arid desert conditions, and when used in conjunction with other methods, such as white non-polarised gridding. The authors also warned that using ARC panels could cause adverse effects under overcast conditions for certain species. The authors suggest that, until more research on a variety of species has been carried out, a more sensible approach would be the strategic deployment of solar panels away from water-bodies in temperate regions.

Evidence of Invertebrate Habitat Fragmentation

2.11 Research by Ewers *et al.* (2006) indicated that species responses to habitat loss / fragmentation are mediated by their life history traits, for example sedentary and specialist species are more affected by habitat fragmentation than more mobile and generalist species. Given that butterflies are widely acknowledged to be sensitive to habitat fragmentation,

2.12 Guiller *et al.* (2017) tested this theory by studying the impacts of Utility-Scale Solar Energy (USSE) on butterfly community (Rhopalocera) movement in Mediterranean agro-ecosystems. The aim of the study was to provide developers with a decision-support tool to mitigate the environmental impacts of solar energy. The authors used resistance-based algorithms to model landscape connectivity, and looked at butterfly communities within pair-wise transects in an 18 Ha solar plant in France. The results suggested that both mobile and sedentary species coped with changes in landscape structure.

Summary

2.13 All of the studies on aquatic invertebrates that are referred to in this review were based in Hungary. However, the species / species groups that were studied are also present in the UK and of relevance in a UK context.

2.14 The Hungarian research has showed that aquatic invertebrates are attracted to horizontally polarised light (as reflected from both water bodies and solar panels), and use this as stimulus to induce egg-laying. White gridding and anti-reflective coatings were found to decrease the attraction of some invertebrate species to solar panels. Anti-reflective coatings were not found to deter all invertebrate species, namely mayflies and midges, under all conditions.

2.15 It follows that it is important to site solar farms away from important / sensitive aquatic invertebrate populations.

2.16 No studies showing landscape-scale impacts on invertebrates relevant to the UK have been located as a result of this review.

Birds

Effects of Mirrored Light on Birds

2.17 One of the most high profile issues regarding birds and solar parks in recent years has been the effect of light reflected from mirrored heliostats[2], which can singe a bird's wings. Most of the articles available draw upon one document, by McCrary *et al.* (1986) which reports on bird mortality at the Solar One facility in the Mojave Desert, California. This is a concentrated solar system, which uses mirrors to concentrate sunlight onto a central tower containing a fluid which is heated and subsequently used to heat water which powers a turbine. This type of solar park is not present in the UK.

2.18 McCrary *et al.* (1986) found that during approximately 40 weeks of survey, 70 bird fatalities were recorded as a result of collision with solar park infrastructure or burning at standby points. The most frequent form of avian mortality was due to collision (81%), the majority of these collisions being with the mirrored heliostat panels. This might be expected, as birds have commonly been recorded colliding with other highly reflective infrastructure such as windows and buildings (Klem, 1990; Dunn, 1993; Erickson *et al*., 2001). McCrary *et al.* (1986) also reports that there were thirteen instances of burning recorded in the heliostat standby points (limited temporary, areas of the sky on which the reflection from the heliostats are focussed during maintenance, testing, etc.) apparently due to birds flying through the heated air. The study concludes that the low number of mortalities from burning is due to the infrequent use of the standby points, and their varying intensity when being used. From the results shown by McCrary *et al.* it is reasonable to assume that by conducting maintenance at times of low light intensity, these incidents could be avoided. Evidence from grey literature (Upton, 2014) also suggests that focusing no more than four mirrors onto any one point during standby can significantly reduce the number of burning mortalities.

2.19 To reiterate, the study applies to large concentrated solar arrays, which are unlikely to be used in the UK. The burning observed cannot occur at photovoltaic solar parks as concentrating reflected light is not part of the design. PV solar panels are designed to absorb as much light as possible, and most are coated with an anti-reflective film for this reason. There has been research to better develop anti-reflective films that will increase the efficacy of solar panels (Achtelik *et al.,* 2013; Li *et al*., 2013). In addition, the grid-like panel design means that any reflection could be fragmented, a principle applied to windows in order to reduce collision events (Klem, 2009; Sheppard, 2011).

