CLEVE HILL SOLAR PARK

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SOLAR PARK

Cleve Hill Solar Park
Microclimate & Vegetation Desk-Based Study

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Executive summary

Based on inferences develop from existing understanding and the outcomes of studies undertaken at south facing array solar parks, an east-west solar park, such as is proposed at Cleve Hill, is likely to lead to the following microclimate compared to the conditions without a solar park:

- Significantly lower photosynthetically active radiation (PAR) receipts;
- Lower average soil temperatures;
- Dampened air temperatures (i.e. higher daily minimum temperatures and lower daily maximum temperature); and
- Spatially variable soil moisture which, on average, is likely to be higher.

The design of the array, in terms of gaps between panels, gaps between tables, translucency of the PV panels and height of the arrays, will dictate the scale of effect on the microclimate.

Using reference vegetation data available from a national database we demonstrate how species richness and dominant plant type may respond to variations in incident light. The findings suggest, using an incident light gradient, that with increasing solar radiation:

- Herbaceous cover (grasses and forbs) will increase;
- Bare ground and bryophyte cover will decrease; and
- Species richness will increase.

Examination of existing studies and reference data we also infer that:

- Vegetation response at the edge of PV arrays could be similar to that under hedges;
- Productivity is likely to decrease with increased shading with implications for grazing density;
- ***Up to a point,*** reduced light could limit the vigour of competitive light-demanding grasses with benefits for species richness; and
- To some degree, plants will adapt to the lower light conditions, for example through changing leaf traits to maximise light capture.

We identify five broad categories of potential vegetation response at Cleve Hill: bare ground, bare ground with some unmanaged vegetation colonisation, and low, moderate and high biodiversity vegetation cover. These different scenarios will have implications for vegetation management, visual amenity, grazing potential, biodiversity value and soil erosion risk. Given the different microclimate conditions and soil types, and the desire to graze the land, minimise maintenance and improve biodiversity, it is likely that a mosaic of options would be optimal. Finally, we identify four desirable land management outcomes, promoting vegetation cover, continued agricultural use, promotion of net environmental gains and efficient site operation and maintenance, and detail some mechanisms to achieve them.

Contents

1.0 Introduction

1.1 Overview

Cleve Hill Solar Park is a proposed approximately 350 MWp solar photovoltaic (PV) electricity generation facility located on the north Kent coast.

The project proposes to use solar PV modules oriented towards the east and west rather than the south, as has been more commonly utilised on UK solar PV facilities.

This report provides a summary of the expected impact of the proposed design on the microclimatic conditions beneath the PV arrays and the likely vegetation responses to inform the land management proposals for the site and the environmental assessments which will accompany the consent application for the project.

This report includes six sections:
- Section 1 – Introduction
- Section 2 – Micro-climatic response
- Section 3 – Vegetation response
- Section 4 – Potential Future Modelling
- Section 5 – References

1.2 Authors

This report has been compiled by Dr Alona Armstrong, Dr Simon Smart and Dr Nicholas Kettridge. ***Dr Alona Armstrong*** is a Lecturer in Energy and Environmental Sciences based in the Lancaster Environment Centre and Energy Lancaster at Lancaster University. She is also a Natural Environment Research Council Industrial Innovation Fellow, a prestigious award that enables her to focus on her research that investigates how renewable energy technologies and the hosting environment interact, with the overarching aim of delivering benefits beyond low carbon energy. She has published an article on the microclimatic, vegetation and carbon cycling response to solar parks (http://iopscience.iop.org/article/10.1088/1748-9326/11/7/074016, open access), which was selected for highlights in Science for Environment Policy, a news service published by the European Commission's Environment Directorate-General (2016). She leads the Natural Environment Research Council funded 'Solar Park Impacts on Ecosystem Services' project (www.lancaster.ac.uk/spies). Email: a.armstrong@lancaster.ac.uk

Dr Nicholas Kettridge is an ecohydrologist who specialises in characterising ecosystem resilience to disturbance. He has obtained research income of £3.1 million and published 48 peer reviewed publications. These include a paper recognised by the American Geophysical Union as a 'research spotlight', a second highlighted by Nature Climate Change, and two of the top 10 most downloaded manuscripts in *Ecohydrology* in both 2016 and 2017. He is an editorial board member for the journal *Scientific Reports*, regional chair for the British Hydrological Society. He supervises 6 PhD students, with 3 further students supervised to completion

Dr Simon Smart is a senior research scientist and botanist at the Centre for Ecology and Hydrology and visiting professor at Liverpool University. He has 30 years' experience in the recording, analysis, interpretation and statistical modelling of ecological change in temperate ecosystems with a particular focus on vascular plants. He has led a range of projects investigating the causes and consequences of large-scale changes in plant species composition. He instigated and continues to manage the development of the MultiMOVE package of realized niche models for British plant species and designed and co-wrote the MAVIS software program for assignment of vegetation to the National Vegetation Classification. For the last four years he has been the lead scientist for biodiversity in the Welsh ecosystem monitoring and surveillance program. He is an experienced botanist and Atlas 2020 recorder for the isle of Jura, Scotland.

1.3 Aims

The aims of this report are:

- To use an evidence-based approach to estimate the likely micro-climatic conditions underneath the solar PV arrays;
- To predict the likely vegetation response to the micro-climatic conditions identified;
- To outline the potential implications of vegetation response scenarios; and
- To suggest land management regimes which could be employed to:
    - Promote vegetation cover;
    - Continue agricultural use onsite;
    - Promote net environmental gains; and
    - Allow for efficient operation and maintenance.

2.0 Micro-climatic response

The physical presence of solar photovoltaic (PV) arrays impacts surface solar radiation receipts, the radiative flux balance (which regulates temperature), precipitation distribution, wind speed and turbulence. Consequently, photosynthetically active radiation (PAR, the proportion of solar radiation used for photosynthesis) receipts, temperature and soil moisture will be altered with direct and indirect effects on vegetation growth and community composition.

2.1 Effects on solar radiation receipts

Solar parks reduce land surface solar radiation receipts, with the magnitude and spatial distribution of the reduction dependent on solar park design, time of year and time of day (due to the position of the sun in the sky). At Westmill Solar Park (westmillsolar.coop, a south facing array), PAR was reduced by 92% under the arrays, 90% of which was diffuse radiation, i.e. that scattered by molecules and particles in the atmosphere (Armstrong *et al.,* 2016) (Figure 1). However, it is important to note that the solar radiation measurements were taken at a height of 130 cm above the land surface at Westmill to avoid over-shading by vegetation; receipts at the surface will be greater. In contrast, at an experimental facility in southern France, 32%-52% and 48%-68% of ambient solar radiation was observed during crop growth cycles (i.e. does not encapsulate the full year) under full and half density south facing arrays respectively (Marrou *et al.,* 2013) (Figure 2). In addition to the proportion of the year monitored, the differences between the two studies reflects the solar array designs: higher arrays and larger gaps between rows in southern France increased solar radiation receipts at the land surface.

