BUTTERFLY COLONISATION OF A NEW CHALKLAND ROAD CUTTING

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Abstract

1. The design of new roads has the potential to provide new habitats and increase biodiversity value. The cutting and verges of the Weymouth Relief Road, Dorset, completed in 2011, replicate low-fertility chalk grassland in an area previously occupied by arable farmland and improved grassland.
2. We examine the results of post-construction butterfly surveys carried out in 2012-2020 to test whether butterfly abundance, species richness and species diversity increased in the post-construction period. Analysis is also undertaken of the factors affecting the colonisation of the verges by butterfly populations.
3. Butterfly abundance increased in the post-construction period when assessed by two methods: mean counts per survey visit and maximum counts. Species richness also increased, but no significant trends were observed with respect to species diversity. The 30 butterfly species recorded on the verges represent 51% of Britain's resident or regularly occurring migrant species and include habitat-restricted chalkland species.
4. The most significant factor affecting speed of colonisation of the cutting and verges was an index of local presence, defined as the number of 1 km squares where 2 or more individuals of a species had been recorded prior to road construction in a 10 km square centred on the site. The separation distance between the site and the nearest butterfly population did not significantly affect the speed of colonisation.
5. Our results validate the low fertility approach to road verge establishment and management. The experience of the Weymouth Relief Road is influencing future road verge construction and management in the UK.

Key words

Biodiversity, colonisation, dispersal, butterfly populations, road verges, habitat creation.

Introduction

Urbanisation and infrastructure construction are among the main drivers for habitat loss and biodiversity decline across the globe (Venter et al., 2016). Declines are identified in indicators for many taxa, including negative trends in population change, extinction rates, and the extent and condition of habitats (Butchart et al., 2010). Even highly conservative extinction rates for vertebrate groups have been shown to exceed estimated 'background' extinction rates (Ceballos at al., 2015). More recently, the focus has expanded to consider declines in less well-studied taxa, including insects. Insects perform essential functions within ecosystems, such as pollination services and the provision of food for other animal groups (Schowalter et al., 2018). Studies suggesting a global 'insect apocalypse' have been questioned (Montgomery et al. 2020; Didham et al., 2020), with the evidence now pointing towards more complex and heterogenous patterns in insect population trends (Wagner et al, 2021b). Nevertheless, there are clear examples of significant insect declines in Northern Hemisphere regions where human impacts, such as increasing urbanisation, are particularly severe (Fox et al., 2015; Wagner et al, 2021a; Warren et al., 2021; Fox et al. 2021).

The construction of new roads is considered to have detrimental biodiversity effects as a result of the disturbance or complete removal of existing ecosystems, habitat fragmentation, pollution and collision mortality (Forman and Alexander, 1998; Skórka et al., 2013). However, the value of road verges as a potential biodiversity resource is becoming increasingly recognized (Gardiner et al., 2018). It has been estimated that there are over 504,000 km of rural road verges in the United Kingdom (Bromley et al., 2019), representing a substantial potential habitat resource, particularly in areas of intensive agriculture containing few opportunities for biodiversity enhancement.

The ecological value of road verges has been assessed in the context of wider studies of habitat creation and restoration. Initially focused largely on plant communities and individual plant species (for example Verhagen et al, 2001), these have broadened out to consider animal colonisation of newly created and restored landscapes (for example: Ries et al, 2001; Saarinen et al., 2005; Valtonen et al., 2006). Such studies have informed the debate about the relative importance of limiting factors, notably habitat quality and population isolation, that affect the persistence of animal populations in fragmented landscapes (WallisDeVries and Ens, 2008; Viljur and Teder, 2018). This persistence derives from a balance between the local extinction of individual populations and the colonisation of previously-vacant habitat patches (Thomas et al., 2001).

Butterflies are an appropriate study taxon for the evaluation of a grassland habitat creation project. They occupy several ecological niches, exhibit a range of life history strategies and rely upon a variety of larval food resources (Asher et al., 2001). Studies have shown that road verges have the potential to support abundant and diverse butterfly communities, including habitat-sensitive species (Ries et al., 2001; Wynhoff et al., 2011). UK butterflies can be split into habitat specialists and wider countryside species (Dapporto and Dennis, 2013; Warren, 2021). Most UK butterfly species are conspicuous and easy to identify and record. The UK Butterfly Monitoring Scheme (UKBMS) is a well-established and validated methodology for long-term monitoring programmes (Pollard and Yates, 1993; Van Swaay et al., 2008; UKBMS, 2019). Relevant to the present study, butterfly recording is well-established in the county of Dorset, with a succession of 1 km grid square county atlases having been produced since 1970 (Thomas and Webb, 1984; Thomas et al., 1998; Butterfly Conservation Dorset Branch, 2020).

Investigation of local butterfly movement patterns has identified the role of habitat differences in restricting dispersal; for example, open-habitat species are known to avoid crossing boundaries between their habitat and a dense treeline (Cant et al., 2005). Nevertheless, dispersal over apparently inhospitable habitats, and the resulting colonisation of isolated patches, has been shown to take place (Viljur and Teder, 2018). It has been suggested that this occurs mostly through special movements that are designed for net displacement and settlement away from the point of origin rather than routine movements associated with, for example, foraging or other resource exploitation (Van Dyck and Baguette, 2005). Dispersal therefore may be a less important limitation on the colonisation of new habitat patches than the quality of the new habitat itself (WallisDeVries and Ens, 2008; Viljur and Teder, 2018). However, given that the potential for an individual species to move through a landscape is varied, it is also necessary to consider both the capacity of a species to undergo such movements and the nature of the environment through which the movements are taking place, for example in respect of consumables (such as food plants) and utilities (such as sites to pupate) – the resource-based habitat concept (Dennis, 2010; Dennis et al, 2013).

