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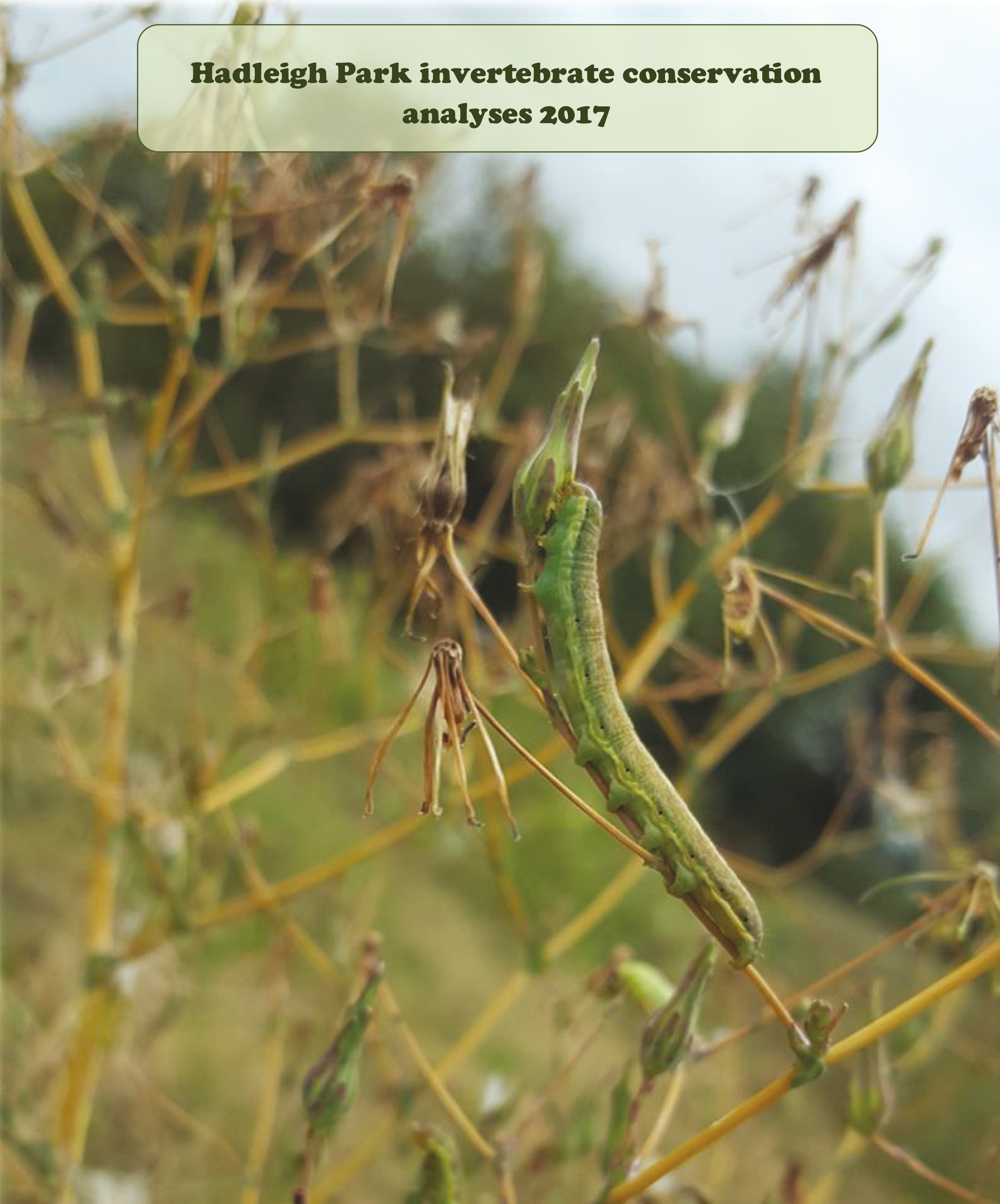
Hadleigh Park invertebrate conservation analyses 2017



Hadleigh Park invertebrate conservation analyses 2017

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Cover photo: Small ranunculus moth caterpillar (*Hecatera dysodea*) on prickly lettuce (*Lactuca serriola*) in green hay experiment area at Hadleigh Park (© Stuart Connop)

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1. Background

Hadleigh Park (HP) SSSI (TQ800869) was a key site for delivery of the 2012 London Olympics hosting the Olympic mountain biking course. As part of the legacy from this event an Ecological Management Plan was developed to conserve and enhance the ecological value of the site. This was to be achieved through a series of strategies:

> *1) To increase habitat extent and improve habitat quality through enhanced habitat management.*
> *2) To enhance habitat connectivity across the foothills by restoring an existing 'weak-link' of arable land to permanent grassland.*
> *3) To develop and fund a programme of ecological monitoring.*

In order to fulfil some of the requirements of the ecological monitoring target of the strategies, invertebrate habitat assessment surveys were established during the summer of 2015 to create a baseline for monitoring the effects of current and future habitat management on the site. This included delivering invertebrate surveys focused on habitats/assemblages that the operational use of the legacy may affect and that are associated with the SSSI designation. The focus of these surveys was in Compartments 1, 2 and 3a (Figure 1). The aim being to obtain results on which ISIS analysis could be carried out to provide common standards monitoring invertebrate assemblage information. The results of these surveys were made available in Harvey (2015).

Additional surveys were carried out during the summer 2015 and 2016 in order to create a baseline and begin monitoring the habitat quality and the effects of legacy habitat management at Hadleigh Park on priority target species and groups. These comprised white-letter hairstreak butterfly (*Satyrium w-album*) surveys, bumblebee (*Bombus* spp.) surveys - with specific focus on the UK Biodiversity Action Plan Priority Species (now the UK Post-2010 Biodiversity Framework) and Section 41 of the NERC Act Listed species: the brown-banded carder bee (*Bombus humilis*), the shrill carder bee (*Bombus sylvarum*) - and bumblebee forage availability surveys. The results of these surveys were made available in Connop and Clough (2016) and Connop and Nash (2016).

This report represents an overview of surveys carried out in the summer of 2017. This includes surveys carried out to assess the short-term effects of changes in habitat management and creation techniques in response to the results of the 2015 and 2016 surveys, and a repeat of the white-letter hairstreak survey methodology. The report also includes a re-analysis of the previous survey data using a novel invertebrate assemblage analysis online tool (PANTHEON). The report is divided into six sections: the white-letter hairstreak surveys, bumblebee forage surveys, the bumblebee surveys, habitat management recommendations based on these results, and the PANTHEON results.

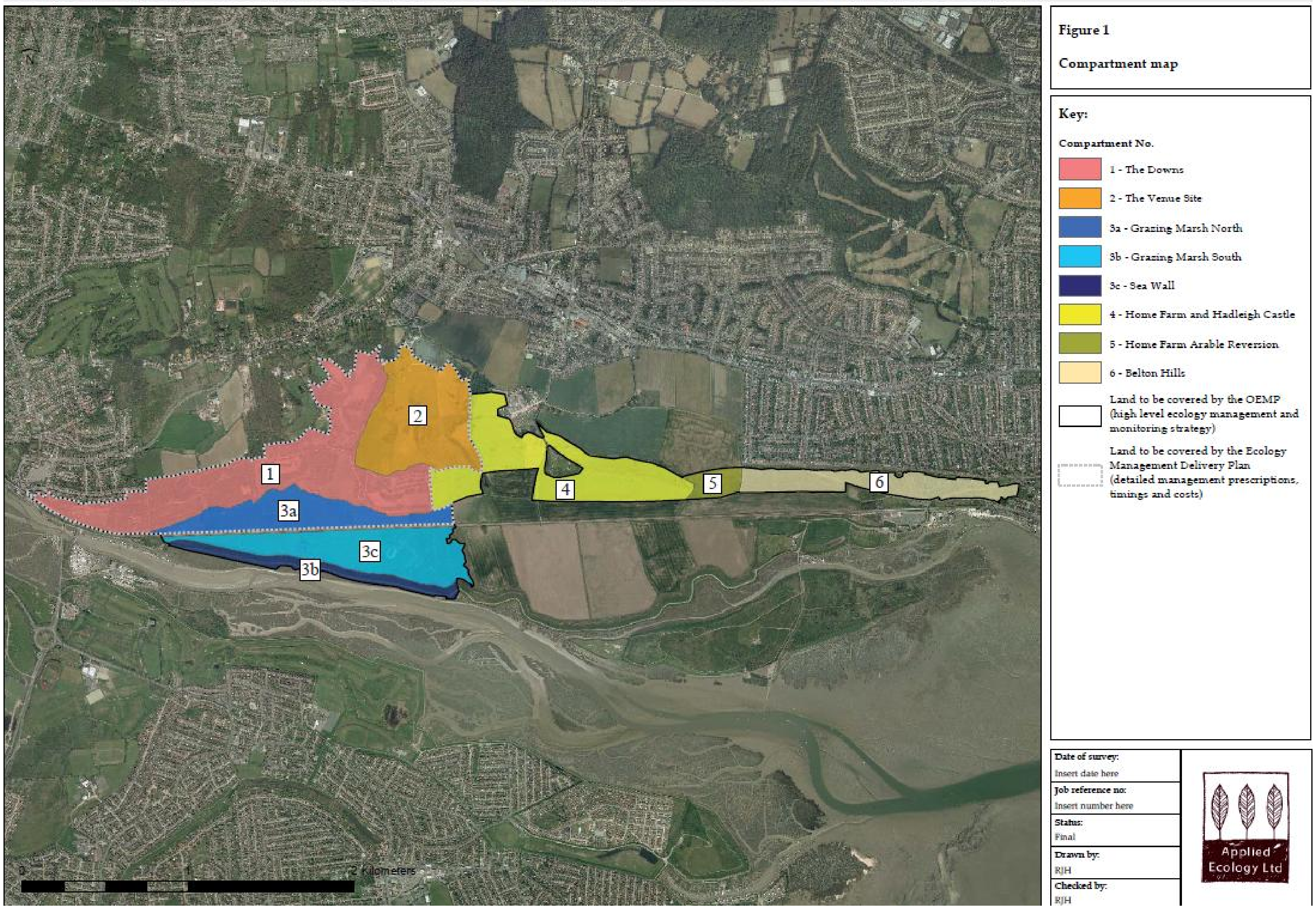


Figure 1. Hadleigh Park Compartment Map. Map displaying the habitat management compartments of Hadleigh Park. © ECC

2. White-letter hairstreak butterfly survey

2.1 Background

The white-letter hairstreak (*Satyrium w-album*) is a small butterfly distinguished by a white 'W' mark across the underside. The species declined in the UK during the 1970s when its foodplants were reduced by Dutch Elm Disease, but is recovering in a few areas (Butterfly Conservation 2016). Due to the species' marked decline in the UK (99% decline in abundance extrapolated over 25 years) it was included on the UK Biodiversity Action Plan list in 1997 with the aims of ensuring monitoring and appropriate hedgerow management (JNCC 2010) and, subsequently, under Section 41 (S41) of the 2006 Natural Environment and Rural Communities (NERC) Act.