Likely implications at Cleve Hill: To the best of our knowledge no studies have quantified the impact of an east-west solar park design on solar radiation receipts. It is likely that the east-west PV array at Cleve Hill would result in lower *direct* radiation receipts compared to a south facing array given the higher PV panel density; gaps between tables will be 2.50 m compared with ~6.75 m at Westmill. Further, the concertina shape of the tables are likely to reduce *diffuse* radiation receipts. Consequently, solar radiation receipts could be very low. However, the proposed gaps of 300 mm between tables will enable some solar radiation penetration.

2.2 Effects on temperature

The physical presence of PV arrays alters the surface energy balance (net short-wave radiation, net long-wave, sensible, latent heat fluxes, and ground heat flux), ultimately determining the ground surface temperature. Short-wave fluxes commonly dominate energy inputs and thus the shading of the land surface by PV arrays tends to cause a reduction in soil temperature. For example, soil temperature at Westmill Solar park peaked at over 5 °C lower under PV arrays when compared with a control area (Armstrong *et al.,* 2016). Soil temperature was less impacted under the experimental array in southern France, with reductions of between 0.5 and 2.3 °C depending on crop (the difference between full and half density was <=0.2 °C) (Marrou *et al.,* 2013). Effects on daily *average* air temperature at Westmill were limited, however, compared with the control, daily *minimum* temperatures were significantly warmer (up to 2.4 °C) and *maximum* temperatures significantly cooler (up to 6.0 °C) under the panels (Armstrong *et al.,* 2016). Further, it has been found that air temperatures *above* PV arrays are higher by 2-3 °C compared with surrounding land at night in Arizona (Barron-Gafford *et al.,* 2016). Finally crop temperature, which

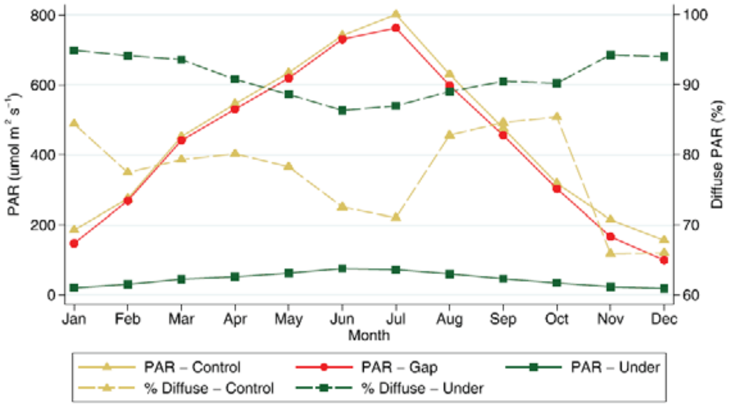

Figure 1. Plot of average monthly day time PAR receipts (μmol m^{-2} s^{-1}) and the proportion of diffuse radiation at control plots, gaps between and under the solar arrays. Re-used under the terms of the Creative Commons Attribution 3.0 license from Armstrong et al., 2016; http://iopscience.iop.org/article/10.1088/1748-9326/11/7/074016 (open access).

regulates function, in southern France was up to ~2 °C warmer at night and up to ~3 °C cooler during the day (Marrou *et al.,* 2013).

Likely implications at Cleve Hill: Overall temperatures will likely be reduced under the PV arrays in response to the reduction in incoming solar radiation. However, the more continuous cover of PV panels may insulate the ground surface, resulting in higher minimum air temperatures and potentially warmer soil temperatures in comparison to south facing arrays, particularly under low wind speed conditions.

2.3 Effects on soil moisture

Soil moisture is the product of inputs (i.e. precipitation and movement of water in the soil) and outputs (i.e. evaporation from the soil, transpiration from vegetation and water movement within the soil). Consequently, soil moisture response to PV arrays depends on changes in transpiration (which will be regulated by photosynthesis ergo solar radiation receipts and influenced by changes in wind speed and turbulence) and evaporation (which will be determined by temperature and influenced by changes in wind speed and turbulence) and the capacity of rainfall to percolate through gaps between the panels. At Westmill Solar there was no difference in soil moisture under the solar arrays. However, the number of sampling points was limited and the spatial variability in soil moisture very high (Armstrong *et al.,* 2016). Shading effects from trees in other ecosystems have been found to promote water conservation (and therefore result in higher water contents) through reducing evaporation, in addition to complex ecological and aerodynamic modifications

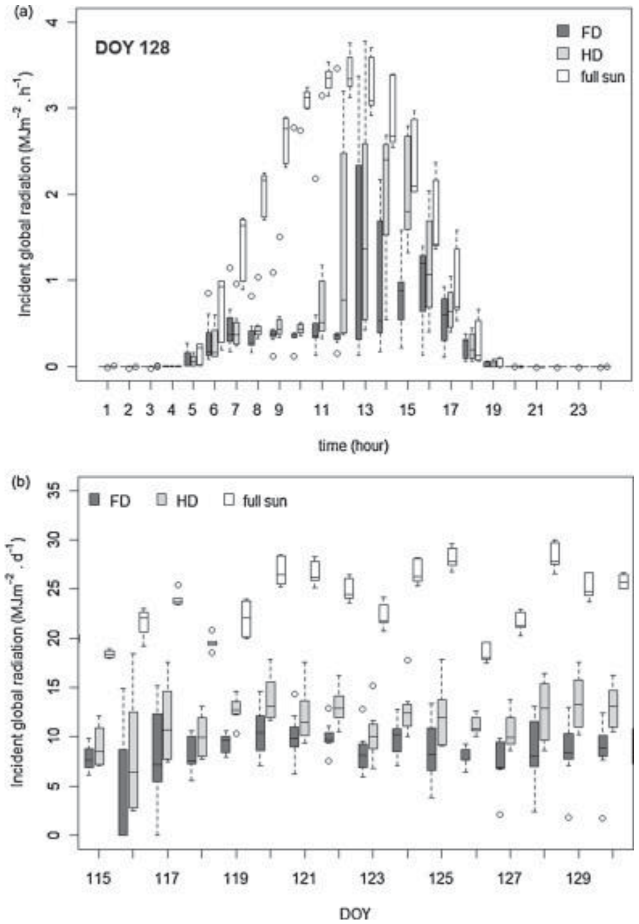

Figure 2. Hourly (a, for DOY 128) and daily (b, from DOY 115 to DOY 230) incident radiation. The boxes feature the spatial variability of the incident radiation (radiation was recorded at the same time by sensors settled at different locations on the North–South axis). FD = full density array, HD = half density array. Source: (Marrou et al., 2013).

that result from the presence of trees (Kettridge *et al.,* 2013). Moreover, Marrou *et al*. (2013) calculated that actual evapotranspiration was reduced by 10-30% under PV arrays which reduced solar radiation by 30-70% (soil moisture levels were affected by irrigation).