Construction of the Weymouth Relief Road (WRR) in Dorset, southern England, provides an opportunity to examine colonisation by butterflies of a new habitat designed to replicate low-fertility chalk downland, located within a landscape of arable farmland and improved grassland. This study explores how the new cutting and verges have been colonised by butterfly species in the nine years following road construction, reviewing changes in butterfly abundance, species richness and species diversity and relating these data to previous surveys in the locality. The specific hypotheses tested were, first, that butterfly abundance, species richness and species diversity would all exhibit a linear increase in the years following road construction and, second, that the speed of colonisation for individual species would have a significantly positive relationship with the proximity of the nearest previously-established population, the degree of presence of that species in the wider locality, the mobility of the species concerned and/or its ecological traits (voltinism and whether it is a generalist or habitat specialist).

Methods

Study Site

The Weymouth Relief Road (WRR) is an approximate 5 km section of the A354 road linking Dorchester and Weymouth in Dorset, southern England. Constructed between 2009 and 2011 to bypass a residential area experiencing traffic congestion, the road cuts through Ridgeway Hill, an Upper Chalk escarpment at a height of approximately 140 metres above sea level (ASL). Prior to road construction, the land was in use as arable farmland with some improved grassland (Dorset County Council, 2005). Creation of a species-rich chalk grassland was an explicit aim of the design and construction of the Ridgeway Hill cutting and verges (Sterling, 2019). Ridgeway Hill was not subject to detailed pre-construction butterfly surveys. The present study site, which comprises the flat verge on the eastern side of the road and the steep sparsely vegetated slopes above (which have been fenced), totals some 3.6 ha in area, and is between 26 and 80 metres wide.

Contrary to usual practice, which is to apply 150mm of topsoil to areas destined for grassland, the eastern cutting was not treated with topsoil, save for a scattering of 15mm in some places. In

2010/2011 the site was hand-sown with a mix of characteristic calcareous grassland plants recorded from the area, with further sowing in 2012/13 (Edwards, 2013). Sowing took place at a rate of 2g per square metre. A resurvey in 2019 showed that all of the sown species remained, with *Hippocrepis comosa* L., *Anthyllis vulneraria* L. and *Leucanthemum vulgare* being the most common, and that additional species had become established, notably chalkland indicators such as *Thymus drucei* Ronninger, *Blackstonia perfoliata* Huds., *Cirsium acaule* Scop. and *Pilosella officinarum* F.W. Schulz & Sch. Bip (Edwards, 2019). The cutting is fenced and subject to occasional grazing. However, a formal management regime is yet to be finalised (A. King, pers. comm.).

Field Surveys

In 2018 a UKBMS site containing nine transect sections was established at Ridgeway Hill. However, butterfly counts broadly consistent with UKBMS protocols had commenced on the eastern cutting and verges (Ridgeway Hill East) in 2012. These counts followed the route that now comprises UKBMS transect sections 1 and 2 – a combined transect length of some 625 metres. Public access to the cutting is limited, and the transect sections follow footpaths from a high point of 140 metres ASL to finish at a point where the road emerges from the cutting onto an embankment to the south of Ridgeway Hill (90 metres ASL).

For the purposes of comparison, the present study combines 2012-2017 survey data from Ridgeway Hill East with 2018-2020 data from sections 1 and 2 of the UKBMS transect. As noted above, the earlier data are from the same route as the later transects. Local survey personnel, all of whom were experienced in operating UKBMS procedures, overlapped the two periods. Between 10 and 20 transects were walked each year during the combined survey period. Butterflies were identified to species level. Butterfly nomenclature and species order in this paper follows Agassiz et al. (2013). Plant nomenclature and authority abbreviations follow Stace (2019). Survey data are summarised in table S1 (supporting information).

Surveys were undertaken where possible on suitable days every week from April to September, although surveys in the initial year (2012) only took place between late May and mid-August, resulting in a reduced number of visits. While a number of early-flying species such as *Pyrgus malvae* L., *Erynnis tages* L. and *Anthocharis cardamines* L. may have been under-counted in that year, the survey periods included a substantial part (>50%) of the local flight periods of the species concerned (Thomas et al., 1998). It is therefore likely that these species would have been recorded if present. In a number of cases where the transects were walked more than once during a single survey week, the data have been averaged for that week and the number of visits adjusted accordingly.

Colonisation Study

The number of years taken for a species to colonise the site was calculated for all species, with the exception of three species – *Colias croceus* (Geoffroy, 1785), *Vanessa atalanta* (Linnaeus, 1758) and *Vanessa cardui* (Linnaeus, 1758) – where populations are largely, or entirely, maintained by continental migration (Dapporto and Dennis, 2013). In order to exclude single vagrant butterflies, colonisation was taken to have occurred when 2 or more individuals of a species were recorded at the site in the same year (maximum count data). This is a somewhat more robust criterion than the initial record of a species applied by Woodcock et al. (2012). A total of 20 species were therefore considered in the colonisation study (table S2 – supporting information).

Butterfly presence prior to WRR construction was calculated from 2005-2009 butterfly survey data supplied on 1 km grid maps prepared by Dorset Environmental Records Centre using DMAP for Windows. A variety of sources contributed to these data, notably surveys organized by Butterfly Conservation Dorset Branch. Separation distances to the nearest established population were calculated between the centroid of the 1km square containing the WRR survey transects (SY6785) and the centroid of the nearest 1 km square containing 2 or more individuals of the relevant species. Squares containing a record of a single butterfly were discounted in order to exclude vagrant records.