The butterfly breeds on various elm species, including wych elm (*Ulmus glabra*), English elm (*U. procera*) and small-leaved elm (*U. minor*). It breeds on mature trees or abundant sucker growth near dead trees (Butterfly Conservation 2016). It breeds where elms occur in sheltered hedgerows, mixed scrub, and the edges of woodland rides, and also on large isolated elms (Butterfly Conservation 2016). Information on the colony structure is sparse, but a marking experiment showed a population numbering several hundred with adults regularly moving between trees up to 300 m apart (Butterfly Conservation 2016). Many colonies are restricted to a small group of trees, but dispersal appears quite common and individuals have been seen several kilometres from known breeding sites (Butterfly Conservation 2016).

With large expanses of scrub containing stands of *Ulmus* species covering compartment areas 1 & 2 (Figure 1), Hadleigh Park is known to support a substantial population of these butterflies. Indeed it has been suggested that the Hadleigh Park population represents the largest colony within Essex (Personal communication Rob Smith transect coordinator for Essex Butterfly Conservation). With continuing losses to Dutch Elm Disease and legacy plans to re-open some areas of flower-rich grassland that have scrubbed over due to lack of management intervention, it is important to map the distributions and number of this species at the park and assess changes in these populations in relation to legacy management plans.

In 2015, a baseline survey methodology was established to monitor the numbers and extent of white-letter hairstreak butterflies across Hadleigh Park. Results of the baseline surveys are reported in Connop and Clough (2016). The methodology was designed to be repeatable and comparable so that trends between years could be monitored. By doing this, it is possible to develop an evidence base in order to support decision-making on the best locations for the scrub removal programme at the park. It is also possible to use this as an early warning system of any impacts of the programme on the white-letter hairstreak population at the park.

2.2 Survey Methodology

Details of the white-letter hairstreak survey methodology can be found in Connop and Clough (2016). In June 2017, this ten minute observational survey methodology was repeated at all of the original observation points established at the park. During the winter 2016/17 surveyor pegs were embedded into the ground at each of the white-letter hairstreak observation monitoring points to ensure that all surveyors were able to operate from the same locations in the park. During this process an additional survey point was added (HP13A) to those established during the baseline survey to correspond with a key forage point within one of the rides identified by David Chandler (Cambs & Essex Branch of Butterfly Conservation) during his butterfly transects at the park. The location of all points including the new point are presented in Figure 2.

During each survey, the number of white-letter hairstreak individuals observed flying around tree tops and nectaring was recorded. Numbers were recorded using two methods. Firstly, the total number of individual sightings was recorded. Secondly, the maximum number of individuals seen at any one time was recorded. These two methods were utilised in an attempt to reduce the effect of observing the same individual twice and recording it as two separate sightings. As such, total observations represented a comparative count that was likely to be an over estimation of total numbers and maximum individuals observed simultaneously was a measure of the minimum number of individuals at each observation point. Observation could be done with binoculars if required but, as the tree tops being observed were near to the observation points and white-letter hairstreaks were likely to be the only small dark triangular butterflies jittering in classic hairstreak style around elm-rich spots in late June (Goodyear and Middleton 2007), it was also possible to carry out the surveys with the naked eye.

In addition to these two original recording methods, the position of each sighting around the observer was recorded on a panoramic photograph taken from each observation point (Table 1).

The selection of monitoring points was designed to cover all of the main elm areas across the park. All monitoring points were surveyed during each visit to the park. Previous surveys have recorded most success in terms of numbers of observations as the morning warmed up and conditions became amenable for active flight, with activity recorded as slow during the middle of the day (Goodyear and Middleton 2007). Based on this, survey rounds were started during mid-morning and the order of the survey points was varied on subsequent visits so that time of survey should not have affected results.

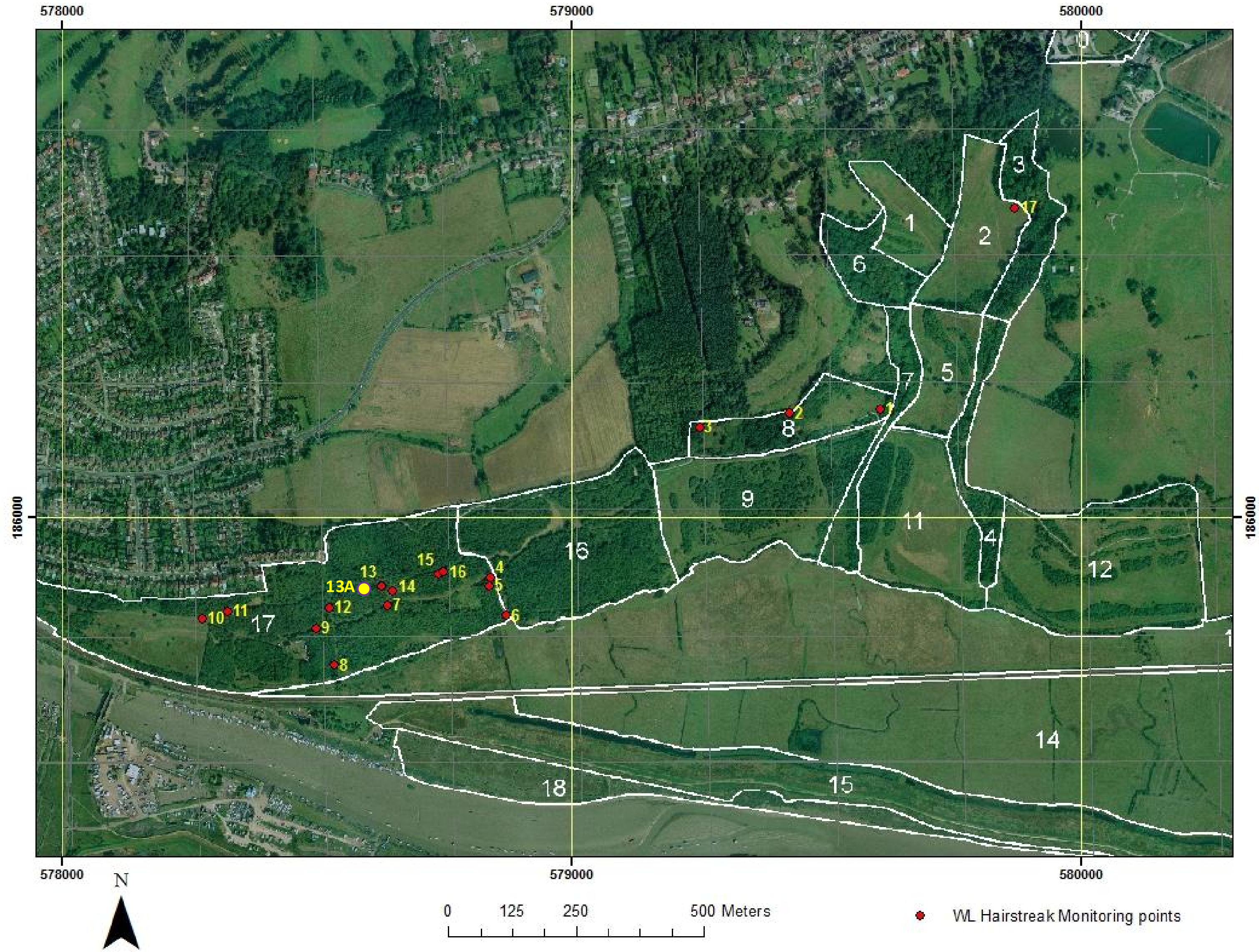


Figure 2. White-letter hairstreak observation points at Hadleigh Park. Observation points represent fixed-points used for timed white-letter hairstreak counts. Aerial Photo © ECC, Map prepared using ESRI ArcGIS. ○ = New monitoring point 13A, established during the 2017 surveys.

Table 1. White-letter hairstreak observation points at Hadleigh Park. Details of observation point name, grid reference, bearing of main concentration of elm/bramble (if appropriate) and a description of how to find each observation point on site. Each point is marked with a blue cross on the ground. HP13A corresponds to a new observation point established at an additional key forage point at the park.

Name	Grid ref	Centre point bearing	Description
HP1	TQ7960586220	328°	U-bend ride bottom of top fields below Chapel Lane car park, off main track
HP2	TQ7943086207	102°	By bench round upper ride from HP1
HP3	TQ7922786168	121°	Edge of boundary looking back over dead elm area
HP4	TQ7883885882	46°	S-ride upwards after green hay area
HP5	TQ7884185867	117°	S-ride downwards after green hay area (different X to HP4)
HP6	TQ7884585836	39°	Bottom of S-ride looking back up
HP7	TQ7863885830	All directions	New ride near pipeline (can see gate from survey point)
HP8	TQ7852885721	32°	Bottom of old pipeline ride looking back up
HP9	TQ7850385781	All directions	Along new ride after pipeline
HP10	TQ7825885790	0°	Eastern end of Benfleet Downs near bench
HP11	TQ7832685808	336°	Second curve in top ride leaving from eastern end of Benfleet Downs (northward curve)
HP12	TQ7851785842	26°	Bramble patch old pipeline - elm above
HP13A	TQ7859385862	All directions	(NEW) Bramble patch old ride
HP 13	TQ7863085868	All directions	Bramble patch old ride
HP14	TQ7864885861	142°	Old ride path junction
HP15	TQ7873885893	0°	Old ride by muddy pool approximately 50m before ride
HP16	TQ7877785927	15° and 195°	Top of S-ride
HP17	TQ7989286573	126°	Top field below Chapel Lane car park near trough

2.3 Results

In total, six survey visits were made to each of the 17 observation points. These were timed to coincide with peak dates from the Goodyear and Middleton (2007) surveys and based on observations of first appearance by the conservation manager at Hadleigh Park. Survey visits ran from 13th June to the 22nd June 2017.

Results of average total counts of white-letter hairstreaks are recorded in Table 2. Results of average maximum number of individuals recorded during each observational survey are recorded in Table 3. The highest number observed during 10 minutes was 82 at HP8 on the 22nd June. This differed from the location of the highest count in the previous round of surveys in 2015 (HP4). The highest maximum number of individuals observed in flight together was 7 recorded at HP8 on the 22nd June. This was the same location as one of the joint highest during the 2015 surveys. The highest average score for total numbers observed was recorded at HP8 (contrasting with HP9 in 2015) and the highest average maximum number of individuals was recorded at HP8 (contrasting with HP7 in 2015). Similarly to 2015, all observation points recorded at least one individual during at least one of the ten minute observation periods.

Graphs to demonstrate how counts varied over time and between observation points are displayed in Figures 3 and 4.

Table 2. Comparison of the average number of observations of white-letter hairstreaks at Hadleigh Park observation points, summer 2015 and 2017. Observations made during a ten minute survey. Numbers represent the average of the total number of sightings during each of the ten minute surveys (*n = 5* in 2015, *n* = 6 in 2017). Numbers in brackets represent the change in average between the two years (+ = increase in 2017, - = decrease in 2017).