Likely implications at Cleve Hill: Soil moisture at Cleve Hill is likely to be high variable but overall will probably be higher under east-west PV arrays due to reduced wind speeds, lower evaporation and reduced transpiration (assuming rainfall is allowed to fall through gaps around panels as is standard at south facing arrays), compared to gap and control areas and south facing arrays.

2.4 Summary of postulated alterations to the microclimate at Cleve Hill

In summary, based on inferences made on existing understanding and the outcomes of limited studies undertaken at south facing array solar parks, an east-west solar park is likely to lead to significantly lower PAR receipts, lower average soil temperatures, dampened air temperatures (i.e. lower maximum and higher minimum daily temperatures), and spatially variable soil moisture which, on average, is likely to be higher. The design of the array, in terms of gaps between panels, gaps between tables, translucency of the PV panels and height of the arrays, will dictate the scale of effect.

3.0 Vegetation response

The most significant constraint on plant growth under the PV arrays will be light (i.e. solar radiation) availability and if it falls below the compensation point for available shade-tolerant species then no plant life can be supported. Without measured data, which summarises the diurnal and seasonal variation, it is not possible to directly and unambiguously link an incident light profile beneath the array to available vegetation analogues and therefore to estimate vegetation cover and which species could survive. To provide some useful insight we use reference vegetation data available from a national database to demonstrate (1) how species richness and dominant plant type changes with reduced incident light, and (2) using an assumed analogue dataset for light and soil conditions along the edge of the array we suggest a likely species compositional profile and species richness distribution. For a more detailed methodology see appendix B.

3.1 How species richness and dominant plant type changes with reduced light

An incident light gradient from Sitka (lowest year-round ambient light), through other plantation conifers and broadleaved woodland, to neutral grassland was used to summarise the effect of shade on species richness, plant cover and bare ground. Grass cover increases consistently moving from Sitka through other conifer-dominated stands to broadleaved woodlands in England and unsurprisingly peaks in the neutral grassland reference data (Figure 3). This is because light availability is especially important for common grass species and their vigour is greatly reduced under shade. Grass cover has a significant impact on the cover of other plant types. For example a range of forbs readily coexist with dominant grass species but can be quickly reduced in richness and cover in unshaded situations if fertility is high and the management regime favours grass production. Total bryophyte and bare ground cover is highest under the Sitka canopy (the lowest light environment). Moreover, understorey species richness increases with decreases in canopy cover (Figure 4) and there is associated variation in the proportions of each plant functional type (Figure B1, appendix B).

Likely implications at Cleve Hill: Whilst light levels at Cleve Hill are likely to be most similar to those found in Sitka and other conifer plantations characterised by year round canopy greenness, the relationships found have shortcomings as analogues for Cleve Hill because of the effect of acidifying litter and differences in species composition prior to planting. Moreover, geographically, the lower humidity and rainfall of coastal Kent will also reduce the abundance of fern and bryophtyes naturally achieved in the more oceanic west of Britain where many of the sitka and conifer sites were located. In addition specialised shade-tolerant forbs and grasses are also likely to be rare or absent in the immediate area around Cleve Hill as the physiological specialisations, including slow dispersal and intolerance of grazing and high fertility, associated with highly shade tolerant plants lead to trade-offs that result in rarity, especially in agricultural landscapes (Kimberley *et al.,* 2013).

However, the relationships do amply demonstrate the effect of canopy cover on understorey species richness in the regions sampled (lowland England and Wales). The geographically nearer reference data for broadleaved woodland show that the higher incident light associated with a deciduous canopy is associated with higher forb cover and bare ground, and lower grass cover.

A key question is to what extent the PV array results in incident light zones of varying width. For example, moving from the array edge under the panels, how does light reduction correspond with conditions relating to unshaded grassland through to light levels analogous to broadleaved woodland then evergreen understoreys through to light levels unlikely to support plant life?

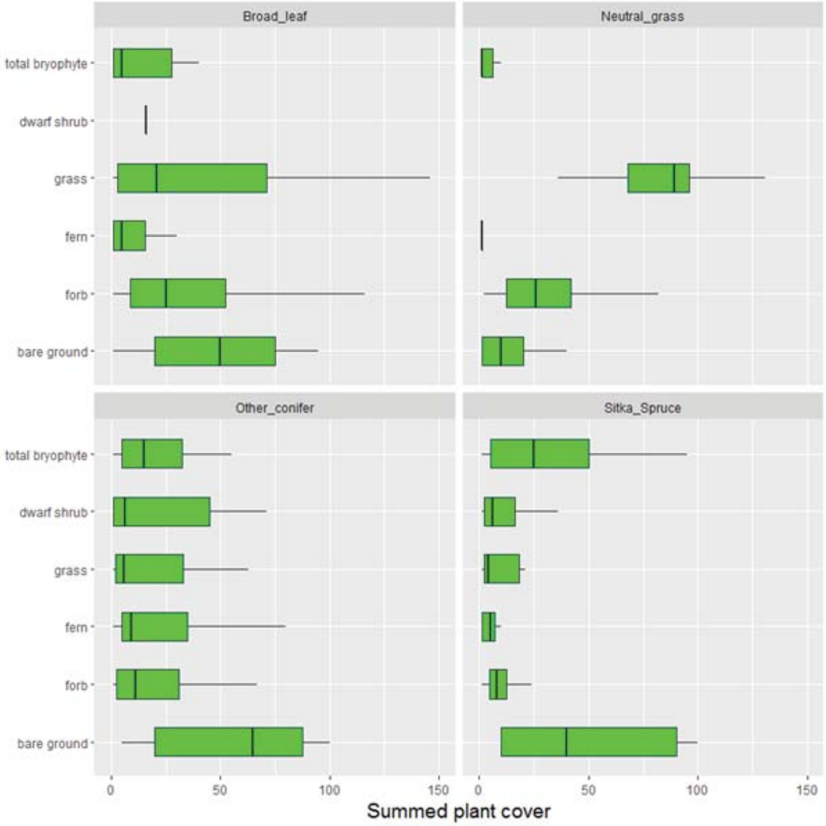

Figure 3. Cover (%) of plant types and bare ground in 200 m^2 quadrats extracted from the Countryside Survey of Great Britain database from a continuum of most to least shaded vegetation (Sitka Spruce and other planted conifers in lowland England & Wales through to broadleaved woodland and neutral grassland in lowland England).