Bird Collision with Solar PV Panels

2.20 The solar parks to which the papers below refer are extremely large projects, built in open savanna or desert habitat. It is difficult to directly compare the impacts of such solar parks with those existing or proposed in the UK due to significant differences in scale and habitat. However, there is some evidence that bird collisions with PV solar parks occur, therefore these studies have been included for completeness.

2.21 Media and grey literature reports indicate that water birds may confuse large solar arrays with water bodies; and of collisions with solar panels at large-scale PV solar parks. A study by Bernath *et al*. (2001) observed birds such as black kite and swallow attempting to drink from plastic sheets which led the authors to the hypothesis that these birds were attracted to sources of polarised light. It has been suggested that birds that drink on the wing, such as swallows, could be at risk of collision with solar panels (which also reflect polarised light), while there is unlikely to be a risk to birds that drink from a perched position (Harrison *et al.* 2017).

2.22 Very few relevant research papers were found during the data search for this review that substantiated these contentions. Furthermore, no studies from the UK or Europe were found.

2.23 Dwyer *et al.* (2018) considered the potential effects of renewable energy, including solar, on raptors. The authors make the point that effects such as direct mortality, habitat loss, avoidance and displacements rarely occur in isolation. The effects are usually additive, co-occurring with one another and other natural or anthropogenic causes of mortality. Some of their observations are based on research carried out by Kagan *et al.* (2014), which summarises data on bird mortality at three different solar energy facilities (one PV facility, one trough system with parabolic mirrors and

[2] An instrument consisting of a mirror moved by clockwork, for reflecting the sun's rays to a fixed point. During times when this energy is not needed, during maintenance for example, sunlight is reflected towards 'standby points', which are predetermined areas of open sky.

one solar flux tower) in southern California, USA. All three facilities experienced avian mortalities. Trauma was the leading cause of death at all three facilities, and the solar flux tower also included singeing injuries. Predation was also a cause of fatality, mostly at the PV facility, which in many cases was associated with stranding or non-fatal impact trauma with panels which leaves birds vulnerable to predation. During the study, the remains of 61 birds from 33 different species of varying size and flight / feeding behaviour were recovered at the PV facility. Superficially, this seems a high number of fatalities when considered in a UK context, however the PV facility (Desert Sunlight Solar Farm) is approximately 1,420 Ha in size (based on a review of aerial imagery), and located on a major bird migration route in desert habitat, so the number needs to be considered in this context.

2.24 Visser *et al.* (2019) investigated the effect of South Africa's largest PV facility (96 MW, 180 Ha) on birds. Bird species richness and density was found to be lower within the PV facility than the surrounding land. During 3 months of mortality surveys[3], eight bird carcasses of six different species[4] were found. Most bird fatalities were inferred from feather spots, with no fresh carcasses or evidence of damaged / imprinted solar panels. The authors comment that the causes of death for these birds were impossible to infer. Seven birds were found under solar panels, indicating that they either did not collide with the surface, or if they did they were moved by scavengers after collision. The remaining bird was found at the fence line. The authors extrapolated the number of carcasses found to give a mortality rate for the site of 435 birds per year, although they noted this number was likely to be a conservative estimate, given that detection probabilities were based on finding intact birds and decreased for older carcasses. Visser *et al.* (2019) recommend using Before-After-Control-Impact (BACI) study designs to assess how PV farms impact bird populations during both the pre-construction and operational phases of solar parks.

2.25 Walston *et al.* (2016) estimate that utility-scale solar energy-related avian mortality is considerably lower than mortality from other anthropogenic causes, such as road mortality, building collisions and wind / fossil fuel development. The study, based in California, combined bird mortality data from two concentrated solar facilities and one solar PV facility and demonstrates that bird fatalities can occur as a direct result of PV solar facilities, albeit in lower numbers than at concentrated solar facilities. The authors acknowledge the need for more research to better understand the risk of solar facilities to bird populations.