Observation Point	2015 Average	2015 S.E.	2017 Average (change since previous survey)	2017 S.E.
HP1	0.25	0.25	25.50 (+25.25)	0.17
HP2	5.00	2.71	4.00 (-1.00)	8.67
HP3	0.50	0.50	9.50 (+9.00)	1.55
HP4	8.50	5.68	8.33 (-0.17)	2.40
HP5	3.25	2.93	1.83 (-1.42)	1.43
HP6	5.00	2.61	5.50 (+0.50)	0.31
HP7	2.50	1.66	9.00 (+6.50)	3.05
HP8	6.75	1.49	34.83 (+28.08)	4.29
HP9	11.00	4.97	16.50 (+5.50)	10.94
HP10	3.50	2.53	6.00 (+2.50)	7.36
HP11	0.50	0.50	6.17 (+5.67)	4.82
HP12	5.50	2.40	9.00 (+3.50)	2.01
HP13A	N/A	N/A	2.17 (N/A)	5.05
HP13	5.75	3.15	5.67 (-0.08)	0.87
HP14	5.75	2.75	5.33 (-0.42)	3.24
HP15	2.50	1.66	12.00 (+9.50)	2.73
HP16	3.25	2.93	6.83 (+3.58)	4.44
HP17	2.00	1.35	1.67 (-0.33)	3.41
Overall change			Net increase - five observation points.	

Table 3. Comparison of the maximum number of white-letter hairstreaks observed simultaneously at Hadleigh Park observation points, summer 2015 and summer 2017. Observations made during a ten minute survey. Numbers represent the average of the maximum number of simultaneously observed individuals during each of the ten minute surveys (*n = 5* in 2015, *n* = 6 in 2017). Numbers in brackets represent the change in average between the two years (+ = increase in 2017, - = decrease in 2017).

Observation Point	**2015 Average**	**2015 S.E.**	**2017 Average (change since previous survey)**	**2017 S.E.**
HP1	3.00	0.71	3.17 (+0.17)	0.26
HP2	0.50	0.50	1.50 (+1.00)	0.48
HP3	2.25	1.31	2.00 (-0.25)	0.22
HP4	1.00	0.71	2.17 (+1.17)	0.26
HP5	1.50	0.65	1.00 (-0.50)	0.17
HP6	0.75	0.48	0.83 (+0.08)	0
HP7	5.00	1.08	2.00 (-3.00)	0.40
HP8	4.75	1.44	3.50 (-1.25)	0.26
HP9	1.00	0.41	2.17 (+1.17)	0.92
HP10	0.25	0.25	1.33 (+1.08)	0.31
HP11	3.00	0.71	1.33 (-1.67)	0.61
HP12	2.25	1.11	2.00 (-0.25)	0.33
HP13A	N/A	N/A	0.83 (N/A)	0.26
HP13	3.75	1.60	1.33 (-2.42)	0.17
HP14	1.50	0.96	1.00 (-0.50)	0.33
HP15	1.50	1.19	1.83 (+0.33)	0.37
HP16	1.25	0.63	1.33 (+0.08)	1.67
HP17	0.25	0.25	1.00 (+0.75)	0.33
Overall change			Net decrease - one observation point	

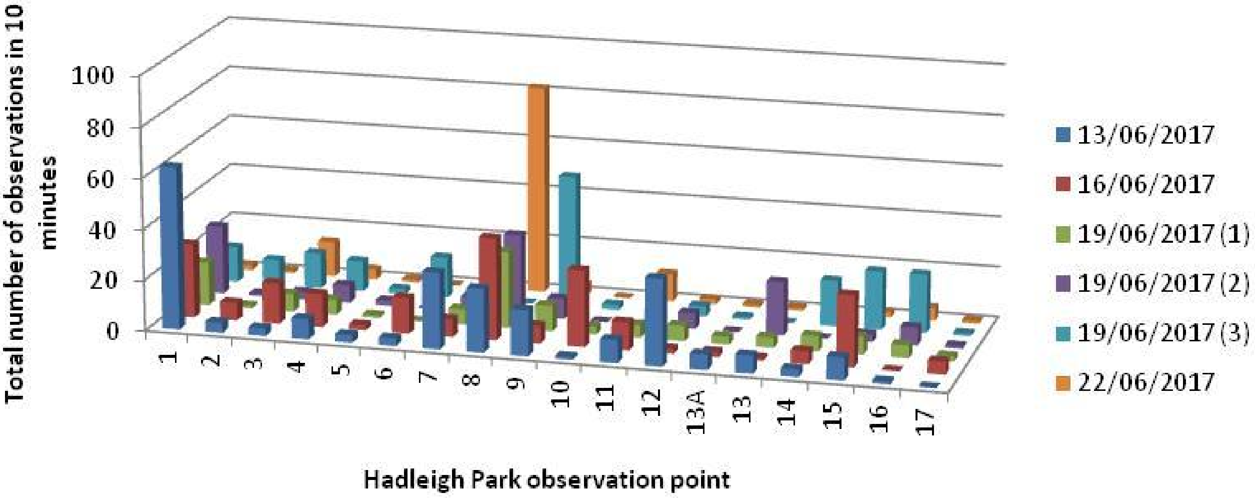


Figure 3. Total number of observations of white-letter hairstreaks at Hadleigh Park observation points, summer 2017. Observations were carried out at a series of fixed points. Each survey lasted ten minutes. Every individual observed during ten minutes was recorded. As such, values represent a measure of activity rather than actual population size.

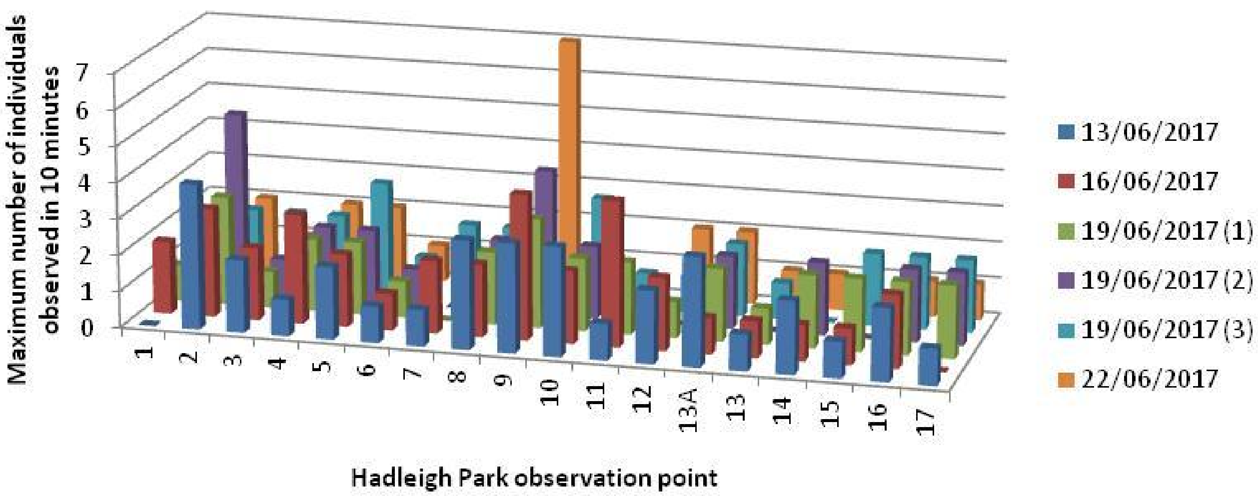


Figure 4. Maximum number of white-letter hairstreaks observed simultaneously at Hadleigh Park observation points, summer 2017. Observations were carried out at a series of fixed points. Each survey lasted ten minutes. maximum number of individuals observed together at one time during ten minutes was recorded. As such, values represent a minimum measure of population size.

2.4 Discussion

Similarly to the 2015 survey, white-letter hairstreak fixed point observation surveys recorded substantial numbers across Hadleigh Park. Individuals were associated with the tops of elms or were observed nectaring on bramble along rides (Goodyear and Middleton 2007). Results from timed counts indicated that individuals were distributed across the park with no single discernible hotspot. All observation points recorded at least one individual during one of the six survey rounds. However, a pattern that did emerged from the 2015 and 2017 surveys, was that observation points 7, 8 and 9 consistently recorded some of the high counts (Figures 5 & 6).

Average absolute counts and average maximum number of individuals counts showed similar patterns to the baseline survey. For average absolute counts, the majority of averages were higher than in 2015 (Table 2). This represented a net increase in average counts at 5 of 17 observation points. The pattern for average maximum number of individual counts was more varied. Of the seventeen observation points, nine recorded decreases and eight recorded increases compared to the 2015 surveys.

The 2015 survey established a standardised and repeatable methodology for assessing white-letter hairstreak numbers and distributions within the park for the future. This follow-up survey demonstrated the effectiveness of the baseline and began to reveal regular patterns in distribution. By repeating the methodology in future years it may be possible to generate more information on the habitat preferences of the butterflies at the park and the effects of habitat management initiatives on the populations.