An index of local presence was calculated by counting the number of 1 km squares where two or more individuals of a species had been recorded in a 10 km square centred on the survey 1 km square during the 2005-2009 period. These range from 0 squares (*Thymelicus lineola* (Ochsenheimer, 1808) and *Cupido minimus* (Fuessly, 1775)) to a maximum of 26 squares (*Maniola jurtina* (Linnaeus, 1758)). Given that 69 squares within the 10 km square contain at least one record in the data set, this represents a well-recorded locality, with records from 71% of terrestrial 1 km squares (three squares are exclusively maritime). The potential effect of species' mobility was investigated using a mobility score derived by Dennis (2010) (quoted in Warren, 2021). Species' habitat preferences (either habitat specialists or wider countryside generalists) were taken from Warren (2021), while data on voltinism uses Dorset flight periods (Thomas et al., 1998).

Statistical Analysis

All statistical analyses were carried out in R 3.6.1 (R Core Team, 2020). Significance for tests was adopted as P=0.05.

Given the variation in sampling effort over the survey period, abundance data are presented as mean butterfly numbers per survey visit. However, in order to check the validity of the use of mean butterfly numbers per survey visit, abundance was also calculated using maximum count data.

Shannon-Weiner and Simpson's diversity indices were calculated from the mean butterfly numbers per survey visit. Along with mean abundance per visit and species richness, these variables were found to be normally distributed through the survey period. Trends in these data over the study period were therefore investigated by linear regression, with the exception of six species where numbers were too low for meaningful analysis. The linear models were verified to test for normal distribution of residuals. The trend in the cumulative number of species recorded on the WRR was investigated by a polynomial regression, which was found to explain more variation than a logarithmic relationship.

For analysis of the colonisation data with arrival year as the response variable, generalized linear models with Poisson errors and a log link function were used. We tested whether the speed of colonisation was affected by the proximity of existing populations and the index of local presence using a Poisson GLM with arrival year as the response variable and separation distance, index of local presence and mobility score as three explanatory variables. The numeric explanatory variables had a weak collinearity (all pairwise correlations ≤ 0.57), so none were initially excluded from analysis. However, the proximity of existing populations, the species' mobility scores and their ecological traits (degree of habitat specialisation and voltinism) were found to have no significant effect on the year of arrival, so were removed from the Poisson GLM. The effect of the ecological traits on arrival year were separately explored using Wilcoxon *U*-tests.

Results

Survey Effort

Two butterfly transects along the eastern cutting of the Weymouth Relief Road (WRR) were surveyed over nine years following the road's construction in 2010/11. The transects were walked during a total of 173 weeks between April and September of each year, with 5845 butterflies of 30 species being recorded in total. The number of butterfly species present in any one survey year ranged from 13 species in 2012 (the first survey year) to a peak of 27 species in 2017.

Abundance

There was a significant increase in total butterfly abundance per survey visit during the period (F=81.54, DF = 1, 7; R-squared = 0.92; P<0.001) (figure 1). A similar trend was found with the maximum count for all species combined (the sum of each species' maximum counts for the year concerned), which was found to significantly increase over the study period (F=7.56, DF = 1, 7; R-squared = 0.52; P=0.029).

Changes in the abundance of individual species were analysed using both mean butterfly abundance and maximum count data. Only three species showed significant increases in both analyses: *Melanargia galathea* (Linnaeus, 1758) (P<0.001 and P<0.01 respectively), *Aphantopus hyperantus* (Linnaeus, 1758) (P=0.024 and P=0.030) and *C. minimus* (P=0.047 and P=0.049). Significant increases in mean butterfly abundance alone were found for *M. jurtina* (P=0.034) and *Pyronia tithonus* (Linnaeus, 1771) (P=0.049), while maximum counts increased significantly for *T. lineola* (P=0.031) and *Polyommatus bellargus* (Rottemburg, 1775) (P=0.023). Maximum counts of *Lasiommata megera* (Linnaeus, 1767) showed a significant decline (P<0.001), while no significant declines were found in mean abundance of any species. The differences in the findings between the two analyses, the relatively small numbers of some of the species sampled and, in some cases, the marginal degree of statistical significance, suggest that species-level findings should be viewed with caution. Nevertheless, it is clear that at least one grassland species (*M. galathea*) has benefitted significantly from the creation of this habitat.

Species richness

Initial colonisation of the site by butterfly species was rapid, with the rate of new additions decreasing markedly during the study period. This pattern was best explained by a polynomial regression ($F=56.9$; $DF = 2, 6$; R-squared=0.95; $p<0.001$) (figure 2). Several species ceased to be recorded during the study period, suggesting either a dynamic pattern of arrivals and local extinctions, or, in the case of species with very small counts such as *Gonepteryx rhamni*, (Linnaeus, 1758), vagrancy. Annual species richness showed a significant increase during the study period ($F=6.55$, $DF = 1, 7$; R-squared = 0.48; $p=0.038$) (figure 1).

Species Diversity

Changes in species diversity were assessed using the Shannon-Weiner and Simpson's diversity indices (Gardener, 2017). In both cases, an initially high species diversity reduced during the first two years following the road's construction but then returned to its original level towards the end of the study, following a V-shaped pattern (figure 3). No significant linear relationship was observed in respect of species diversity during the overall study period (Shannon-Weiner: $F=1.96$, $DF = 1, 7$; $P=0.204$; Simpson's: $F=0.82$, $DF = 1, 7$; $P=0.396$).