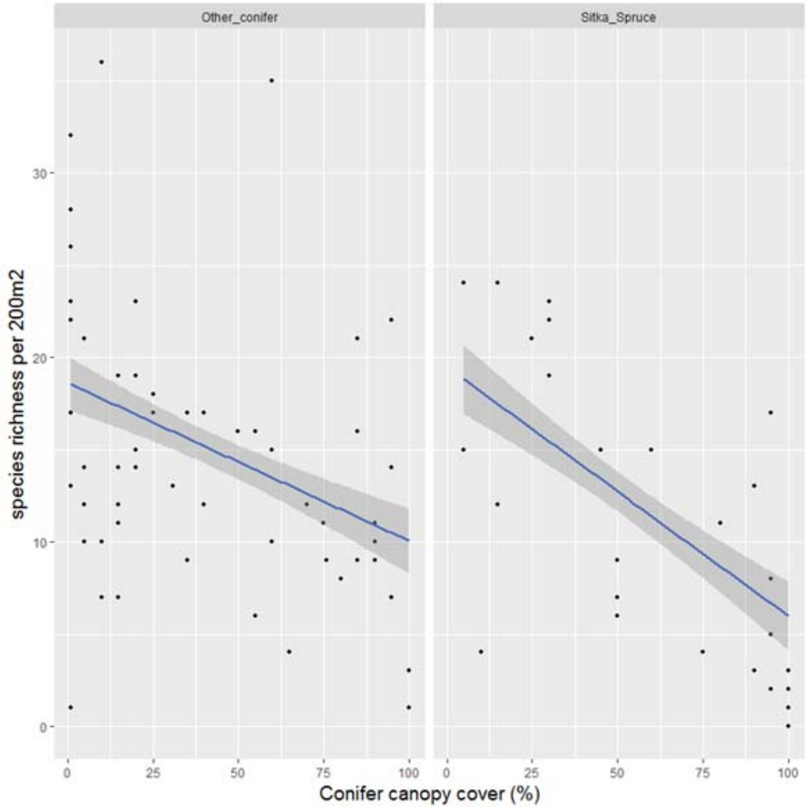

Figure 4. The relationship between understorey species richness and conifer canopy cover in the 200 m^2 reference data.

3.2 Vegetation growth in the light regime at PV array edges

There will be an illumination gradient at the edge of the array from well-lit conditions through to deep shade. The width and light regime of this zone are not known but a plausible reference dataset is lowland hedgerows in England with varying degrees of woody canopy cover (see appendix B). Some hedgerows have a highly species-rich field layer, however, most in lowland England support a mix of common shade-tolerant and shade-intolerant plants very typical of the high fertility and disturbance associated with the boundaries of intensively managed land. Appendix B lists the species frequency table for the hedgerow reference data and indicates those found on site by the 2015 Phase 1 survey. This provides a crude guide to the assemblages that could be potentially be realised in gaps and at the edge of the array, assuming a light regime equivalent to the hedgerow reference data (Figure 5).

A comparison of Figure 5 with Figure 3 shows that the total bryophyte, forb and bare ground cover composition of the hedgerow data were overall more similar to the neutral grassland and broadleaf profile than the conifer data. However, a similar negative relation between species richness and woody canopy cover is seen, again testifying to the effect of decreased incident light on plant biodiversity per unit area (Figure 6).

Likely implications at Cleve Hill: Since hedgerows are usually between 1 and 5 m wide the incident light regime maybe similar to that at the edges of the proposed PV panel array. Moving further under the PV array into deeper shade, conditions will increasingly deviate from a lowland hedge. Moreover, a fundamental difference centres on the year round shade cast by the PV panels, resulting in a regime more analogous to a dense conifer plantation, versus the seasonal window of increased incident light under a deciduous hedgerow. This seasonal window of increased light is highly significant since it presents opportunities for growth and flowering throughout the year (except under dense summer shade). Consequently, gaps in the PV array should support a greater density of less shade-tolerant common species typical of neutral grassland. The gradient of conditions along the edges of the array will act as a filter for species that vary in shade-tolerance. The assembly of shade-tolerant plants most typical of species-rich hedgerows is likely to be particularly constrained by residual fertility, the grazing or mowing regime applied post-installation and the availability of propagules.

3.3 Observed impacts of PV arrays on underlying vegetation

A few studies have assessed the response of vegetation to the presence of PV arrays and provides insight to possible vegetation response at Cleve Hill. Significant differences in the vegetation biomass and community composition under panels compared with between PV array rows and in control areas were observed at Westmill Solar Park (Armstrong *et al.,* 2016). Specifically, above ground biomass under the PV arrays was 25% that found between the rows and in control areas. There were also significantly fewer species under the arrays and, with the exception of *Achillea millefolium,* the control and gap areas had a higher diversity of forbs and legumes. However, the differences in species composition is likely to have been impacted by management; whilst the whole site was seeded prior to construction there was limited germination and only the gap and control areas were re-seeded.

The experimental array in southern France was designed to grow crops underneath and lettuces and cucumbers were found to have the same growth rate during the period of maximum growth but rates were slower at the beginning of the growth cycle (Marrou *et al.,* 2013). Moreover, the lettuce crops adapted to the conditions, increasing radiation interception efficiency through increasing leaf area and changing the distribution of leaves (Marrou *et al.,* 2013). Further, a study in Colorado (arid) found that vegetation could be successfully re-established under a south-facing solar array, which shaded about one third of the ground during the day and almost no proportion of the ground was devoid of direct sunlight on clear days (Beatty *et al.,* 2017). Moreover, there have been experiments that have investigated the effect of spacing lengths between PV panels and pole, distances between rows of PV panels, PV panel heights, pole depths and the implications for yields in pasture crops, corn and barley (Macknick *et al.,* 2013).

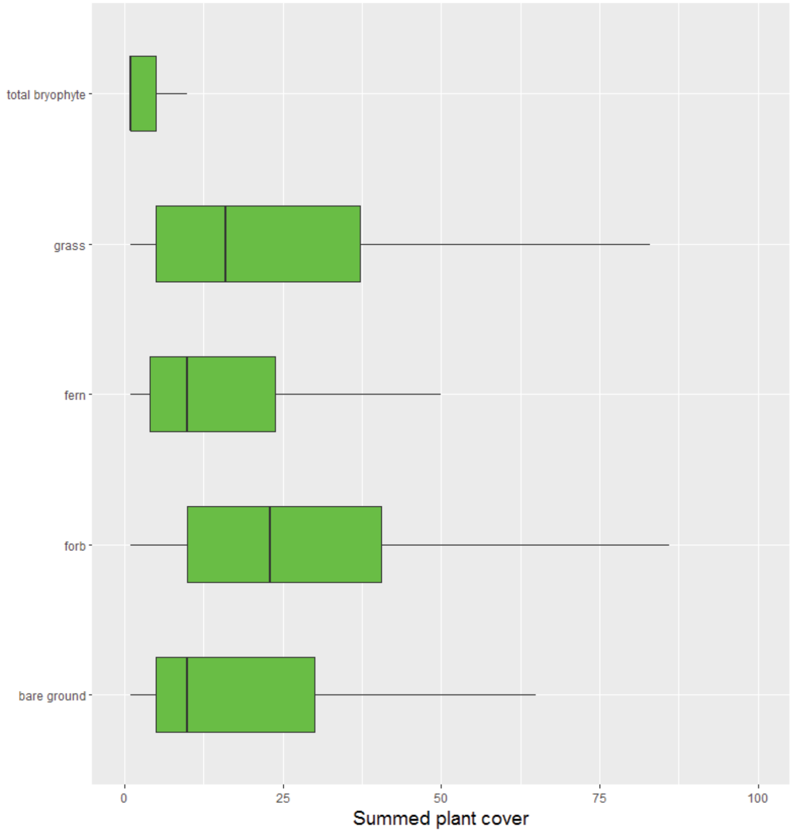

Figure 5. Understorey % cover of plant types and bare ground in the hedgerow reference data (1x10 m quadrats) for the lowland south and east of England extracted from the Countryside Survey of Great Britain database.