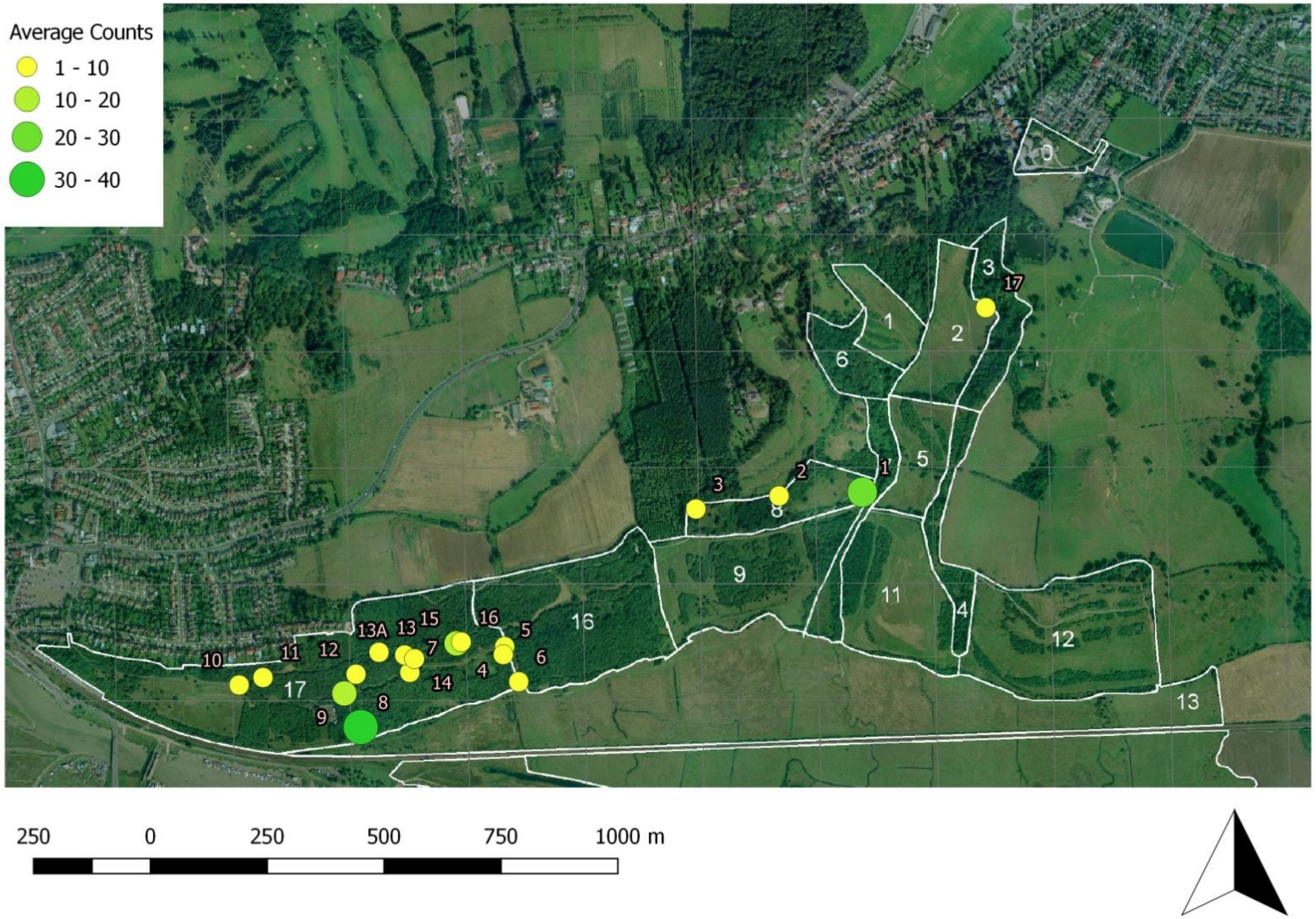


Figure 5. Distribution of average timed counts of all white-letter hairstreak butterfly individuals observed at Hadleigh Park observation points, summer 2017. Observations were carried out at a series of fixed points. Each survey lasted ten minutes (*n* = 6). Every individual observed during ten minutes was recorded. As such, values represent a measure of activity rather than actual population size. Location markers are scaled and coloured to represent the magnitude of the average count. Map prepared using QGIS. (www.qgis.org)

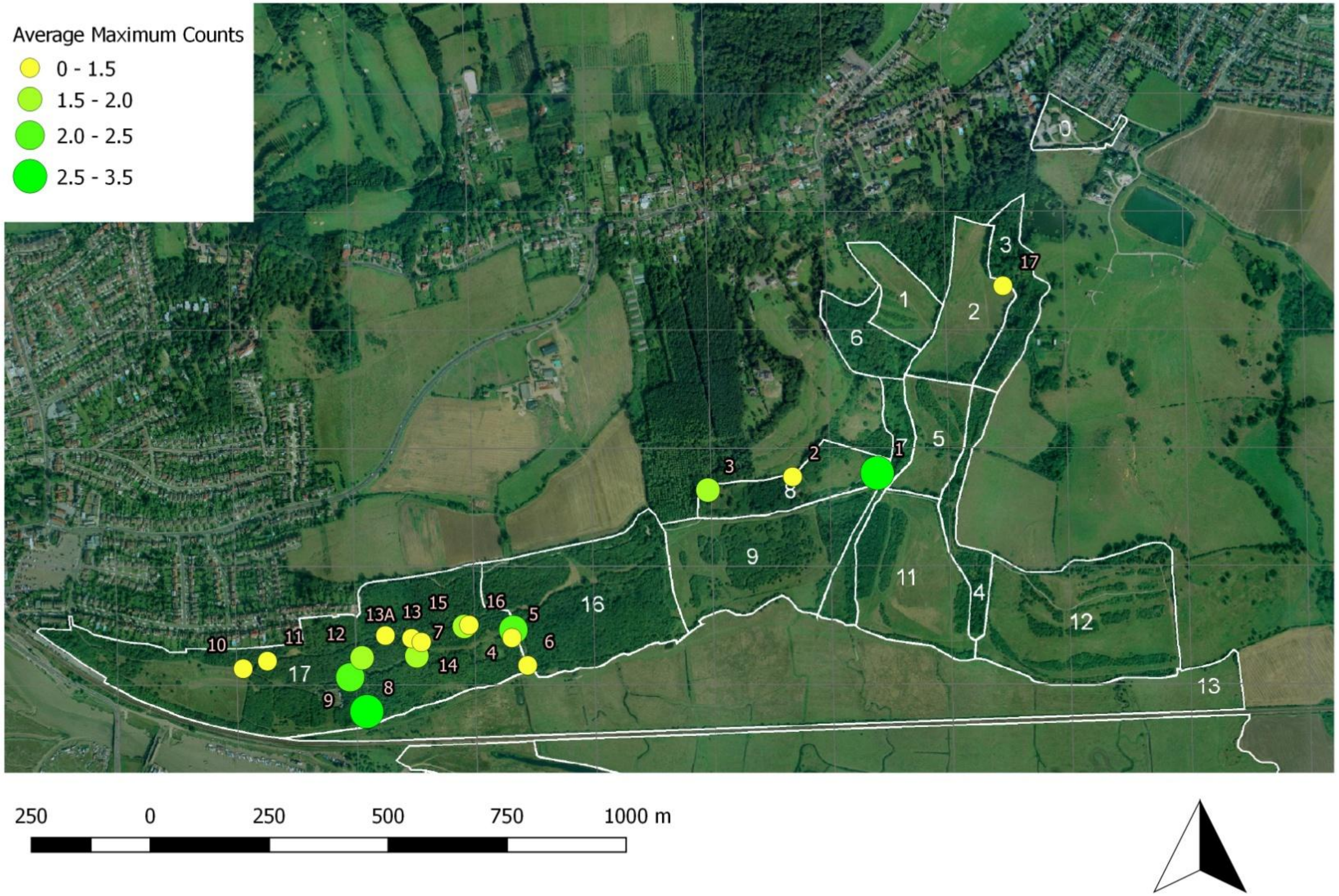


Figure 6. Distribution of average maximum number of white-letter hairstreak butterflies observed simultaneously at Hadleigh Park observation points, summer 2017. Observations were carried out at a series of fixed points. Each survey lasted ten minutes (*n = 6)*. Maximum number of individuals observed at any one time during ten minutes was recorded. As such, values represent a measure of minimum population size. Location markers are scaled and coloured to represent the magnitude of the average count. Map prepared using ESRI ArcGIS.

2.5 Habitat management recommendations

Based on the results of the summer 2017 white-letter hairstreak surveys and comparison of these results with the 2015 baseline, a series of conclusions can be drawn in relation to current legacy habitat management plans:

White-letter hairstreaks:

- White-letter hairstreak individuals continue to be broadly distributed throughout the park associated with elm stands and neighbouring bramble along rides.
- Overall sightings were up compared to the 2015 baseline, although patterns in terms of maximum numbers observed simultaneously were more varied with declines at some of the observation points;
- Continued monitoring of these populations is vital in order to understand these patterns over longer time periods and to assess how the Hadleigh Park population is faring compared to recently reported national declines (Guardian 2016);
- Whilst the overall distribution was broad and variable across the park (dependent upon the location and the survey visit), observation points 8, 9 and 1 typically recorded the highest counts. This should be taken into account in relation to scrub removal planning. It might also prove beneficial to try to characterise whether any habitat features are unique to the habitat surrounding these observation points that might lead to the consistently higher counts in these locations.
- As reported in the baseline survey report (Connop and Clough 2016), it may also be of benefit to introduce elm monitoring to assess the health of the current population of trees. During a site walk with the site's conservation manager it was apparent that certain areas of elm within the park were dying off, presumably as a response to Dutch Elm Disease. Monitoring tree health and, potentially, identifying resistant trees could help support future management decisions.

3. Green haying forage creation experiment

3.1 Background

World-wide studies of native bees, both solitary and social, have revealed disturbing trends of decline over the last 40-50 years (Williams 1982; Rasmont, 1995; Biesmeijer et al., 2006; Kosior et al., 2007; Williams and Osborne 2009). If declines in UK bumblebees are to be halted and reversed, an adequate supply of suitable forage sources must be provided for the bees (Williams 1982). For forage provision to be effective, the specific foraging requirements of individual bumblebee species must be understood (Edwards 1998).

A three year investigation of the south Essex populations of UK Biodiversity Action Plan bumblebees, *Bombus humilis* and *Bombus sylvarum*, was carried out to assess their habitat management requirements (Connop 2008a). Foraging behaviour of the bees was recorded and the dietary preferences of the bees were assessed (Connop et al. 2010). Results of this study were fed into an experimental programme of forage creation at Hadleigh Park. The site was selected due to its suitability for a bumblebee habitat improvement program. The site runs between South Benfleet and Hadleigh in South Essex and is a mix of woodland, hedgerows, grassland and coastal grazing marsh with ponds and ditches. Historically the area was used for agriculture and much of the site was managed as open grassland. In more recent times, management has led to the development of substantial areas of scrub and loss of much bumblebee foraging and nesting habitat.

Site surveys at Hadleigh Park between 2003 and 2005 revealed both *B. humilis* and *B. sylvarum* were present due to existing management. Areas of forage containing *Odontites verna*, *Lotus corniculatus/glaber*, *Trifolium pratense*, *Centaurea nigra*, *Ballota nigra* and *Cirsium* species supported the highest numbers of these bees. These flowers are generally most abundant on areas of the site managed for rough hay crops. Many of these areas were previously cut by mower but, due to management changes in 2003, they were managed by low-level grazing by cattle. Following the change in management, the target forage patches improved considerably. The fields were grazed twice a year, for approximately two months starting in March and again in September/October when bumblebee forage plant flowering is typically over. Scrub bands were kept down and several paths were mown on these sites along the edges of which much of the *Odontites verna* was found. Areas of tall grassland with a tussocky structure were also present on the site which might act as nesting habitat for the bumblebees (Carvell 2002; Connop 2008a).

To increase the area of suitable bumblebee forage and nesting habitat for *B. humilis* and *B. sylvarum* a programme of scrub clearance was initiated in 2005 (Figure 8). Within this habitat management programme, an area of approximately 0.5 ha of scrub has been cleared annually. Scrub was cleared by chainsaw with stumps removed using a grab on an excavator.

Scrub is a valuable habitat for a variety of wildlife. In relation to bumblebee conservation, *Rubus fruticosus* has been recognised as being of importance to *B. humilis* and *B. sylvarum* both in the Connop study (2008a) and by Peter Harvey (1999). It is also of value to other conservation priority species the occur at the park such as the white-letter hairstreak (*Satyrium w-album*). Due to the abundance of scrub on the site compared to semi-natural grassland, however, it was decided that removal of 0.5 ha each year, initially over ten years, would still leave substantial scrub on the site whilst at the same time increasing the area of semi-natural grassland vital for many of the region's nationally important invertebrates (Harvey 2000). Scrub clearance began in management unit 9 (Figure 2) in 2005 and a report was produced for the park recording clearance and initial recolonisation of the area (Connop 2006). This programme of clearance has continued annually extending into management unit 16 (Experiment areas 2 to 9, Figure 7) and part of the Legacy Ecological Management Plan includes continued rollout of this programme of scrub clearance combined with a monitoring programme to assess the effects of this habitat management on the availability of suitable forage, bumblebee numbers on the site, and potential effects on other priority conservation species.