Colonisation

There was a significant negative relationship between the year of butterfly arrival and the local presence of the species, defined as the number of 1 km squares previously occupied by the species in a 10km square centred on the survey site ($Z=2.62$, $DF=19$, R-squared=0.42, $P=0.0089$) (figure 4). Greater local presence was therefore found to increase the speed of butterfly arrival. However, the proximity of existing populations, the species' mobility scores and their ecological traits (degree of habitat specialisation and pattern of voltinism) were found to have no significant effect on the speed of arrival.

Discussion

Overview

This study documents the expansion and development of the butterfly fauna on a roadside cutting and verges designed to replicate low-fertility chalk downland. It demonstrates that suitably designed and seeded verges can create an impressively species-rich butterfly habitat, supporting the view that road verges can support biodiversity conservation (Gardiner et al., 2018; Bromley et al., 2019).

Thirty butterfly species were recorded, with a maximum of 27 in any one year (table S1). Butterfly abundance and species richness were found to increase significantly during the nine-year study period, although species diversity measured by two indices did not show significant linear trends. Investigation of butterfly data for the wider locality demonstrated that the speed of colonisation of the road verges by butterfly species was significantly related to the degree of local presence of that species but had no significant relationship to the proximity of the nearest population of that species, its mobility score as defined by Dennis (2010) or other ecological traits.

Creation of a species-rich butterfly habitat

The 30 butterfly species recorded on the WRR verges represent 51% of Britain's resident or regularly occurring migrant species (Asher et al., 2001), and 63% of those occurring regularly in Dorset (Thomas et al., 1998). It is a substantial number by British standards, and approaches that of comparable chalk downland nature reserves. For example, 35 butterfly species have been recorded at the Dorset Wildlife Trust reserve of Fontmell and Melbury Downs, which is designated as a Site of Special Scientific Interest and Special Area of Conservation (Branson, 2015). Five of the species recorded on the WRR verges are identified as priority terrestrial invertebrate species in the UK Biodiversity Action Plan 2007 (JNCC, 2007): *Coenonympha pamphilus* (Linnaeus, 1758), *C. minimus*, *Erynnis tages* (Linnaeus, 1758), *L. megera* and *Pyrgus malvae* (Linnaeus, 1758). In addition, two geographically restricted species – *Polyommatus coridon* (Poda, 1761) and *P. bellargus* – that exclusively use chalk and limestone grassland (Asher et al., 2001) were recorded in the study; these have not previously been recorded within the site's immediate locality (Thomas et al, 1998). This finding amplifies the view, discussed further below, that the restoration success of the cutting and verges was not significantly impeded by dispersal limitation.

The increase in butterfly abundance and species richness that followed construction of the road and seeding of the cutting is consistent with a model of populations establishing at the site as the vegetation has increased in maturity and diversity. Although a theoretical limit to abundance may be expected based upon the site's carrying capacity in respect of food resources, notably the availability of food plants and nectar (Curtis et al., 2015), there is no evidence that this has yet been reached on the Weymouth Relief Road cutting. As such, the biodiversity value of the site can be expected to continue to improve for the time being, subject to continued appropriate management.

Given the significant increases in abundance and species richness, it might have been expected that species diversity would also have increased during the study period. However, analysis of two diversity indices (Shannon-Weiner and Simpson's) showed no significant linear trend. For both indices, species diversity declined sharply in the first two years before increasing towards the end of the study period, creating a U-shaped pattern. This is explained by the dominance of two species – *Pieris rapae* (Linnaeus, 1758) and *Polyommatus icarus* (Rottemburg, 1775) – which together accounted for 57% of the total mean butterfly abundance in 2014, followed by the sole dominance of *P. icarus* which accounted for 52% of mean butterfly abundance in 2015.

Although several roadside butterfly faunas have been previously studied – for example in Iowa, USA (Ries et al., 2001), Finland (Saarinen et al., 2005; Valtonen et al., 2006) and Poland (Skórka at al, 2013) – most are not directly comparable to the WRR site, given the UK's relatively low butterfly species richness. An exception is a study in Dorset and Hampshire, UK, where twelve road verges were examined using similar transect methods to the present study (Munguira and Thomas, 1992). Those authors recorded a total of 27 species across all sites, with the richest site (Bere Regis, Dorset) containing 23 species. The verges sampled in the 1992 study were therefore markedly less species rich than the WRR site. This may be a function of the geological characteristics of the verges surveyed at that time, as well as the shorter survey length (100 metre transects compared with the 625 metres surveyed at the WRR) and the larger size of the WRR verges and cutting (for example, the Bere Regis verge totalled 1.4 ha in area, under half the area of the WRR site) (Munguira and Thomas, 1992). Nevertheless, a comparison of the two studies suggests that the adoption of the low fertility approach on the WRR cutting and verges has resulted in the creation of a richer butterfly habitat than other road verges in the county and its neighbour.

While systematic surveys of the Lepidoptera of Ridgeway Hill were not undertaken prior to the WRR's construction, historic butterfly survey data for the 1 km square suggests that species richness was markedly lower; for example, during the survey period 1980-1996, only 22 species of butterfly were recorded (Thomas et al., 1998), although the degree of survey activity at that time is unlikely to have been consistent with efforts in the present study. No survey data for this 1 km square is available for the period (2005-2009) immediately prior to WRR construction. Nevertheless, it appears that the road verges' establishment within an area previously occupied by arable farmland and improved grassland has resulted in a material biodiversity gain.