Likely implications at Cleve Hill: It is highly likely that biomass production at Cleve Hill will be lower in areas of greater shade. This could be beneficial to the maintenance of species richness because light-demanding competitive grasses are reduced in vigour preventing them from capitalising on high residual fertility (Smart *et al.,* 2006); however it is a balancing act. Too much

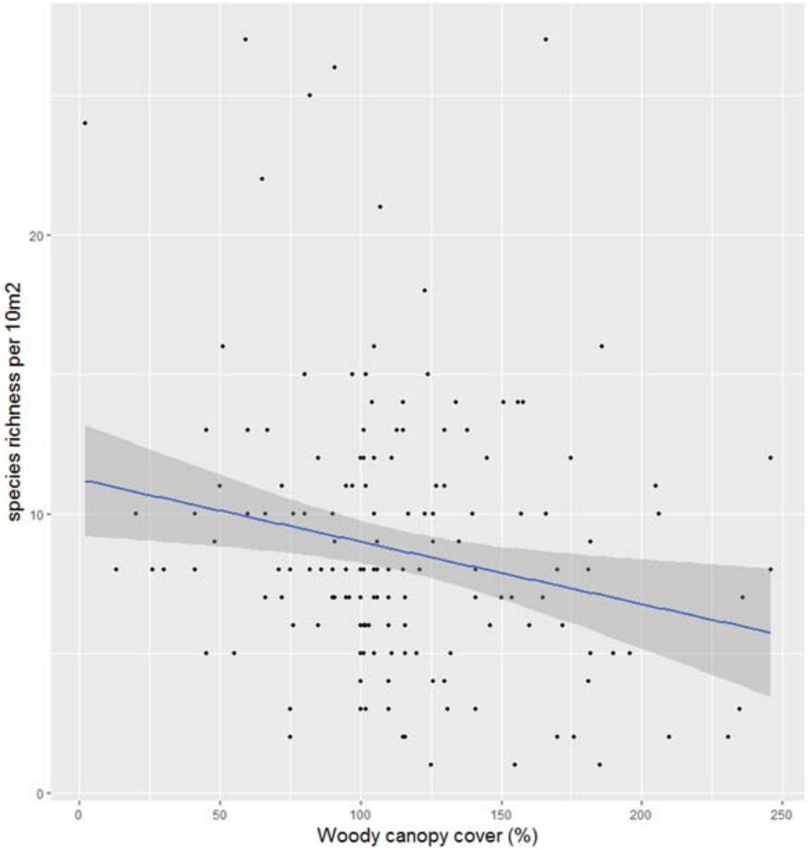

Figure 6. The relationship between understorey species richness and woody canopy cover in the hedgerow reference data for lowland England.

year-round shade is likely to filter for a diminishing pool of ferns, bryophytes and weedy species whilst bare ground will increase. The better lit zone at array edges will provide the greatest opportunity for establishing a forb and grass-rich assemblage akin to that typical of a lowland hedgerow and its immediate outer edge. The international studies provide insight that vegetation can be established and also that species will adapt in an attempt to colonise. For example many herbaceous species demonstrate changes in leaf traits as shade increases thereby maximizing light interception and maintaining a positive carbon balance (Valladares *et al.,* 2016).

4.0 Potential vegetation response scenarios at Cleve Hill Solar Park

The variability in micro-climate imposed by the proposed solar park at Cleve Hill will lead to spatial variation in vegetation response, with implications for vegetation management, biodiversity, potential for grazing, visual amenity (where visible) and soil erosion risk. Together, understanding of the likely microclimatic variation with the Cleve Hill Solar Park, insight provided by the light analogues and observed vegetation response at existing sites, suggest a suite of potential vegetation responses. The plausibility of each potential response will be primarily dependent on the limited light availability, but also on soil type and selected management options, and thus a vegetation mosiac response is likely to develop across the site (Table 1). Overall, conversion from arable agricultural land to a well-managed grassland should lead to increased vegetation biodiversity, with other nature benefits possible (Hayhow et al., 2016).

Table 1. Overview of potential vegetation responses and their relative advantages and disadvantages.

Potential response	Area where likely to occur	Advantages	Disadvantages
Bare ground	Directly under arrays away from edges and gaps	No need for vegetation management.	Soil erosion is a high risk, with potential implications for stream water quality dependent on slope and connectivity. Very poor visual amenity if visible. Not available for grazing. No biodiversity value.
Bare ground with some unmanaged vegetation colonisation	Directly under arrays away from edges and gaps	Limited requirement for vegetation management.	Soil erosion is a risk, with potential implications for stream water quality dependent on slope and connectivity. Not likely to be available for grazing. Poor visual amenity if visible. Very limited biodiversity value.
Low biodiversity vegetation cover	Between arrays and at edges of arrays where there are some direct PAR receipts	Available for grazing. Requires limited management. Low risk of soil erosion.	Limited biodiversity value. Moderate visual amenity if visible.
Moderate biodiversity vegetation cover	Between arrays and at edges of arrays where there are some direct PAR receipts	Available for grazing. Some biodiversity value. Good visual amenity if visible. Low risk of soil erosion.	Requires moderate management.
High biodiversity vegetation cover	Between arrays and at edges of arrays where there are some direct PAR receipts	Available for grazing. High biodiversity value. Very high visual amenity if visible. Low risk of soil erosion.	Requires careful management.

5.0 Desirable land management outcomes

There are four key desirable outcomes for land management which may inform the target vegetation response: promoting vegetation cover, enabling the continuation of agriculture, promoting net environmental gains and minimising operation and maintenance costs.

5.1 Promoting vegetation cover

Aim: To ensure vegetation cover to increase biodiversity, visual amenity and land available for grazing and decrease soil erosion risk.