Following the clearance of the first 0.5 ha of scrub, an experiment was initiated to assess good practice for promoting the recolonisation of these scrub-cleared patches by floral species known to be favoured by foraging *B. humilis* and *B. sylvarum* workers. The cleared area was divided in half creating two trial plots (Figure 8), one of which was left to recolonise naturally, the other was covered in green hay (Trueman and Millet 2003) cut using a Ryetec flail mower collector from a nearby flower-rich area of the park (Figure 9). The area used for green hay harvesting was the same each year to ensure that the floral species comprising the majority of the green hay was as similar as possible. Initial response to the treatment was good and two further experimental areas were established in 2009 and 2010 following the same design.

In order to compare the value of the experimental areas for foraging bumblebees, floral and bumblebee surveys were carried out on the plots in 2007, 2008, 2009 and 2010, 2011. Results of these studies are presented in series of consultancy reports produced by Connop (2007; 2008b; 2009; 2010; 2011). Following the positive results from these surveys in terms of provision of suitable forage and the numbers and diversity of bumblebees foraging on these areas, a programme of green haying was carried out on all areas cleared subsequently.

The continued roll out of the scrub clearance programme at the park through the Legacy Ecological Management Plan and the associated monitoring programme provided an opportunity to re-visit the site and repeat the baseline surveys established as part of the original experimental research. This was re-initiated in the summer of 2015 and repeated in 2016. By doing this it was possible to investigate:

- whether management of the scrub cleared areas had been successful in retaining the bumblebee forage (specifically target species for *B. humilis* and *B. sylvarum*);

- whether *B. humilis* and *B. sylvarum* were still present on the site in substantial numbers;
- whether *B. humilis* and *B. sylvarum* were still utilising the scrub cleared areas;
- any effects of changes to the management of these areas through a shift from an annual cut to a return to low-level grazing.

The results of these surveys are available in Connop and Clough (2016) and Connop and Nash (2016). Included within the habitat management recommendations of these reports were two proposals for increasing the quality of forage provision through the green hay creation and management process. These recommendations were:

1) To investigate why green hay habitat creation in experiment areas created after experiment area 4 became much more grass dominated than experiment areas 1 to 4:
AND
2) To investigate whether late forage could be provided for the target bumblebee species by manipulating existing cutting regimes.

The following section focuses on 2017 monitoring results from experimental manipulations related to recommendation 1.

Figure 7. Plan of Hadleigh Park green hay plots (Aerial photo © Hadleigh Park). Areas 1-7 represent areas of scrub within management unit 9 (Figure 2) that have been cleared for bumblebee forage habitat creation. Experiment Area 8 represents the green hay experiment created in 2015/16 to investigate novel methods for increasing wildflower availability after green haying. Area 9 represents the area that was cleared in 2016.

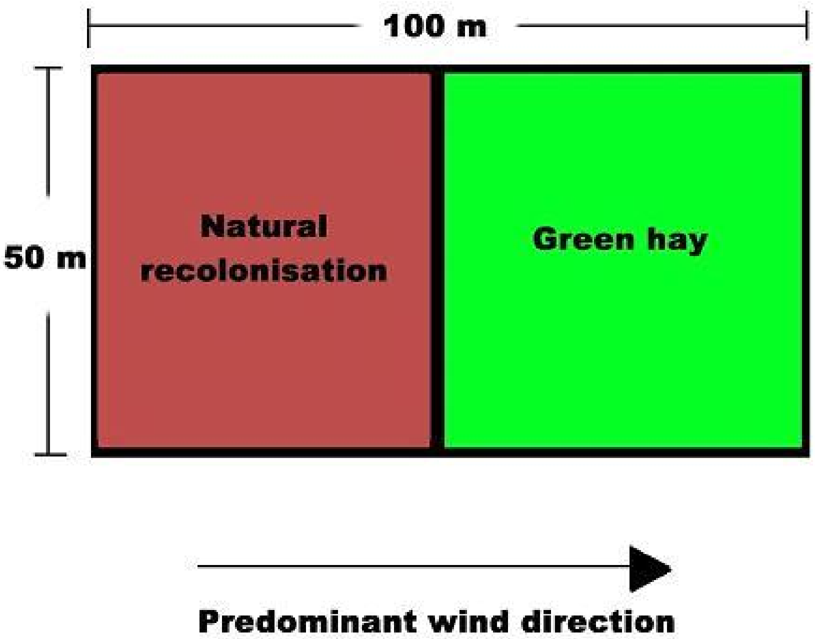


Figure 8. Plan of scrub removal forage patch creation experiment at Hadleigh Park.

Figure 9. Green hay cutting on flower-rich area of Hadleigh Park. Ryetec used to cut hay and collect seed which was then spread by volunteers.

3.2 Soil inversion trial

3.2.1 Background

The results of the green haying habitat creation programme on areas to the west of the green hay donor area (expt. areas 5 - 7) contrasted starkly with those to the east (expt. areas 1 - 4). Areas to the east of the ride developed into wildflower dominated swards regardless of whether they were originally green hayed or left to naturally recolonise (although the timescales over which these wildflowers developed varied dependent upon the habitat creation method adopted) (Connop 2007; 2008b; 2009; 2010; 2011). In contrast to this, areas to the west of the ride developed into much more grass dominated swards with fewer available wildflowers (Connop and Clough 2016; Connop and Nash 2016). Whilst such habitat can also be of value for bumblebees in terms of providing nesting opportunities, the original target of increasing forage availability at the park meant that it was important to investigate why these two differing outcomes in terms of habitat creation were occurring following the same 'treatment' after scrub clearance.

Historic management of the two areas differed and it is possible that this was the driver for the contrast in recolonisation patterns between the two areas following scrub clearance. The area to the west of the green hay donor area had a longer history of scrub cover, whilst the area to the east had a more recent history of management as open grassland (Personal Communications - Andrew Woodhouse - Hadleigh Park Senior Ranger). It would be expected that this difference in historical management would have affected the soil chemistry, the physical soil properties, humic content and seed bank. In order to begin to investigate whether these factors were impacting sward redevelopment following scrub clearance, a novel habitat management trial was initiated on Experiment Area 8.

The trial involved assessing a soil profile inversion technique in addition to the green hay/natural recolonisation methods that have been employed previously. This method was implemented to investigate the effect of reducing any established humic layer and exposing historic seed banks. Such a method has been applied in other habitats with positive outcomes (Olsson & Ödman 2014; Allisen and Ausden 2006; Buisson et al. 2006; Holzel and Ottel 2003; Jaunatre et al. 2014; Jones et al. 2010; Verhagen et al. 2001) Initially an area of approximately 0.5 ha of scrub was cleared using the same methods as employed in previous years (Expt Area 8). This area was then sub-divided into a natural recolonisation trial area and a green hay trial area following the standard pattern for the site (Figure 8). Each of these two areas was then further sub-divided to create a mosaic of soil inversion plots (Figure 10). Each plot was approximately 7 x 7 metres. Within each of these plots a depth of between 30 to 60 cm of the soil profile was inverted using a digger (Figure 10). The soil in the cleared areas around these plots was not inverted. This created a series of three trial plots and interwoven control areas on each half of the cleared area. The western half of the experiment area was then left to recolonise naturally (Figure 12i) and the eastern half was covered with green hay (Figure 12ii) from the donor hay cut area used for all of the other experiment areas (Figure 8).

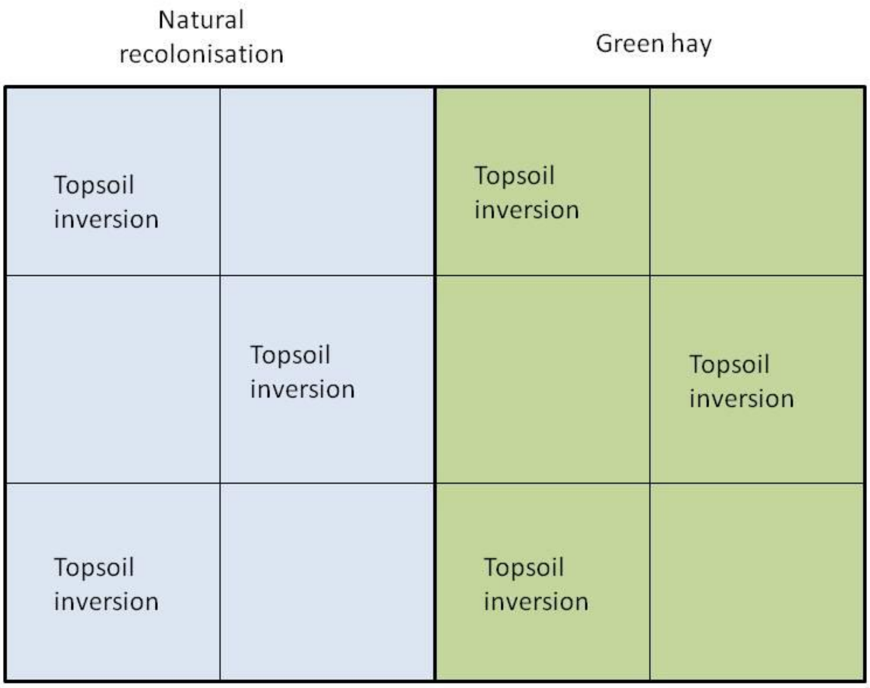


Figure 10. Plan of topsoil inversion in Experiment Area 8, Hadleigh Park, 2016.
Experimental trial to investigate the impact of humic build up on the creation of wildflower-rich bumblebee forage areas at the park. Subplots were 7 x 7 metres and a soil inversion depth of approximately 50 cm was carried out.

Figure 11. Soil inversion subplot being created at Hadleigh Park, September 2016.

i)

ii)

Figure 12. Soil inversion subplots on the i) Natural recolonisation and ii) Green Hay trial plots of Experiment Area 8, Hadleigh Park, November 2016. Plots created to assess the effect of soil inversion on the creation of wildflower areas for bumblebees following scrub clearance. Plots 7 x 7 metres and soil inversion carried out to a depth of approximately 50 cm.

3.2.2 Methods

The experiment was established in September 2016. Monitoring was carried out in July/August 2017 to assess the sward composition that had developed on each of the plots following the varied treatments.

Surveys comprised five 1 x 1 m quadrats (Figure 13) randomly placed across each of the soil inversion plots within the green hay plot and the natural recolonisation plot of experiment area 8. Fifteen quadrats were also randomly placed in the non-inverted areas of each treatment plot. The percentage of bare ground and relative abundance of each species within the quadrat in terms of number of flowers/inflorescences of each flowering plant species that were present and available to foraging bumblebees were recorded. One flower 'unit' was counted as a head (e.g. *Trifolium* species), spike (e.g. *Prunella vulgaris*), capitulum (e.g. *Centaurea nigra*), umbel (e.g. *Achillea millefolium*) or individual flower (e.g. *Ranunculus acris*) (Bowers 1985, Dramstad and Fry 1995, Carvell 2002 and Carvell et al. 2004). Flower identification followed Stace (2010).

In addition, two assessments of area covered by each species were made. Firstly, an objective assessment was made by counting the number of 10 x 10 cm squares each floral species/feature was present in. Secondly, a subjective estimate of percentage cover was calculated by estimating the proportion of the 100 sub-units within the quadrat that each species was dominant in (creating a total score of 100 for each quadrat). These methods were used to ensure that some measure of species not currently flowering at the time of survey was also made and so that a measure of all vegetation cover was recorded.