Colonisation

Construction of the Weymouth Relief Road cutting has created habitat of a suitable quality to attract colonisation by both generalist (wider countryside) and habitat specialist butterfly species (Dapporto and Dennis, 2013; Warren, 2021). However, the finding that speed of colonisation is not related to the separation distance between the site and the nearest population of the species concerned is, at first sight, surprising. The relationship between degree of local presence and arrival year suggests that colonisation is not a simple process involving small scale movements from a single population, but is more likely to be the product of more complex movements involving a number of local populations. Such movements may well be amplified by longer range dispersal – the special movements described by Van Dyck and Baguette (2005). In the present study, a number of outlying data points suggest movements of this nature, notably the colonisation by *C. minimus* and *T. lineola* in years 1 and 3 respectively – species that had no 2005-2009 records within the 10km square centred on the study site and nearest populations some 8-10 km distant. This degree of dispersal is unexpected; both species are classed as 'sedentary' by Pollard and Yates (1993), while Dennis (2010) attaches mobility scores of 2 (low) and 4 (medium) respectively to these species. It is however also possible that both species have been previously under-recorded in the site's wider vicinity, a concern that especially applies to *T. lineola* given the potential for confusion with the similar *Thymelicus sylvestris* (Poda, 1761). Nevertheless, the present study is consistent with a resource-based habitat model that shows a wide variability in the dispersal and colonisation activity of UK butterfly species (Dapporto and Dennis, 2013). It also accords with the view of Dennis et al. (2013) that all butterfly species, even the most sedentary, are to some extent capable of crossing apparently 'empty' landscape areas.

Looking forward, it is noted that two species that have previously been recorded in the survey 1 km square – *Hipparchia semele* (Linnaeus, 1758) and *Thymelicus acteon* (Rottemburg, 1775) – have yet to appear on post-construction transect surveys. *H. semele* is a species generally declining in abundance and distribution in the British Isles (Asher et al., 2001). The nearest record of this species during the 2005-2009 survey period was some 4 km east of the WRR site. This species uses a variety of grasses as larval foodplants, favouring sites with sparse vegetation and bare ground. These factors suggest it as a potential future colonist of the WRR cutting and verges. The distribution of *T. acteon*, which in the British Isles is restricted to south Dorset, is strongly determined by the presence of its larval foodplant *Brachypodium rupestre* Host. Although not part of the original seed mix, and not recorded in 2013, this grass species is now present on both the eastern and western cuttings, suggesting that *T. acteon* could be a potential future colonist.

A further species of South Dorset's calcareous grasslands is *Plebejus argus* (Linnaeus, 1758). Its nearest populations to the WRR cutting and verges are on limestone grassland at Portland, some 12 km to the south, and on heathland at Tadnoll, some 12 km to the east (Butterfly Conservation Dorset Branch, 2020). This is a somewhat greater degree of separation than the largest distance suggested by the present study (10.2 km for *T. lineola*). Intervening habitats, comprising urban areas and open water to the south of the WRR site and farmland (mainly arable and improved grassland) to the east, appear unfavourable for this species and may indeed form a true barrier to dispersal. Taking these factors together, and bearing in mind its particularly low relative mobility (Cowley et al., 2001), *P. argus* would therefore appear to be an unlikely coloniser of the WRR site, despite the presence of suitable larval foodplants such as *H. comosa* and *Lotus corniculatus* L..

As already noted, several species that have been observed on the WRR did not appear in sufficient quantities in the present survey to be considered as colonists. One of these (*P. coridon*), first recorded on the transects in 2017, has the potential to become established at the site given the abundance of *H. comosa* in the cutting. Absence of this larval food plant has been suggested as the main factor limiting recolonisation of previously suitable sites by this species (Brereton et al., 2007). Several of the other species (including *Anthocharis cardamines* L., G*. rhamni*, *Polygonia c-album* L. and *Celastrina argiolus* L.) depend upon larval food plants that are either rare or absent on the WRR eastern cutting, which at present lacks substantial hedgerows, areas of shrubs or shading – the last factor being also likely to deter *Parage aegeria* L. *Gonepteryx rhamni* has been recorded breeding in an area of planted scrub on the opposite side of the WRR, to the south of the present survey site. Future woody shrub growth on or adjacent to the eastern cutting, for example through natural succession, could increase the range of butterfly species colonising the study site, although excessive cover could threaten those grassland species that are presently established.

Conclusions

This study provides a validation of the low fertility approach to road verge establishment and management. Road verges represent previously-overlooked resources with the potential to provide good quality habitat in their own right as well acting as corridors or ‘stepping stones’ that can create linkages in presently fragmented landscapes. Appropriate road verge design and management can therefore form part of a wider strategy aimed at reducing declines in butterfly populations (Warren et al., 2021). Encouragingly, the example of the Weymouth Relief Road cuttings and verges has been cited by Highways England in support its recent Major Project Instruction (MPI) on the adoption of Low Nutrient Grasslands for major schemes on the strategic road network. This MPI is intended to create a step change towards a long-term objective of maximising biodiversity opportunities through the delivery of road improvement projects, through the creation of grassland biodiversity on its soft estate while also reducing maintenance requirements (Highways England, 2020).

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Conflict of interest

The authors declare that there is no conflict of interest.