Mechanism: After soil disturbance ceases, cover of perennial vegetation is likely to become established in the first three years as a result of the natural regeneration of ex-arable land (Critchley & Fowbert 2000). Species typical of previous cultivation will persist for varying lengths of time and species accumulation will depend on the composition and distance of nearby sources as well as recruitment from the seedbank (Critchley & Fowbert 2000). Key to achieving rapid vegetation cover at Cleve Hill is ensuring sufficient PAR receipts and seeding with appropriate species (i.e. shade-tolerant species under the PV arrays as many short, shade-tolerant forbs are poor dispersers). If incident light is too low beneath the array to support a viable sward then attention should focus on the edges of the arrays where a vegetation zone with a light regime similar to a lowland hedgerow might develop. Given that the site would be ex-arable land, high residual fertility may also require mowing and biomass removal to maintain and encourage species richness, reduce grass dominance and encourage gap availability. Mowing would need to be timed to allow flowering and seed set to maximise nectar provision, aesthetic appeal and reproduction from seed. Particular attention should be given to the more calcareous soil in the north west of the site since this may support a more species rich assemblage. Highest biodiversity values would probably arise from assisted dispersal into the array edges. The simplest way to do this might be to cut and spread hay from the most species-rich areas of surrounding neutral grassland. Deciding which regime is appropriate is likely to mean monitoring the development of perennial vegetation over the first three years. Vegetation buffer strips should be maintained between any areas of bare soil and streams to reduce connectivity.

5.2 Continued agricultural use onsite

Aim: To ensure grazing is possible to keep the site in agricultural use.

Mechanism: In areas where there is sufficient light to maintain a sward the site could be used for sheep grazing. A stock management plan would need to be developed in order to ensure sustainable long-term use and other benefits. For example, rotational grazing would probably be necessary to allow nectar-providing forbs to flower in the growing season. Stocking densities may need to be reduced compared to a field without a solar park to take into account any reduced grass cover and productivity under and around the arrays.

5.3 Promotion of net environmental gains

Aim: to promote net environmental gains as detailed in the UK Governments 25 year Environment Plan, and reflected in the updated National Planning Policy Framework.

Mechanism: Intensively managed low-grade agricultural land, the current land management at Cleve Hill, is the most significant driver of decline in UK nature (Hayhow et al., 2016). Consequently, conversion to a solar park offers opportunities to deliver environmental net gains beyond that of low carbon energy provision. Working with local stakeholders, such as Wildlife Trusts, to identify suitable options, e.g. habitat provision and increased biodiversity, would be a good mechanism to achieve this.

5.4 Efficient operation and maintenance

Aim: to ensure that any land management options do not have adverse impacts on operation and maintenance.

Mechanisms: Vegetation growth is a key factor to the ease and expense of land management. Vegetation height would need to be limited to avoid shading of the PV panels and thus reducing electricity production. Options include grazing, mowing and spraying. Grazing would be preferable, if the site is managed to produce sufficient sward. If grazing is not practical then mowing would be preferable to spraying to avoid chemical inputs. Mowing is not a common agricultural practice in Britain but is a regime of course widely used to manage road verges, golf courses and other amenity grasslands. Mowing with no removal of biomass would likely lead to the lowest biodiversity grassland developing.

6.0 Limitations and potential future refinement of predictions

6.1 Limitations

The limited number of studies at solar parks and dearth of data for east-west orientated arrays presents some limitations for the outcomes of this study and, as such, t*he findings should be approached with caution.* Specifically, given the differences in design, geographical location and dynamic nature of solar radiation receipts at diurnal and annual time scales it is not possible to quantify the reduction in ambient solar radiation at Cleve Hill, nor implications for temperature and soil moisture. This leads to uncertainty in vegetation response primarily due to unknown changes in incident light and, to a lesser extent, observations of soil conditions on site. Whilst natural analogues have been used to infer potential effects on vegetation response, notable differences exist (e.g. differences in soil type between conifer plantations and Cleve Hill and the lack of seasonal light under the PV arrays compared with hedgerows) which requires the outcomes to be considered with caution.

6.2 Modelling solar radiation receipts, temperature and soil moisture

Scientific methodology exists to both estimate solar radiation receipts and the response of vegetation. Using a modelling approach, we can estimate light receipts throughout the year, and use meteorological data from different years to capture inter-annual variability, across the proposed solar park (i.e. between array rows, under the arrays and at the edges). This could include the gaps between solar panels, which would be equivalent to sunflecks within a dense forested canopy and thus could act as a significant source of available light (Chazdon and Pearch, 1991).These data, along with information on the soil types and existing species, can be used to predict the potential evolution of vegetation assemblages and consequent implications for land management actions inferred.

To simulate solar radiation receipt across a solar park, a model that examines the radiation effect of trees on the ecosystem energy balance (Kettridge *et al*., 2013) has been modified to simulate solar parks. The model determines the spatiotemporal variation in direct and diffuse radiation receipts in 2-D for any given solar park design, driven by real micrometeorological data. This can be used to assess the implications in a wide range of meteorological conditions, capturing inter-annual variations, or using long-term mean data.

In addition to the capability of the model to simulate short wave radiation receipts, the model also has the capacity to simulate long wave radiation, sensible and latent heat fluxes, and thus simulate both the wider soil thermal behaviour of the solar park and an important component of the water balance (evapotranspiration). This information could be useful in determining vegetation community compositions and soil carbon sequestration.

6.3 Modelling vegetation response to the imposed microclimate

Estimating PAR receipts through the above modelling approach, assembling soil measurements and undertake a more detailed vegetation survey adjacent to the proposed PV array would greatly increase the accuracy of modelled estimates of plant community composition and help select appropriate vegetation management options. For example key unknowns at the moment relate to variation in fertility and soil pH at the site. Simple measurements in a representative series of locations would enable us to achieve much greater accuracy in predicting which species will be likely to find conditions suitable given variation in soil moisture and light levels. The first step would be to show that the species niche models can effectively reproduce the current vegetation composition at the site. This builds confidence in the outcomes of the second step which involves predicting the response of the vegetation to scenarios of change in soil moisture and incident light given varying array design. The models therefore act as a filter operating on the species known to occur in the local area indicating which ones will be likely to persist as conditions change and different vegetation management solutions are considered.

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Appendix B – Vegetation modelling methods and additional results

Data used for vegetation analysis

Reference quadrat data was extracted from the 2007 Countryside Survey of Great Britain database (http://www.countrysidesurvey.org.uk/). This survey comprises a GB-wide random stratified sample survey of the countryside and urban fringe. It uses fixed quadrats to record the plant species composition (all vascular plants and common bryophytes) in habitat areas and along the full range of linear features (Smart *et al*., 2003). The last survey covering the whole of Britain was in 2007 resulting in a database of c.18,000 quadrats.