These methods were adopted to ensure complementarity with vegetation surveys carried out on Experiment Areas 1, 4 and 5.

Figure 13. 1 x 1 m quadrat used for floral surveys at Hadleigh Park.

3.2.3 Results

3.2.3.1 Floral and habitat feature diversity

Observations of the floral species and habitat features recorded on the green hay plot and natural recolonisation plot of experiment area 8 during the August 2017 vegetation surveys are listed in Table 4. Interesting patterns in relation to the soil inversion trial were recorded. For both the green hay plot and the natural recolonisation plot, number of species recorded was higher on the soil inversion plots than the corresponding non-soil inversion plots. This was substantially so for the natural recolonisation plot with half as many species recorded in quadrats on the inversion plot. Highest diversity was recorded on the green hay soil inversion plot (25 spp).

Numbers of target species for *Bombus humilis* and *Bombus sylvarum* were higher on the green hay plots than the natural recolonisation plots. Numbers were the same on the inverted and non-inverted plots of the green hay plot. The number of target species on the natural recolonisation plots was slightly higher on the inverted plot than the non-inverted plot.

All experimental plots recorded some bare ground, deadwood and grass.

Table 4. Presence/absence list of floral species for experiment area 8 recorded during 2017 floral surveys. Thirty 1 x 1 m quadrats were surveyed in the green hay plot and in the natural recolonisation plot respectively. Of these, fifteen were in inverted soil profile plots and fifteen were in non-inverted soil profile plots. Floral species highlighted by shading are those that are considered to be target forage species for *Bombus humilis* and *Bombus sylvarum* (Connop 2008a). Total floral species for each experimental plot is given under 'Count'. The number in brackets represents the total number of target forage species.

	Experiment Area 8			
Species	**Green hay (Inverted)**	**Green hay (Not Inverted)**	**Natural recolonisation (Inverted)**	**Natural recolonisation (Not Inv)**
Agrimonia eupatoria	x	x		
Amaranthus retroflexus			x	
Arctium lappa	x			x
Bryonia alba			x	
Centaurea nigra	x	x		
Cerastium spp			x	
Cerastium fontanum		x		
Cirsium arvense	x	x	x	x
Cirsium vulgare	x	x	x	x
Claytonia perfoliata			x	
Crataegus monogyna	x		x	x
Daucus carrota	x			

Epilobium spp				x
Galium aparine	x	x	x	
Geranium dissectum	x	x		
Glechoma hederacea			x	
Lactuca serriola		x		
Lathyrus nissolia		x		
Medicago lupulina	x	x		
Odontites verna	x	x		
Picris echioides	x	x	x	x
Plantago lanceolata	x	x		
Polygonum aviculare			x	
Potentilla reptans			x	
Prunus spinosa	x			
Ranunculus repens	x		x	
Rhinanthus minor		x		
Rosa canina	x			
Rubus fruticosus	x		x	x
Rumex conglomeratus	x		x	
Silene dioica	x	x	x	x
Sonchus asper	x	x	x	x
Sonchus oleraceous			x	x
Stellaria media	x		x	x
Tordylium apulum		x		
Trifolium pratense	x	x	x	
Trifolium repens	x	x		
Urtica dioica	x		x	
Vinca minor			x	
Vicia sativa	x	x		
Vicia tetrasperma		x		
Count (Count target spp)	25 (7)	22 (7)	22 (3)	11 (2)
Bare	x	x	x	x
Dead	x	x	x	x
Grass	x	x	x	x

3.2.3.2 Total flower heads

In addition to floral diversity, total number of flower heads available to foraging pollinators can be used as a measure of the benefit of the habitat creation areas to bumblebees and other target pollinator groups. Figure 14 shows the median flower head numbers on each of the trial plots of experimental area 8. Similarly to previous trials, green hay plot flowerhead counts were generally higher than those on the natural recolonisation plots. Counts on the non-inverted green hay plots were generally higher than those on the inverted green hay plots. A less consistent trend was observed on the natural recolonisation plots, with highest maximum value recorded on the inverted plots but highest median value recorded on the non-inverted plots. This was due to the inverted natural recolonisation plot counts being more variable.

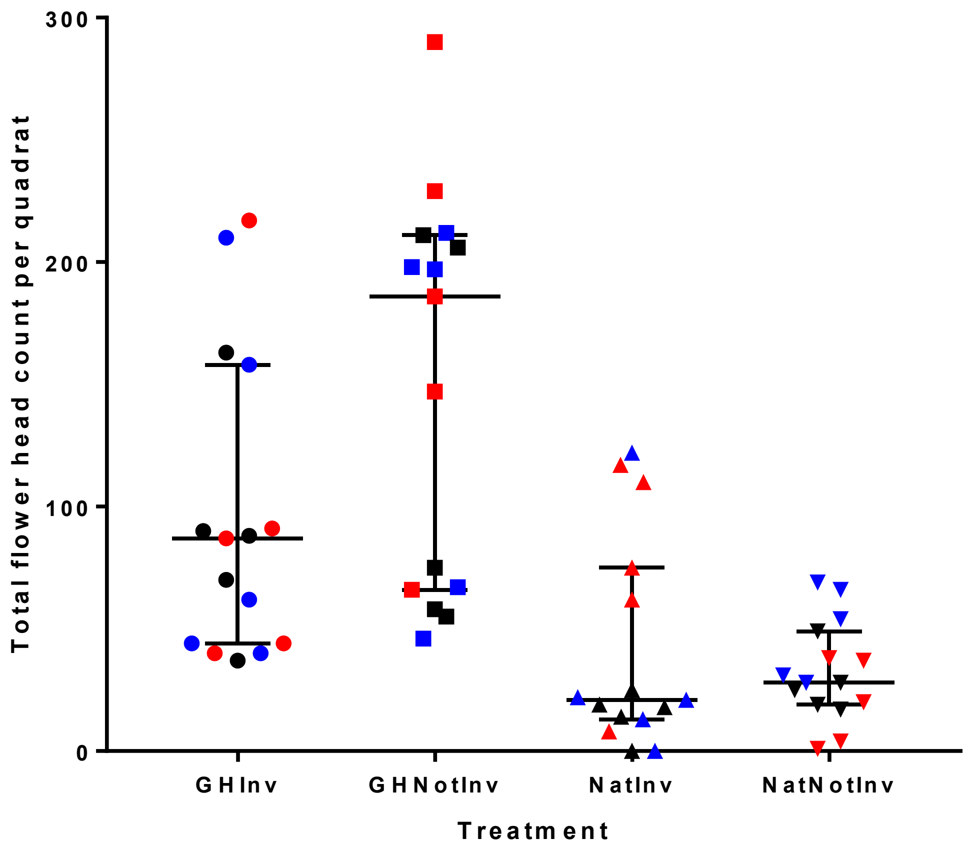


Figure 14. Flower head numbers on the trial plots of experiment area 8, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 15 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: green hay inverted (GHInv), green hay not inverted (GHNotInv), natural recolonisation inverted (NInv) and natural recolonisation not inverted (Ninv). Bars represent the median with interquartile range.

The scale and management implications of creating an experimental set-up in a real-world situation meant that a truly randomised design was not possible. In order to adapt to these practicalities, a systematic rather than randomised positioning was used for treatments. Although randomisation was built into the sampling with these treatments, this represented randomisation of a sub-sampling approach within the subplots. It is intended that, in future years, more experimental plots will be established to add greater replication to the experiment. However, in the current study, the nature of the experimental design meant that some of the principles of pseudoreplication (Hurlbert 1984) could not be avoided. This should be considered when interpreting the results from this study.

Nevertheless, such is the underlying randomness in microclimate, physical and chemical characteristics of soils (Gülser et al. 2016), that significant variation in conditions could be expected within small spatial scales across the study area. As such, the underlying substrate conditions themselves would be expected to introduce natural randomisation into the systematic experimental design. These underlying characteristics would increase the likelihood that consistent patterns emerging from the study in relation to treatments were the result of the treatment rather than the experimental design. In view of this, data obtained from sub-sampling plots were analysed as independent data. Prior to analysis, this assumption of independence was checked using scatter plots to display the distribution of values within and between treatment plots. Under the scenario that values from different plots with the same treatment appeared to be discrete (and sub-samples were thus potentially not independent), quadrat counts were combined for subsequent statistical analyses to create a total for each of the treatment plots.

A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of flowerheads ($p < 0.001$). This relationship between flower head number and treatment type was further analysed using Dunn's Multiple Comparison test for post-hoc pairwise comparison. Selected pairwise comparisons were carried out to compare green hay treatments (i.e. green hayed vs not green hayed) and inversion treatments (i.e. soil profile inversion vs not inverted). P-values were adjusted to account for multiple comparisons. Graphpad Prism 7.03 software was used for all statistical analyses.

There was no significant difference in terms of total flower head counts between the inverted and non-inverted areas on the green hay plot ($p = 0.88$) or on the natural recolonisation plot ($p > 0.99$). There was, however, a significant difference in terms of total flower head counts between the inverted areas of the green hay and natural recolonisation plots ($p = 0.02$) and the non-inverted areas of the green hay and natural recolonisation plots ($p < 0.001$).

3.2.3.3 Target forage species

In addition to total number of all flower heads available to foragers, analysis was also made of the availability of target forage species. Target forage species are floral species on which *Bombus humilis* and *Bombus sylvarum* have been most consistently recorded foraging at Hadleigh Park (Connop 2008a). These target species were *Odontites verna*, *Lotus glaber*, *Lotus corniculatus*, *Trifolium pratense*, *Trifolium repens*, *Centaurea nigra*, *Cirsium vulgare*, *Cirsium arvense* and *Ballota nigra*.

Odontites verna

Results for each treatment area are presented in Figure 15. The non-inverted green hay areas recorded the highest *O. verna* flower head counts both in terms of median and maximum counts. Both the inverted and non-inverted green hay areas recorded higher median counts than the corresponding natural recolonisation areas. No *O.verna* flower heads were recorded on either of the natural recolonisation plots.