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TABLES (SUPPORTING INFORMATION)

	2012		2013		2014		2015		2016		2017		2018		2019		2020	
	Total/visit	Max Count	Total/visit	Max count	Total/visit	Max count	Total/visit	Max count	Total/visit	Max count	Total/visit	Max count	Total/visit	Max count	Total/visit	Max count	Total/visit	Max count
Erynnis tages	0.00	0	0.00	0	0.05	2	0.20	2	0.31	2	0.74	7	0.35	6	2.26	18	0.06	1
Pyrgus malvae	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.05	2	0.00	0	0.00	0	0.00	0
Thymelicus lineola	0.00	0	0.00	0	0.00	0	0.13	2	0.00	0	0.32	8	0.00	0	0.26	5	1.76	13
Thymelicus sylvestris	0.00	0	0.00	0	0.37	3	1.00	7	1.08	7	2.63	34	0.90	5	0.26	2	2.18	7
Ochlodes sylvanus	0.00	0	0.05	1	0.11	2	0.27	2	0.23	2	0.21	3	0.80	5	0.26	4	0.12	1
Anthocharis cardamines	0.00	0	0.05	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Pieris brassicae	1.20	8	0.70	11	0.05	1	0.47	4	0.38	3	0.42	3	0.65	3	0.42	5	1.29	5
Pieris rapae	0.60	2	4.80	33	0.74	5	1.33	9	2.00	8	0.63	3	1.10	3	2.11	16	3.29	9
Pieris napi	0.00	0	0.15	2	0.05	3	0.20	3	0.15	3	0.05	1	0.10	1	0.00	0	0.06	1
Colias croceus	0.00	0	1.70	21	0.47	6	0.07	1	0.08	1	0.26	2	0.30	5	0.68	6	0.18	1
Gonepteryx rhamni	0.00	0	0.10	1	0.05	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.06	1
Lasiommata megera	0.30	3	0.25	3	0.26	3	0.13	2	0.23	2	0.21	2	0.10	1	0.05	1	0.29	1
Pararge aegeria	0.00	0	0.00	0	0.00	0	0.07	1	0.15	1	0.05	1	0.00	0	0.00	0	0.00	0
Coenonympha pamphilus	0.00	0	0.00	0	0.00	0	0.27	2	0.31	2	0.05	1	0.20	3	0.05	1	0.06	1
Aphantopus hyperantus	0.10	1	0.00	0	0.05	1	0.00	0	0.00	0	0.21	4	0.35	4	0.16	2	0.35	4
Maniola jurtina	2.30	16	1.75	20	3.58	21	4.87	26	5.62	27	12.37	51	10.05	26	5.58	22	7.94	33
Pyronia tithonus	0.20	2	0.20	3	0.47	5	0.33	2	0.23	2	1.89	17	0.30	3	1.05	7	4.88	33
Melanargia galathea	1.30	9	0.20	2	1.37	16	1.87	19	2.15	19	5.00	46	6.50	45	7.11	104	12.59	57
Vanessa atalanta	0.30	2	0.25	2	0.16	1	0.20	2	0.08	1	0.37	2	0.05	1	0.21	1	0.06	1
Vanessa cardui	0.20	1	0.10	1	0.00	0	0.40	3	0.54	3	0.16	2	0.20	2	1.16	5	0.00	0
Aglais io	0.00	0	0.25	2	0.26	2	0.33	3	0.31	3	0.21	2	0.20	1	0.21	2	0.41	4
Aglais urticae	0.80	4	2.75	18	2.53	19	1.07	7	0.92	3	0.74	4	0.70	5	0.16	1	0.53	3
Polygonia c-album	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.16	1	0.00	0	0.00	0	0.06	1
Lycaena phlaeas	0.00	0	0.05	1	0.05	1	0.07	1	0.00	0	0.05	1	0.00	0	0.16	1	0.06	1
Cupido minimus	1.10	10	0.75	5	0.58	7	2.93	20	2.08	20	2.53	31	4.95	30	16.47	76	5.47	21
Celastrina argiolus	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.05	1	0.00	0	0.00	0	0.00	0
Aricia agestis	0.10	1	0.05	1	0.05	1	0.40	4	0.31	4	0.37	3	0.00	0	0.53	3	0.12	1
Polyommatus icarus	0.7	5	7.55	58	11.95	89	13.87	35	10.77	61	6.05	24	7.35	19	4.47	11	2.06	5
Polyommatus bellargus	0	0	0.00	0	0.16	2	0.00	0	0.00	0	0.53	7	2.65	24	4.84	25	1.00	10
Polyommatus coridon	0	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.05	1	0.00	0
All Species	9.20		21.70		23.37		30.47		27.92		36.32		37.80		48.51		44.88	
Number of visits	10		20		19		15		13		19		20		19		17	

Table S1: Weymouth Relief Road eastern cutting – mean annual butterfly numbers per survey visit maximum counts for each species. Mean annual butterfly numbers and visit numbers have been adjusted to correct for several occurrences of multiple visits during a single survey week.

	Arrival Year	Separation Distance (km)	Index of Local Presence	Mobility Score	Habitat Specialisation	Generations
Erynnis tages	3	2.83	4	2	HS	1
Pyrgus malvae	6	7.28	0	2	HS	1
Thymelicus lineola	3	10.2	0	4	WC	1
Thymelicus sylvestris	3	2	5	5	WC	1
Ochlodes sylvanus	3	2	6	5	WC	1
Pieris brassicae	1	1	24	8	WC	2
Pieris rapae	1	1	23	8	WC	2
Pieris napi	2	2	11	7	WC	2
Lasiommata megera	1	1	7	5	WC	2
Coenonympha pamphilus	4	1	7	4	WC	2
Aphantopus hyperantus	6	2	4	3	WC	1
Maniola jurtina	1	1	26	6	WC	1
Pyronia tithonus	1	2	20	4	WC	1
Melanargia galathea	1	2	11	2	WC	1
Aglais io	2	2	13	8	WC	2
Aglais urticae	1	1	9	8	WC	2
Cupido minimus	1	8.06	0	2	HS	1
Aricia agestis	4	2	4	2	WC	2
Polyommatus icarus	1	1	8	6	WC	2
Polyommatus bellargus	3	1.41	7	1	HS	2