Bird Displacement by Solar PV Panels

2.26 Dwyer *et al.* (2018) also comment on the indirect effects of solar energy, including habitat loss, displacement and avoidance. There are a number of accounts of birds nesting on the structures that support solar panels including personal observations of such nesting by Hernandez *et al*. (2014). It is also reasonable to hypothesize that some ground-nesting birds would be attracted to solar parks due to the availability of a safe nesting area, as the security fencing around the solar parks may deter ground predators (Smith *et al.,* 2010). However, during a comparative study of 11 UK PV solar farms, Montag *et al.* (2016) found that skylark tended to use undeveloped control plots more than the solar farms. Montag *et al.* (2016) are of the view that ground-nesting birds need an unbroken line of sight and would therefore avoid nesting at solar farms.

2.27 DeVault *et al.* (2014) demonstrated that solar PV facilities could potentially alter the structure of bird communities. At five airport locations across the US, the diversity of species using PV array sites was lower than in adjacent grasslands (37 and 46 species, respectively). In contrast, bird densities at those PV array sites were more than twice those of adjacent grasslands. DeVault *et al.* (2014) suggest that shade and the provision of perches increased bird use of the PV array sites. However, the results were species-specific, with some small passerines more abundant at PV facilities compared with adjacent grasslands, but corvids and raptors less abundant. Raptor abundance was found to be higher pre-construction compared with post-construction at one site, suggesting avoidance of the facility. Solar facilities can often result in surrounding bare earth which

[3] The solar field divided into 3 sample areas. One set of solar arrays (representing 9-10% of each sample area) was searched every 4 days for the first 6 weeks and then every 7 days thereafter. The second set (8-10% of the total area) was surveyed every 14 days. Bird mortalities arising from other infrastructure within the solar field were also monitored e.g. the substation and evaporation pond (every 4 days), perimeter fence (divided into 3 sections – 55% checked every 4 days, 9% every 7 days and 36% every 14 days). Searcher efficiency trails and carcass persistence tests were also carried out but it is unclear how often.

[4] These species were fiscal flycatcher, red-eyed bulbul, Eastern clapper lark, orange river-francolin, speckled pigeon and crowned lapwing.

is unsuitable for hunting or nesting by raptors. Raptors may also avoid habitats in and around solar facilities as a result of increased human activity and habitat alteration (DeVault *et al.* 2014). This study gave no reference to the habitat management of the PV sites, indicating only that the adjacent grasslands had taller vegetation than the PV sites and were mowed at least once annually. It is therefore not possible to determine whether habitat alteration due to solar farm development was likely to have resulted in displacement effects.

Stakeholder Position

2.28 There does not appear to be any hard evidence to suggest that solar farms are likely to cause the displacement of bird populations in the UK. An RSPB policy briefing on solar (RSPB, 2014) concluded: "*If correctly sited (so as not to impact on sensitive species) and with appropriate land/habitat management and other mitigation measure employed, the deployment of solar might be of benefit to wildlife and the wider countryside. There is little scientific evidence for fatality risks to birds associated with solar PV arrays. However, birds can strike any fixed object so this lack of evidence might reflect absence of monitoring effort, rather than absence of collision risk. Structurally the risk is broadly similar to many other man-made features, though PV arrays may be more likely to be developed in sensitive locations. The RSPB would like to see investment in monitoring and developing our understanding of the collisions risks associated with solar PV*".

2.29 Birdlife Europe (2011) suggest that there could be significant negative impacts to bird species such as lapwing and skylark where solar panels are sited on farmland, with reduced opportunities for foraging, roosting and breeding. However, no scientific evidence to support this was presented in the document. Draft best practice guidelines provided by BirdLife South Africa (Jenkins *et al.* 2015) acknowledge the lack of sufficient data collection to enable analysis of the effect of solar energy on birds. The authors highlight the need to carry out thorough scoping and data collection, impact assessment, pre-construction and post-construction monitoring (for which the latter should effectively duplicate the baseline data collection work) of the site.

Summary

2.30 Most of the studies concerning solar impacts on birds are from large concentrated solar systems in the US, where bird mortalities caused by collision or singeing have been noted.