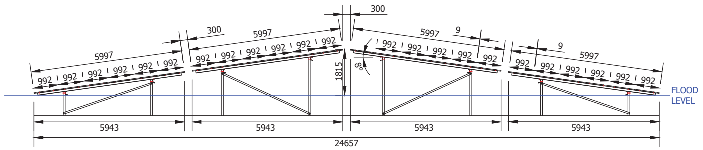
Section 2.1

Vegetation data from Countryside Survey was extracted to define a gradient of shade at ground level. The vegetation type subject to the greatest shade in the Countryside Survey database is middle-aged Sitka Spruce (*Picea sitchensis*) plantation. This reflects the density of stems and the year-round greenness of the canopy. We extracted 200 m^2 quadrat data for any stand with Sitka present. A complex of other factors are likely to be confounded with the shading effect of the Sitka canopy in this dataset. These are associated with the geographic preference for planting in the oceanic west of Britain where high rainfall and peaty, acidic soils are present. These confounding factors reduce the ability of the Sitka understorey data to provide a direct analogue for the species composition we might find under the array at Cleve Hill but our purpose in this section is rather to demonstrate the effect of shade on field layer species richness than to define a possible species compositional profile. To reduce the influence of Sitka data that is ecologically dissimilar to conditions at Cleve Hill we excluded all quadrats containing *Sphagnum* and those in Scotland and in upland zones of England and Wales. Further data was then added to help define a plausible continuum of decreasing shade at ground level. We extracted 200 m^2 data for all other planted conifer stands in lowland England and Wales, also for broadleaved woodland in lowland England and for neutral grassland in lowland England.

Section 2.2

The hedgerow data were extracted from the Countryside Survey of Great Britain database from the most recent survey in 2007. The quadrats are 1x10 m long aligned with the 10 m edge of the quadrat positioned along the centre of the hedge and then defining a 1 m width moving toward the outside of the hedge. Only hedgerow quadrats in the southern and eastern lowlands of England were selected (n=173). The frequency of vascular plants and bryophytes are given in Table A1 and offer insight into the potential species at the edges of solar arrays.

Appendix A - Cleve Hill Solar Park cross-sections



CLEVE HILL

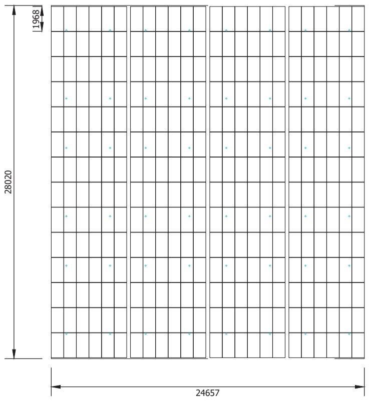
ARCUS

NOTES:
1. ALL DIMENSIONS SHOWN ARE IN MILLIMETRES
2. MODULE DIMENSIONS: 1968x992x40
3. ALL BANKS ARE 5997mm WIDE WITH 300mm SPACING BETWEEN.
4. ALL PANELS ARE 992mm WIDE WITH 9mm SPACING BETWEEN.

Produced By: KB	Ref: 2238-DR-P-0005	Rev:
Reviewed By: DB	Date: 23/05/18	
Approved By: MB	Scale: 1:100	

Figure 5.5a
Mounting Structure Table Elevation

Cleve Hill Solar Park
Preliminary Environmental
Information Report



CLEVE HILL
SOLAR PARK

ARCUS

NOTES:
1. ALL DIMENSIONS SHOWN ARE IN MILLIMETRES

Produced By: KB
Reviewed By: DB
Approved By: MB

Ref: 2238-DR-P-0006
Rev:
Date: 23/05/18
Scale: N.T.S.

Figure 5.5b
Mounting Structure Table Plan

Cleve Hill Solar Park
Preliminary Environmental
Information Report

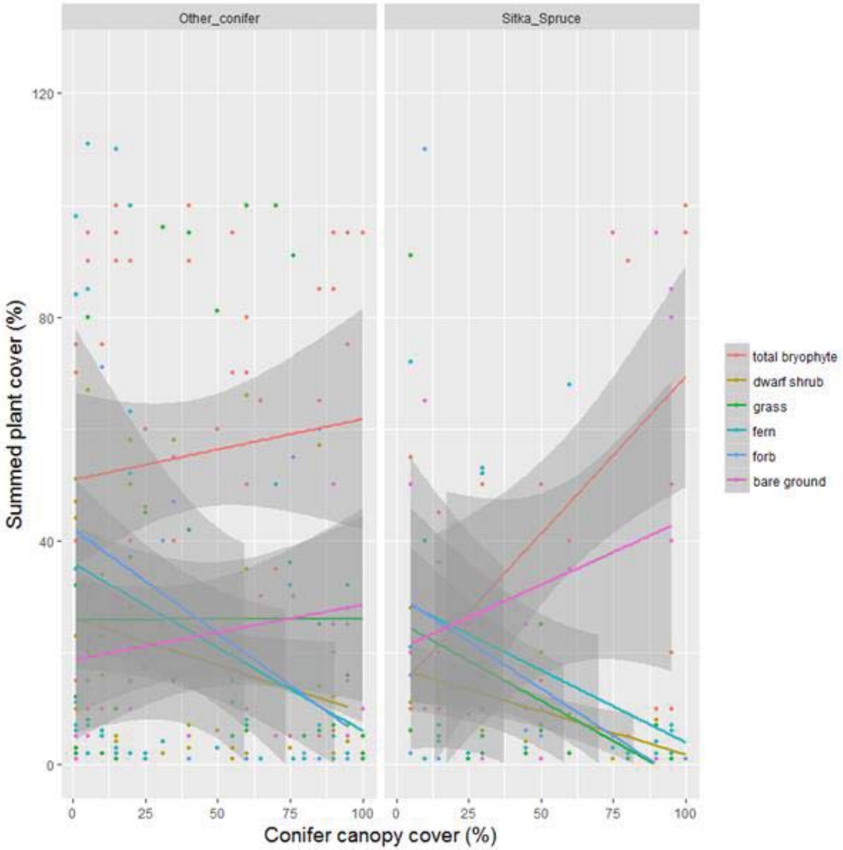


Figure B1. Relationships between cover of plant types and conifer canopy cover in the 200m^2 reference data. Note that the 95% interval on each regression line is truncated where insufficient data exists to estimate it. Sums of all plant types exceed 100% given vegetation layering.

Table B1. Percentage frequency of vascular plants and common bryophytes in reference quadrats representing a random sample of hedgerows in lowland England in 2007 (n=173). Species found in the Phase 1 survey at Cleve Hill are highlighted. Trees and shrubs have been excluded. Nectar plants follow the list in Baude *et al*. (2016). Butterfly larval food plants were extracted from a database held at the Biological Records Centre, CEH Wallingford. Injurious weeds are notifiable under the Weeds Act 1959 (https://www.legislation.gov.uk/ukpga/Eliz2/7-8/54/contents).