Table S2: Colonisation data. Arrival year 1 is 2012. Butterfly survey data for the 2005-2009 period supplied on 1 km grid maps prepared by Dorset Environmental Records Centre using DMAP for Windows. Index of local presence represents the number of 1km squares in which the species was recorded (2005-2009) within a 10km square centred on the Weymouth Relief Road cutting at Ridgeway Hill East. Mobility categories from Dennis (2010) cited in Warren (2021). Habitat specialism - 'Habitat Specialist' (HS) and 'Wider Countryside' (WC) – from Warren (2021). Data on voltinism is from Dorset butterfly records (Thomas et al., 1998).

FIGURES

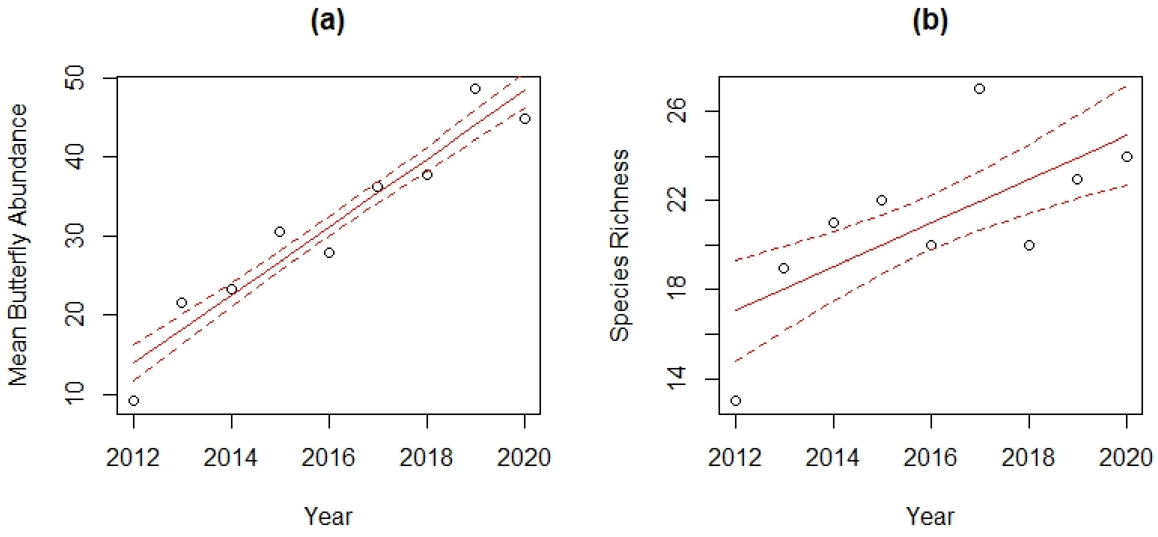

Figure 1: Weymouth Relief Road cutting – (a) mean butterfly numbers per survey visit 2012-2020 (all species). Dotted lines indicate standard errors. (F=81.54, DF = 1, 7; R-squared = 0.92; P<0.001); (b) species richness 2012-2020. Dotted lines indicate standard errors. (F=6.55, DF = 1, 7; R-squared = 0.48; p=0.038).

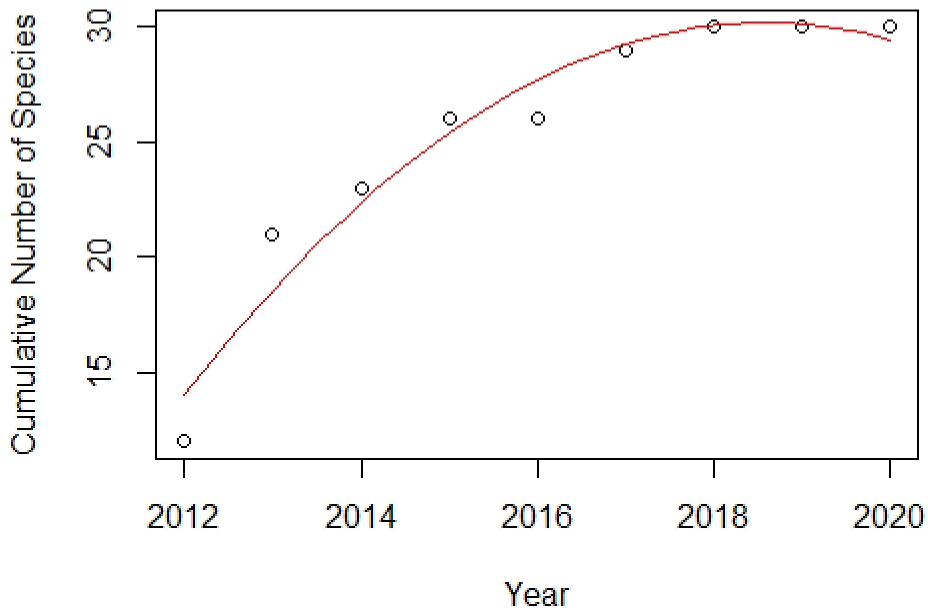

Figure 2: Weymouth Relief Road cutting – cumulative number of species recorded (2012-2020) plotted with a polynomial regression (F=56.9; DF = 2, 6; R-squared=0.95; p<0.001).