2.31 Very little research has been found on the effect of PV solar panels on birds. None of the studies that have been reviewed to inform this document were conducted in the UK. In general, the studies relating to PV panels are from very large solar farms in savanna or desert habitat, and are not comparable with the UK, due to large differences in solar farm scale, habitat type, and the local abundance and behaviour of birds.

2.32 It has been suggested that the most likely effect of PV solar panels in the UK is the displacement of birds due to habitat alteration, although there is also evidence to suggest that attractant effects may also occur for some species that use solar panels for shelter and nesting. A review published by Natural England (Harrison *et al.* 2017) suggests that the effects of solar development on birds are likely to be species-specific, depending on a species' spatial requirements and foraging behaviour. Most sources of information concur that there is lack of robust data on this subject.

2.33 The best practice guidelines by BirdLife South Africa, Birdlife Europe (2011), the RSPB Policy Briefing, and the Natural England review (Harrison *et al.* 2017) all highlight the need for both pre-construction and post-construction monitoring of sites in order to effectively study their impact on birds and to allow solar farms to be correctly sited to avoid sensitive species.

Bats

Bat Collision with Solar PV Panels

2.34 As for birds, some solar technologies not relevant to the UK, such as concentrated solar power towers, are likely to impact on bats (Manville II, 2016).

2.35 There has, however, been some concern that there may be collision fatalities at PV parks due to bats mistaking solar panels for water, and this is referred to in Natural England's technical advice note TIN101 (2011):

"*Very little research has been conducted to date, but one laboratory study undertaken by Bjoern Siemers and Stefan Grief [sic] (2010) showed that bats attempted to drink from the panels and occasionally collided with them. If the plates were vertically aligned they often crashed into them when attempting to fly through them. Juvenile bats are expected to be more prone to this behaviour*."

2.36 The paper by Greif and Siemers (2010) aimed to investigate an innate recognition of water bodies by bats. For this they observed the behaviour of 15 species of bat towards smooth and rough panels of wood, metal and plastic placed on a sand-covered floor. They observed that bats appeared to only attempt to drink from the smooth surface and not from the rough one. This suggests that the bats were mistaking the panels in this environment for water. However, there are a number points made in this paper which suggest that this mistake may not be made with solar panels in natural conditions (a hypothesis that was not tested in this experiment):

- The experiment was conducted in both low light levels and in complete darkness. The authors observed an increase of 60% in attempts at drinking from smooth panels in complete darkness. From this Greif and Siemers (2010) concluded that bats integrate information from several senses when forming a perception of their environment.

- The experiment relied on bats needing to drink, and therefore the bats had water withheld from them during the day and were released into the flight room in the condition they would be in after roosting for the day. In the wild, light levels at emergence could be relatively high, depending on the species of bat, so other senses (such as sight) may not be as limited as they were in the flight room.

- The bats did not have access to water during the experiment, and therefore they could not 'choose' between the plate and water; they just kept attempting to find somewhere to drink.

2.37 It is also worth noting that the panels of metal, wood and plastic were aligned horizontally on the floor, rather than vertically. There is also no mention of the bats colliding with the panels, although the authors note that on rare occasions, bats accidentally landed on the smooth plate, but continued to behave as though it was water after this.

2.38 Greif and Siemers (2010) conclude that bats have an innate ability to echolocate water, by recognising the echo from smooth surfaces, and that bats may therefore perceive all smooth surfaces as water. The authors do not suggest that bats will be negatively affected by this mistake. Russo *et al.* (2012) assessed the ability of bats to tell the difference between water and smooth surfaces in the wild. A water trough used by bats was covered with Perspex and another left open. A third water trough was half covered in Perspex, with the other half left open. There was no difference in numbers of bats visiting each trough. However, in this experiment, the authors found that having had a number of failed drinking attempts from the Perspex side of the trough the bats would either return to drink from the water side of the trough or leave the site in search of water elsewhere. There was no mention of bats colliding with the Perspex.