Frequency (%)	**Species name**	**Present in the Cleve Hill Phase 1 survey**	**Injurious weed**	**Nectar plant**	**Butterfly larval food plant**
79	*Urtica dioica*	*Y*			1
66	*Galium aparine*			1	
57	*Arrhenatherum elatius*	*Y*			1
57	*Rubus fruticosus agg.*	*Y*		1	
42	*Anthriscus sylvestris*	*Y*		1	
40	*Dactylis glomerata*	*Y*			1
39	*Hedera helix*	*Y*		1	1
39	*Anisantha sterilis*				
34	*Elytrigia repens*				1
29	*Rosa canina agg.*	*Y*		1	
28	*Heracleum sphondylium*	*Y*		1	
26	*Convolvulus arvensis*	*Y*		1	
25	*Cirsium arvense*	*Y*	1	1	1
19	*Poa trivialis*				1
18	*Glechoma hederacea*			1	
18	*Agrostis stolonifera*				
18	*Holcus lanatus*	*Y*			1
14	*Festuca rubra agg.*	*Y*			
12	*Lolium perenne*	*Y*			1
12	*Tamus communis*				
10	*Lamium album*			1	
10	*Stachys sylvatica*			1	
9	*Ranunculus repens*	*Y*		1	
9	*Bryonia dioica*				
8	*Ballota nigra*	*Y*			
8	*Rumex sanguineus*				
8	*Alliaria petiolata*				1
7	*Cirsium vulgare*	*Y*	1	1	1
7	*Chaerophyllum temulentum*				
7	*Geum urbanum*			1	
6	*Silene dioica*	*Y*		1	
6	*Rumex obtusifolius*	*Y*	1		
6	*Bromus hordeaceus*	*Y*			
6	*Agrostis capillaris*				1
6	*Brachypodium sylvaticum*				1
5	*Geranium robertianum*			1	
5	*Mercurialis perennis*				
5	*Pteridium aquilinum*				
5	*Taraxacum agg.*			1	
4	*Arum maculatum*	*Y*			
4	*Veronica chamaedrys*			1	1
4	*Sonchus asper*	*Y*		1	
4	*Calystegia sepium*	*Y*		1	
3	*Eurhynchium praelongum*				
3	*Clematis vitalba*	*Y*		1	
3	*Arctium agg.*	*Y*		1	
3	*Eurhynchium sp.*				

3	*Brachythecium sp.*				
3	*Stellaria holostea*			1	
3	*Equisetum arvense*	Y			
3	*Poa pratensis sens.lat.*				
3	*Plantago major*	Y			1
3	*Plantago lanceolata*	Y		1	1
3	*Avena fatua*	Y			
3	*Lonicera periclymenum*			1	1
3	*Achillea millefolium*	Y		1	
3	*Lapsana communis*			1	
3	*Phleum pratense sens.lat.*	Y			1
3	*Stellaria media*			1	
3	*Solanum dulcamara*			1	
3	*Geranium dissectum*	Y		1	
3	*Senecio jacobaea*	Y	1	1	
3	*Rosa arvensis*				
3	*Deschampsia cespitosa*				1
2	*Ligustrum vulgare*			1	
2	*Alopecurus pratensis*				
2	*Conium maculatum*	Y			
2	*Holcus mollis*				1
2	*Torilis japonica*				
2	*Sonchus oleraceus*	Y		1	
2	*Rumex acetosa*				1
2	*Rosa seedling/sp*				
2	*Potentilla reptans*	Y		1	1
2	*Bellis perennis*			1	
2	*Hypochaeris radicata*			1	
2	*Veronica persica*	Y		1	
2	*Anthoxanthum odoratum*				1
2	*Trifolium repens*	Y		1	1
2	*Trifolium dubium*				1

2	*Agrimonia eupatoria*	Y		1	
2	*Stellaria graminea*			1	
2	*Artemisia vulgaris*	Y			
2	*Sisymbrium officinale*			1	1
2	*Senecio vulgaris*			1	
2	*Angelica sylvestris*			1	
2	*Cerastium fontanum*			1	
2	*Cirsium palustre*			1	1
2	*Prunella vulgaris*			1	
2	*Epilobium hirsutum*	Y		1	
2	*Poa annua*	Y			1
2	*Digitalis purpurea*			1	1
1	*Cynosurus cristatus*	Y			1
1	*Silene latifolia*				
1	*Galium mollugo*			1	
1	*Lathyrus pratensis*	Y		1	1
1	*Triticum aestivum*	Y			
1	*Viola riviniana*			1	1
1	*Vicia cracca*			1	1
1	*Humulus lupulus*				1
1	*Hordeum murinum*	Y			
1	*Bromus racemosus*				
1	*Centaurea nigra*			1	
1	*Geranium molle*	Y		1	1
1	*Cruciata laevipes*				
1	*Rumex crispus*	Y	1		
1	*Brachythecium rutabulum*				
1	*Ranunculus acris*			1	
1	*Hyacinthoides non-scripta*			1	
1	*Trisetum flavescens*				
1	*Bromus commutatus*				
1	*Myosotis arvensis*			1	

1	*Moehringia trinervia*				
1	*Cardamine hirsuta/flexuosa*			1	
1	*Carduus crispus*				
1	*Lamiastrum galeobdolon*			1	
1	*Teucrium scorodonia*			1	
1	*Festuca arundinacea*				
1	*Phragmites australis*				
1	*Capsella bursa-pastoris*	*Y*		1	1
1	*Anthriscus caucalis*				
1	*Lolium multiflorum*				
1	*Vicia sativa*			1	
1	*Knautia arvensis*			1	1
1	*Rhytidiadelphus squarrosus*				
1	*Poa angustifolia*				
1	*Coronopus didymus*				
1	*Veronica filiformis*				
1	*Galeopsis tetrahit agg.*			1	
1	*Crepis capillaris*			1	
1	*Festuca pratensis*				1
1	*Crepis biennis*				
1	*Polygonum aviculare agg.*			1	
1	*Elymus caninus*	*Y*			
1	*Anagallis arvensis*	*Y*			
1	*Geranium pratense*			1	
1	*Lythrum salicaria*			1	
1	*Matricaria discoidea*	*Y*		1	
1	*Trifolium pratense*	*Y*		1	1
1	*Potentilla anserina*			1	1
1	*Filipendula ulmaria*				
1	*Rubus caesius*				
1	*Juncus effusus*	*Y*			
1	*Ruscus aculeatus*				

1	*Fissidens sp.*				
1	*Juncus articulatus/acutiflorus*				
1	*Centaurea scabiosa*			1	
1	*Vicia hirsuta*				
1	*Alopecurus myosuroides*				
1	*Lamium purpureum*	*Y*		1	
1	*Petasites fragrans*				
1	*Galium verum*			1	
1	*Hypericum perforatum*				
1	*Sinapis arvensis*			1	
1	*Anchusa arvensis*			1	
1	*Ajuga reptans*			1	
1	*Malva sylvestris*	*Y*			
1	*Anisantha diandra*				
1	*Vicia tetrasperma*				
1	*Chamerion angustifolium*			1	
1	*Epilobium montanum*			1	
1	*Carex remota*				
1	*Lotus corniculatus*	*Y*		1	1
1	*Bromopsis erecta*				1
1	*Veronica hederifolia*				
1	*Primula vulgaris*			1	1
1	*Hypericum calycinum*				
1	*Solanum nigrum*				
1	*Carex hirta*				
1	*Leucanthemum vulgare*			1	
1	*Juncus bufonius sens.lat.*				
1	*Pseudoscleropodium purum*				