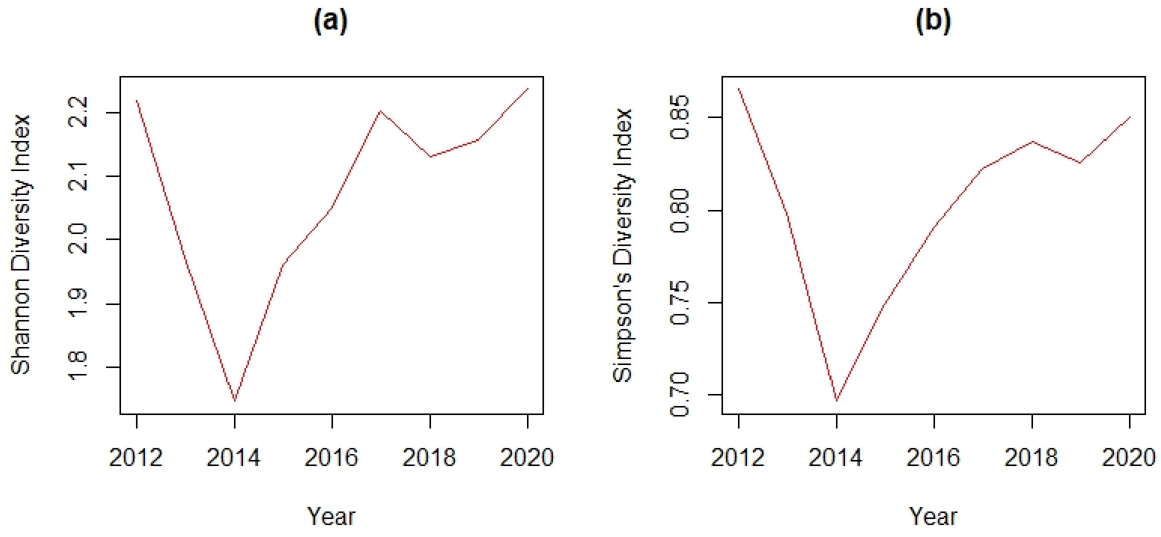

Figure 3: Weymouth Relief Road cutting – changes in (a) Shannon-Weiner Diversity Index and (b) Simpson's Diversity Index during the study period. No significant linear relationships were observed. (Shannon-Weiner: F=1.96, DF = 1, 7; P=0.204; Simpson's: F=0.82, DF = 1, 7; P=0.396)

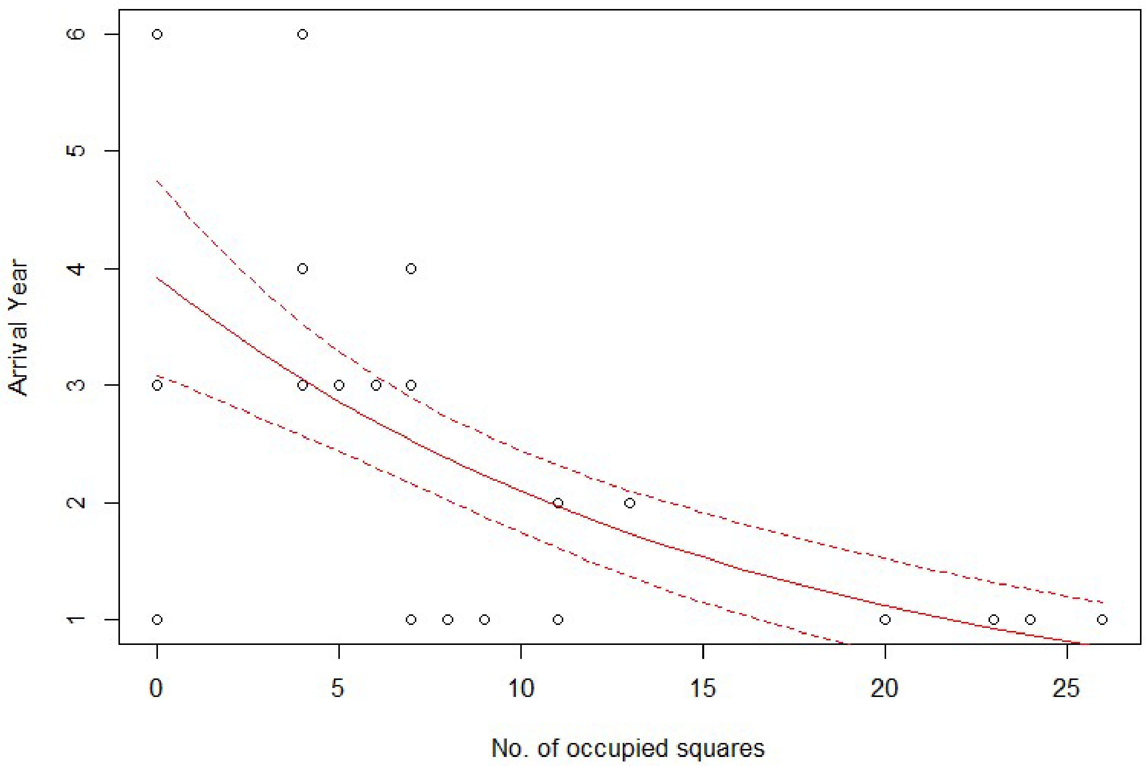

Figure 4: Plot of Poisson GLM showing the relationship (+/- SE) between year of arrival and the degree of local presence of a species (defined as the number of occupied 1 km squares in a 10 km square centred upon the Weymouth Relief Road cutting site) (Z=2.62, DF=19, R-squared=0.42, P=0.0089).