2.39 A more recent study by Grief *et al.* (2017) investigated how both smooth vertical surfaces and smooth horizontal surfaces can deceive bats. As bats have been known to collide into reflective surfaces such as windows (Stilz, 2017), the authors sought to determine how bats use these as sensory cues. By analysing the echolocation calls of bats during the experiments, the authors found that bats often mistake smooth vertical surfaces for open flight paths, resulting in collision. In support of their previous work, they also found that bats mistake smooth horizontal surfaces with water bodies, eliciting drinking behaviour. Given that solar panels were not used in this study, and most PV solar arrays in the UK are tilted, no potential impacts to bats can be inferred from these results.

2.40 The review released by Natural England (Harrison *et al.* 2017) provides a table listing hypothetical causes of collision mortality for bats at PV solar farms and recommended experimental approaches to test each hypothesis. This table was modified from the approach for bat collision at wind farms provided by Cryan and Barclay (2009). Harrison *et al.* (2017) state:

"*In order to determine the impacts of solar PV developments on bats, experimental or observational research is urgently required and should be conducted on a species or guild basis in the UK due to behavioural differences and variation in ecological requirements. The hypotheses and experimental approaches presented in table 2 provide a rudimentary foundation for further research.*"

Summary

2.41 There has been no research that directly addresses the effect of PV solar facilities on bats. The studies above found that bats can mistake horizontal surfaces for water bodies and vertical surfaces for open flight paths, although there is no evidence to suggest that this would result in collision in the context of solar PV panels.

Biodiversity Impacts and Opportunities of Solar PV

The Nature of Biodiversity Impacts

2.42 Gasparatos *et al.* 2017 identified various ways in which solar energy can cause impacts on biodiversity. These included direct mortality (through collision), habitat loss / fragmentation, alteration of habitat quality, species assemblage changes, microclimate disturbance and pollution. In turn, these effects can cause reduced connectivity between populations in some species.

2.43 Natural England (2011) published a document that highlighted the negative impacts that solar development could have in areas of high ecological value or when sited close to designated sites. A subsequent Natural England review (Harrison *et al.* 2017) looked at the planning decisions for all solar PV development applications in the North West of England (as of July 2015) in order to determine how many applications were refused on an ecological basis. Of the 32 applications that had been processed at the time of data acquisition, 12 were refused planning permission, eight of which were refused for ecological reasons. The authors note that some applications were refused despite providing details for ecological mitigation.

2.44 There has been a lack of empirical research on the scale of environmental impacts of solar energy, however, with information mainly documented in grey literature. Furthermore, very little of this research has concerned biodiversity in the UK[5]. Throughout their review, Harrison *et al.* (2017) reiterate that the lack of scientific evidence relating to impacts on biodiversity is concerning, and that research should be undertaken to assess the impacts across a broad range of taxa at multiple geographical scales.

2.45 A study by Armstrong *et al.* (2016) looked at the effect of solar parks on microclimate and ecosystem processes under PV arrays, in the gaps in between and in control areas (sited on species-rich grassland) at Westmill Solar Park, UK. The authors did this by measuring soil and air microclimate, vegetation and greenhouse gas emissions over 12 months, with measurements taken from 12 randomly selected 1.5 m² plots (four from each treatment). They found that PV arrays caused seasonal and diurnal variation in soil and air microclimate. In summer, there was cooling (up to 5.2°C) and drying under PV arrays compared with gap and control areas. In winter, the gap areas were up to 1.7°C cooler compared with PV arrays and control areas. The diurnal variation in temperature and humidity was lower during the summer under the PV arrays. Species diversity and plant biomass was lower under the PV arrays. The authors noted that this was explained by differences in microclimate and vegetation management between treatments.

Minimising and Offsetting Impacts

2.46 The review by Gasparatos *et al.* (2017) suggests measures to mitigate the negative effects of solar energy on biodiversity. The primary suggestion was to locate solar energy facilities in areas supporting little biodiversity. This suggestion is feasible in countries such as the US where areas of desert habitat are available, and can be feasible in the UK if solar PV is sited on arable or improved pasture land with little biodiversity interest. DeVault *et al.* (2013) provide a case for installing solar facilities at airports, as they are some of the only land types where wildlife conservation is actively discouraged due to aviation safety concerns.