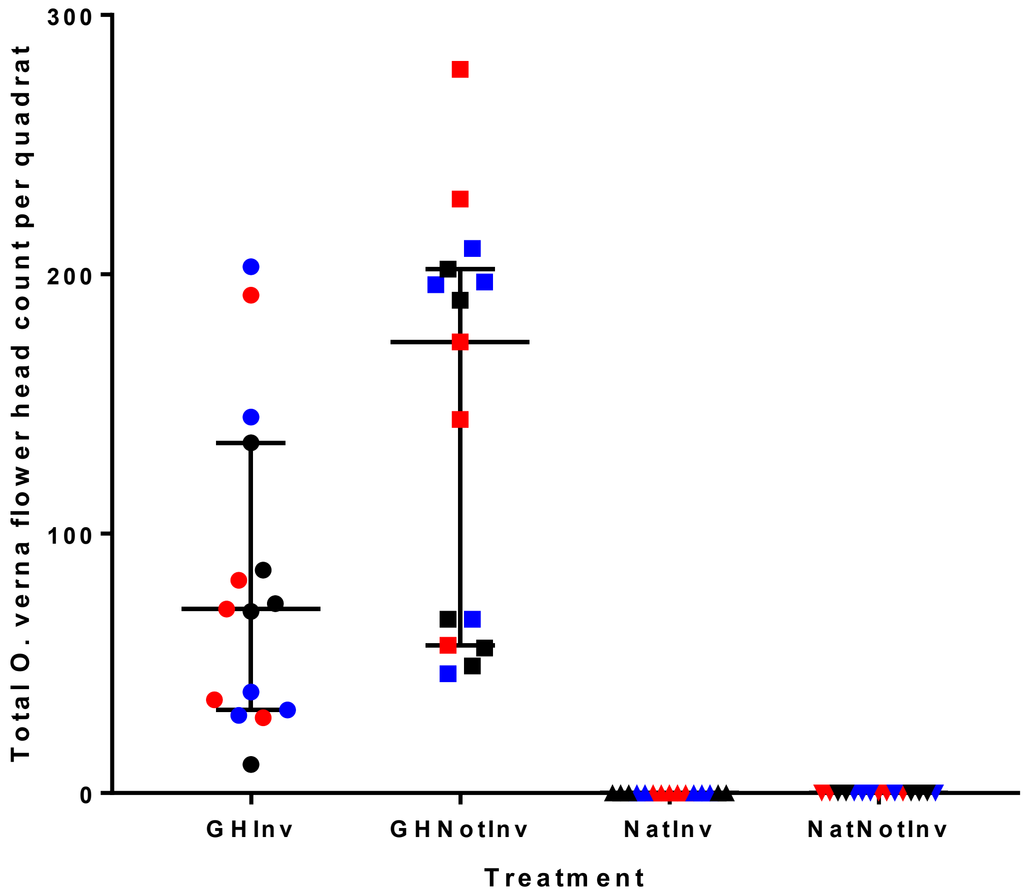


Figure 15. *Odontites verna* flower heads numbers on the trial plots of experiment area 8, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 15 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: green hay inverted (GHInv), green hay not inverted (GHNotInv), natural recolonisation inverted (NInv) and natural recolonisation not inverted (Ninv). Bars represent the median with interquartile range.

A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of *O. verna* flowerheads ($p < 0.001$). This relationship between flower head number and treatment type was further analysed using Dunn's Multiple Comparison test for post-hoc pairwise comparison. Selected pairwise comparisons were carried out to compare green hay treatments (i.e. green hayed vs not green hayed) and inversion treatments (i.e. soil profile inversion vs not inverted). P-values were adjusted to account for multiple comparisons.

There was no significant difference in terms of total flower head counts between the inverted and non-inverted areas on the green hay plot or on the natural recolonisation plot ($p > 0.99$ respectively). There was a significant difference in terms of total flower head counts between the inverted areas of the green hay and natural recolonisation plots and between the non-inverted areas of the green hay and natural recolonisation plots ($p < 0.001$ respectively).

Other target forage species

Of the other target forage species, no Lotus spp., *Ballota nigra*, *Centaurea nigra*, or Trifolium spp flower heads were recorded during the quadrat surveys. Graphs of Cirsium species are presented in Figures 16 and 17. Statistical analyses of differences are also presented.

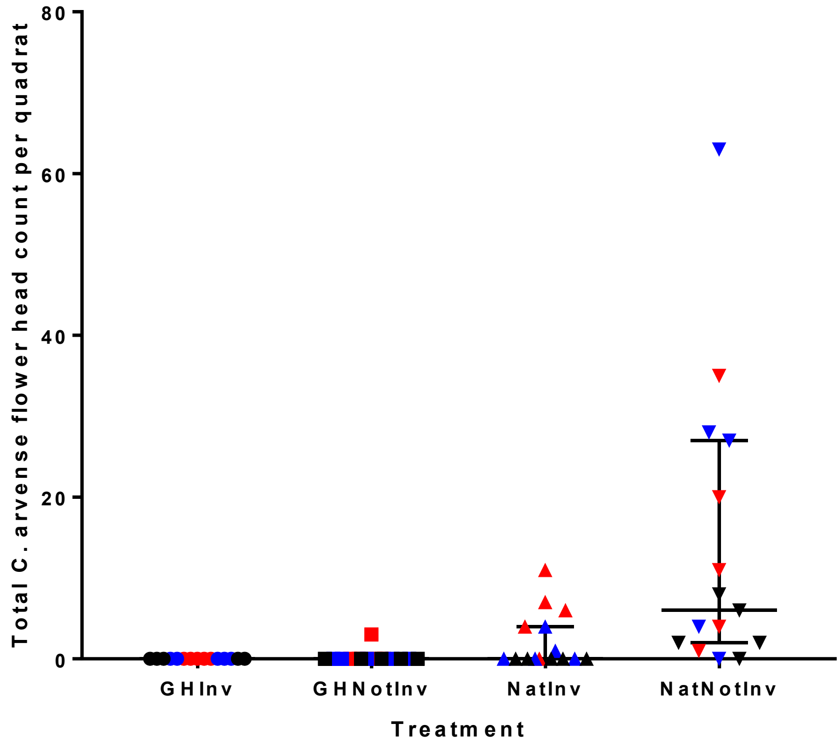


Figure 16. *Cirsium arvense* flower heads numbers on the trial plots of experiment area 8, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 15 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: green hay inverted (GHInv), green hay not inverted (GHNotInv), natural recolonisation inverted (NInv) and natural recolonisation not inverted (Ninv). Bars represent the median with interquartile range.

Cirsium arvense flower heads were more numerous on the natural recolonisation plot than the green hay plot. Only a single quadrat on the green hay plot recorded *C. arvense* flowerheads, on a non-inverted area. A Kruskal Wallace Exact test indicated that there was a significant difference between the treatment types in relation to total number of flowerheads ($p = 0.001$). Dunn's Multiple Comparison tests for post-hoc pairwise comparison resulted in no significant difference in terms of total *C. arvense* flower head counts between the inverted and non-inverted areas on the green hay plot ($p > 0.99$ respectively), but a significant difference between the inverted and non-inverted areas on the natural recolonisation plot ($p = 0.01$). There was no significant difference in terms of total flower head counts between the inverted areas of the green hay and natural recolonisation plots ($p = 0.13$) but there was a significant difference between the non-inverted areas of the green hay and natural recolonisation plots ($p < 0.001$).

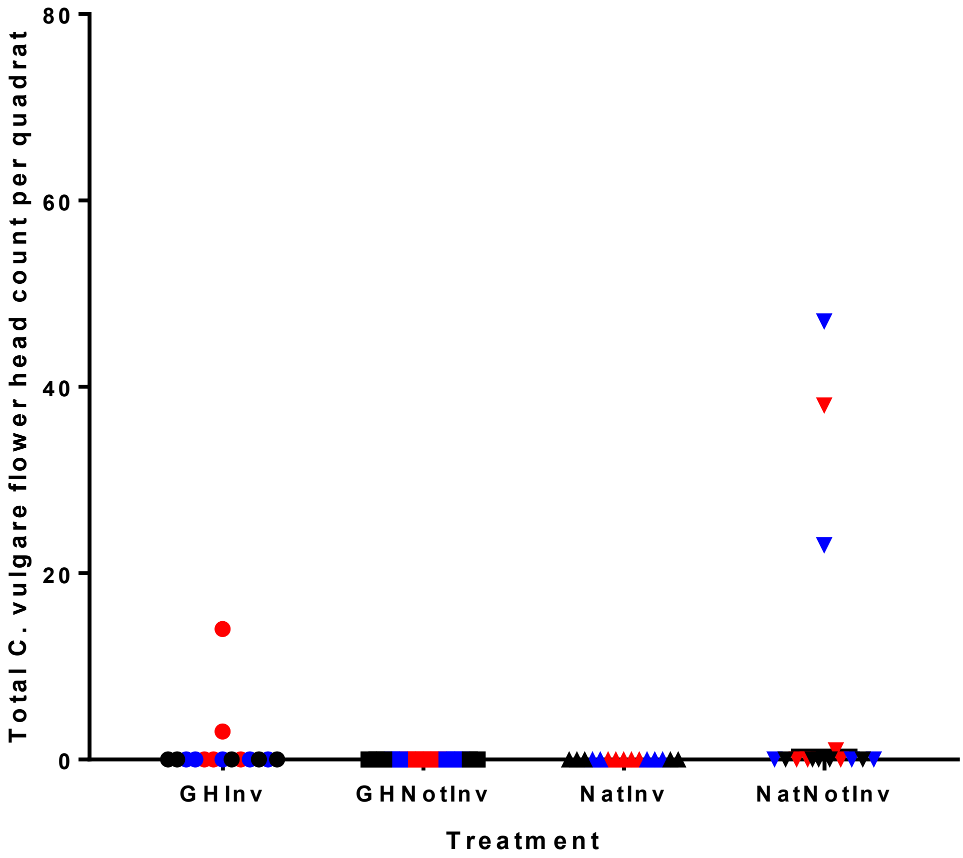


Figure 17. *Cirsium vulgare* flower heads numbers on the trial plots of experiment area 8, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 15 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: green hay inverted (GHInv), green hay not inverted (GHNotInv), natural recolonisation inverted (NInv) and natural recolonisation not inverted (Ninv). Bars represent the median with interquartile range.

Cirsium vulgare flower heads were most numerous on the non-inverted natural recolonisation although some were recorded on the green hay inverted plot. A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of *C. vulgare* flowerheads (p = 0.04). Dunn's Multiple Comparison tests for post-hoc pairwise comparison resulted in no significant difference in terms of total *C.vulgare* flower head counts after correction for multiple testing.

3.2.3.4 Vegetation cover

In addition to available flower heads, vegetation cover can provide a valuable measure of habitat value for pollinators and the effectiveness of management interventions. In particular vegetation cover surveys can quantify:

- cover of target floral species not currently flowering but having recently flowered or still to flower providing additional forage resources;
- presence of grassy swards providing nesting opportunities for ground nesting bumblebees such as *Bombus humilis* and *Bombus sylvarum* (Connop 2008a), or over-abundance of grass when open flower-rich sward creation is being targeted;
- abundance of recolonising scrub species that were targeted for removal by the original habitat management programme.

Grass cover

Critical to these objectives, and the critical reason for establishing this inversion experiment, was to assess the proportion of grasses in the recolonising sward after scrub clearance. Grass cover was compared between experimental treatments in terms of the objective measure of number of squares and the subjective measure of proportional dominance within each quadrat.

In terms of total number of squares in which grass was recorded, the natural recolonisation plot consistently recorded less grass than the green hay plot. There was also a difference between the inverted and non-inverted treatment subplots on the natural recolonisation plot, with less grass cover on the inverted subplots. There was no obvious difference in terms of grass cover on the green hay inverted and non-inverted subplots with almost all quadrat sub-units recording some grass.