2.47 For situations where these recommendations cannot be achieved, Gasparatos *et al.* (2017) suggest developing biodiversity-friendly operational procedures. Once utility-scale PV plants have been installed, it is estimated that approximately 70-95 % of ground remains available, and that this has the potential to support wildlife and contribute to national biodiversity targets if good management practices are implemented (Esteves, 2016). The security and 20 year lifespan of completed sites, together with very little disturbance from humans or machinery, provides the potential for long-term benefits to biodiversity (RSPB, 2014). Recommended practices include the following (BRE, 2014; RSPB, 2014; Esteves, 2016)

- Installation / retention of boundary features such as hedgerows, ditches, stone walls, rough grassland, field margins and scrub.

[5] Most of the research has been carried out in arid desert habitats, with very few focused on temperate climates.

- Planting pollen and nectar strips
- Security fencing – plant growing climbers e.g. honeysuckle, and ensure there is 20-30 m gap between the base of the fence and the ground to allow small wildlife to pass through
- Grassland habitat – e.g. wildflower meadow and tussocky grassland
- Controlled grazing by sheep between panels, with a pause in spring and summer to allow vegetation growth
- Installation of artificial structures such as nest boxes, hibernacula and log piles.

Monitoring Studies

2.48 One comparative study from the UK, released by Montag *et al.* (2016) demonstrates how these management practices can have a positive impact on biodiversity at solar farms. The study investigates whether solar farms can result in greater biodiversity when compared with equivalent undeveloped sites. This study was carried out across 11 solar farms in the southern UK, all of which had been operational for at least one growing season but had varied approaches to their land management. The authors assessed the abundance and diversity of four key biodiversity indicators – plants, invertebrates (butterflies and bumblebees), birds and bats. Montag *et al.* (2016) categorised each site as having a low, medium or high level of land management for wildlife. This categorisation took account of positive / negative biodiversity management measures such as re-seeding grassland, grazing regimes, herbicide use and management of hedgerows / field margins.

2.49 The authors assessed changes in biodiversity by comparing the wildlife at the solar farm to that in nearby undeveloped control sites located within the same farms that were under the same management regimes as the solar farms prior to their construction. The botanical survey results showed that overall, solar farms supported a significantly greater diversity of species than control plots, especially for broadleaved plants. The authors comment that this was partly a result of re-seeding of species-rich wildflower mixes at the solar farms. Botanical diversity was also found to be influenced by management of the grassland with controlled grazing. There was no significant difference between plant diversity under panels and between rows. The authors suggest that this could be a case of niche selection, whereby more shade-tolerant plants are able to grow beneath the panels.

2.50 Generally, the study by Montag *et al.* (2016) revealed a greater diversity and/or abundance of invertebrate, bird and bat species on solar farms compared to the control plots. The greatest number of invertebrates occurred where plant diversity was also high. Overall there was a significantly greater abundance of invertebrates at solar farms than at control sites. There was no significant difference in invertebrate diversity between solar farms and control sites except for those solar farms assessed as having a high level of land management for wildlife. The bird survey results showed overall higher diversity found within solar farms compared with control plots, however this result was not significant. A significantly higher abundance of birds were observed at two solar sites compared with their controls. For these sites, it was suggested by the authors that there may be greater foraging opportunities which reflects the good grassland management practices and availability of structures for cover / perching. The solar sites were found to be of significant importance for declining farmland bird species, due to relief from intensive agricultural practices. The bat survey results suggested that a significantly higher abundance of bats are found over control areas as opposed to PV solar farms. However, the authors note that the results were inconclusive, as malfunctions in recording equipment resulted in limited data collection.

2.51 The three sites with the most focused management regime for biodiversity had the highest biodiversity level overall. This study provides evidence that solar farms can result in increased biodiversity if managed appropriately post-construction. The authors suggest that research should be conducted on a large number of UK sites with a broad age range in order to determine the relationship between site age and biodiversity level.

2.52 A similar (unpublished) study was undertaken by Parker & McQueen (2013) at four solar farms in comparison with control plots in southern England. All four solar farms were sited on previously arable land and all were subject to grassland management regimes; two were established as wild flower meadows and two were managed as pasture. The solar farms and control plots were surveyed for bumblebees, butterflies and plant species. All four solar farms showed a form of biodiversity increase compared to the control plots. The wildflower meadow sites showed a significant increase in all three indicators, with less of an effect observed for the pasture sites. It is not clear how many times these surveys were repeated per site; however the authors acknowledge that their surveys were limited in sample size and duration. Despite this, the study used statistical analysis and showed that, in certain circumstances, solar farms can benefit biodiversity.

2.53 Guidance published by the BRE National Solar Centre (2014) provides advice to developers on how to effectively support biodiversity at solar farms. It states:

"*Biodiversity enhancements should be selected to fit the physical attributes of the site and should tie in with existing habitats and species of value on and around the site. Furthermore they should be compatible with the primary purpose of the site – to generate solar power. If agricultural production is also planned for the site, biodiversity enhancements should aim to dovetail with these goals*."

Data Gaps

2.54 With regards to future research on the effect of solar energy installations on biodiversity, a number of reviews (e.g. Hernandez *et al.* 2014; Grodsky *et al.* 2017; Harrison *et al.* 2017; Holland *et al.* 2018) recommend that studies focus on "bottom-up" ecological interactions, ecosystem-wide effects and landscape level impacts. The need to monitor sites both pre- and post-construction in order to produce robust results that are directly comparable has also been identified.

Summary

2.55 Very few studies were found that related to impacts on biodiversity in the UK.

2.56 Publications by Natural England recommend the avoidance of solar developments in or near to areas of high ecological value or designated sites, and highlight how planning applications can often be rejected based on the ecology of the proposed site.

2.57 The study at Westmill Solar Park, UK found that differences in plant biomass and plant diversity under PV arrays and in the gaps within the array could be explained by differences in microclimate and vegetation management. This is expected given that UK plant species are sensitive to significant changes in temperature and humidity.

2.58 In order to minimise the impacts of solar farms on biodiversity, the literature comes to a general consensus that:

a. Consideration should be given to the correct siting of solar farms within the landscape.

b. Biodiversity-friendly operational procedures, including managing the remaining land for wildlife, should be a priority and considered early in the planning process.

2.59 The comparative studies of solar farms across the southern UK provide evidence that positive outcomes for biodiversity can be achieved if such sensitive land management processes are implemented.

3 Conclusions

3.1 From the body of research reviewed[6] it is likely that the majority of concerns that have been discussed in the media are not well-founded, or are based on scientific experiments that were not specifically designed to evaluate ecological impacts of ground mounted solar PV sites.

3.2 Our original review, published in 2014, concluded that the ecological impacts of ground-mounted solar panels in the UK were relatively limited and location-specific. Five years on, the evidence base has not increased significantly (particularly with regard to UK studies), and most of the literature acknowledges the need for further research. The objectives and design of surveys and the development of ecological monitoring recommendations at ground-mounted PV parks should be considered on a case-by-case basis, to ensure that any design restrictions or mitigation / compensation measures are justified and effective.

3.3 We have reviewed the papers of ecological researchers and guidance from non-governmental organisations. These sources indicate that many authors see the installations of solar PV as an opportunity for biodiversity enhancement. This is broadly in line with what planning policy requires: e.g. The Environment (Wales) Act 2016 places emphasis on enhancing the resilience of ecosystems, while the National Planning Policy Framework (NPPF) 2019 refers to biodiversity net gain, stating:

"*Development whose primary objective is to conserve or enhance biodiversity should be supported; while opportunities to incorporate biodiversity improvements in and around developments should be encouraged, especially where this can secure measurable net gains for biodiversity*."

3.4 In March 2019, DEFRA confirmed that the delivery of biodiversity net gain would be a mandatory requirement for all new developments in England.

[6] Some of the reports and ongoing monitoring mentioned in reviewed articles could not be located during this review, which restricts our ability to fully assess the potential impacts of ground-mounted PV solar panels. Notwithstanding this, the amount of research and monitoring data currently available appears to be too limited to allow definitive conclusions to be drawn.

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