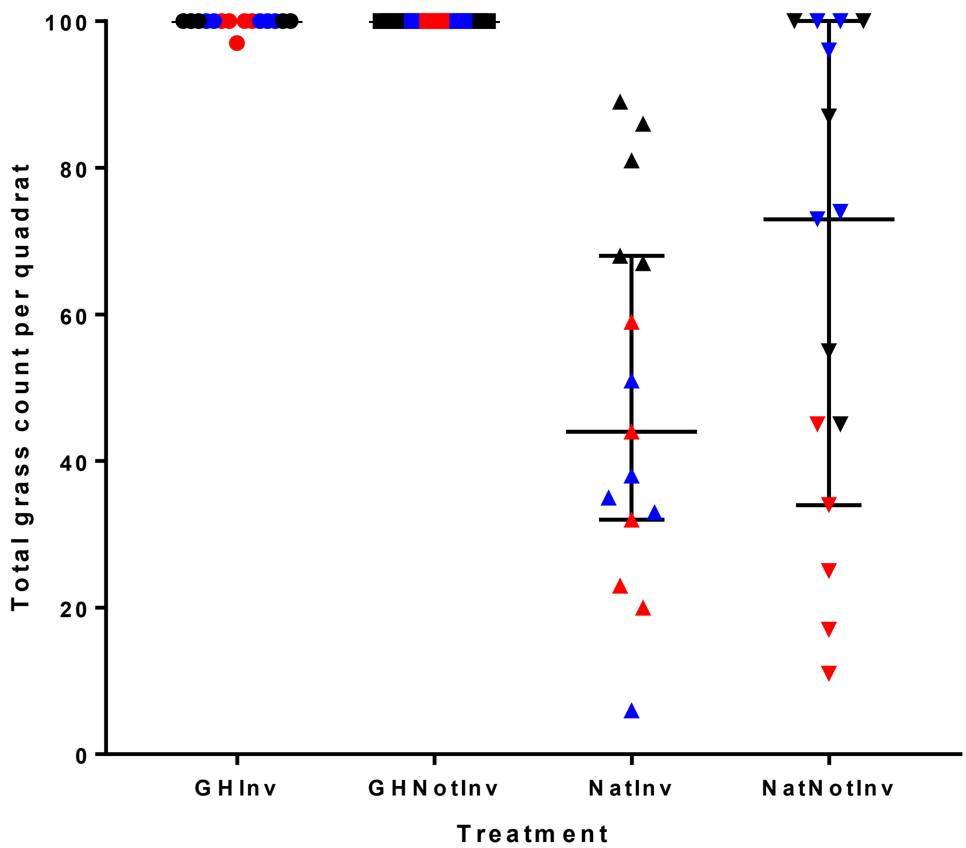


Figure 18. Number of quadrat squares in which grass was recorded on the trial plots of experiment area 8, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 15 for each treatment. Maximum count = 100. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: green hay inverted (GHInv), green hay not inverted (GHNotInv), natural recolonisation inverted (NInv) and natural recolonisation not inverted (Ninv). Bars represent the median with interquartile range.

One of the sub-plots for natural recolonisation inverted and natural recolonisation non-inverted respectively, appeared to be discrete from the other sub-plots when displayed (Figure 18). This indicated that the sub-plot records for grass may not have been independent and so were grouped for subsequent analysis.

After grouping data to reduce the risk of error for non-independence, a Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of squares in which grass was recorded ($p = 0.008$). Dunn's Multiple Comparison tests for post-hoc pairwise comparison resulted in no significant difference in terms of total number of squares in which grass was recorded for any of the pairwise comparisons.

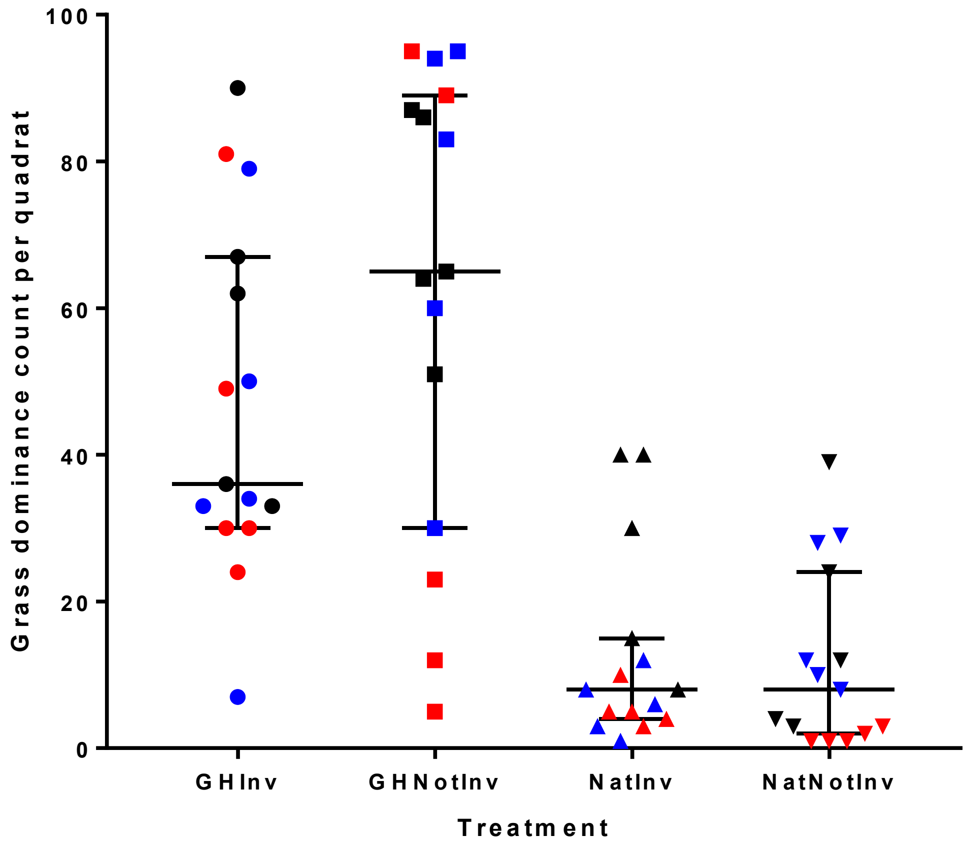


Figure 19. Grass dominance on the trial plots of experiment area 8, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 15 for each treatment. Dominance calculated as approximate proportion cover within quadrate area (i.e. 100 = 100% grass). Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: green hay inverted (GHInv), green hay not inverted (GHNotInv), natural recolonisation inverted (NInv) and natural recolonisation not inverted (Ninv). Bars represent the median with interquartile range.

In terms of grass dominance, the natural recolonisation plot generally recorded lower dominance than the green hay plot. There was also a difference between the inverted and non-inverted treatment areas on the green hay plots, with a trend towards more clustered grass dominance on the inverted plots and more varied on the non-inverted plots. There was no obvious difference in terms of grass cover on the natural recolonisation inverted and non-inverted areas. A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to grass dominance ($p < 0.001$). Dunn's Multiple Comparison tests for post-hoc pairwise comparison resulted in no significant difference in terms of total number of squares in which grass was recorded for the green hay inverted and non-inverted areas, or the natural recolonisation inverted and non-inverted areas ($p > 0.99$ respectively). A significant difference was recorded for the comparison of the inverted areas of the green hay plot and the natural recolonisation plot ($p = 0.004$) and the non-inverted areas of the green hay and natural recolonisation plots ($p < 0.001$).

Scrub

Also of interest is how green haying and inversion techniques effect scrub re-encroachment. Scrub cover was compared between experimental treatments in terms of the objective measure of number of squares and the subjective measure of proportional dominance within each quadrat.

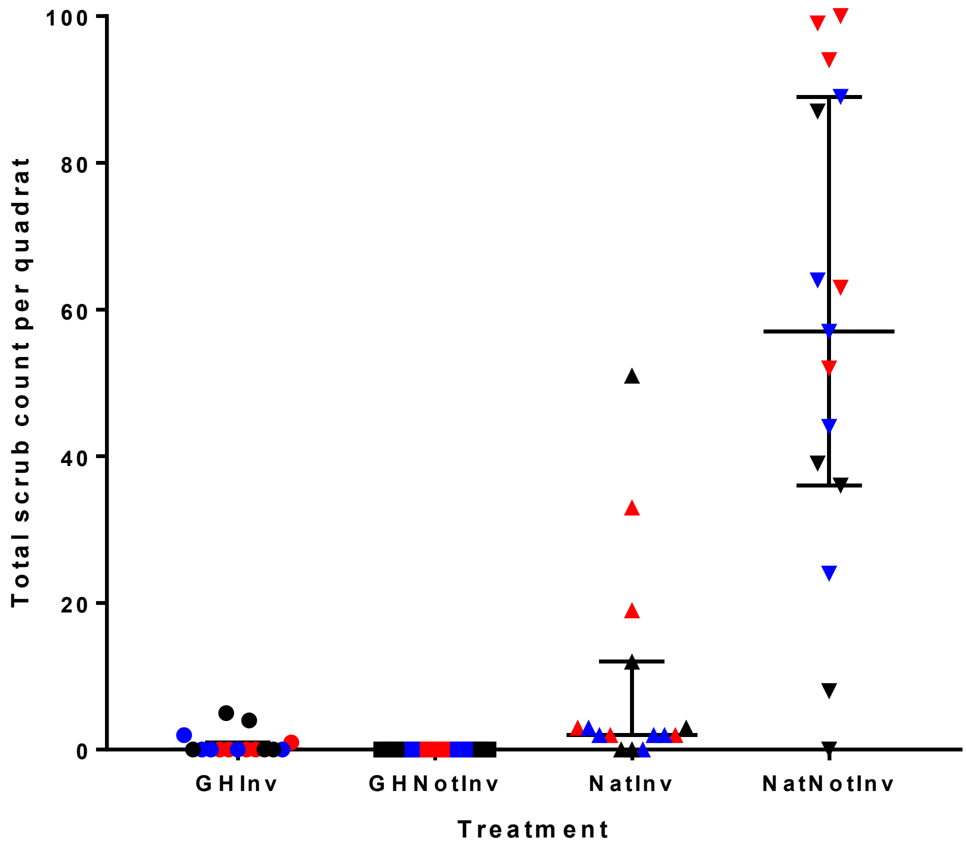


Figure 20. Number of quadrat squares in which scrub species were recorded on the trial plots of experiment area 8, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 15 for each treatment. Maximum count = 100. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: green hay inverted (GHInv), green hay not inverted (GHNotInv), natural recolonisation inverted (NInv) and natural recolonisation not inverted (Ninv). Bars represent the median with interquartile range.

In terms of total number of squares in which scrub species were recorded, the green hay plot had substantially less scrub than the natural recolonisation plot. There was also a difference between the inverted and non-inverted treatment areas on the natural recolonisation plots, with more scrub on the non-inverted plots. There was no substantial difference in terms of scrub on the green hay inverted and non-inverted areas. A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of squares in which scrub was recorded ($p < 0.001$). Dunn's Multiple Comparison tests for post-hoc pairwise comparison resulted in no significant difference in terms of total number of squares in which scrub was recorded for the green hay inverted and non-inverted areas ($p > 0.99$), but there was for the natural recolonisation inverted and non-inverted areas ($p = 0.04$). No significant difference was recorded for the comparison of the inverted areas of the green hay plot and the natural recolonisation plot ($p = 0.09$). The non-inverted areas of the green hay and natural recolonisation plots were significantly different ($p < 0.001$).

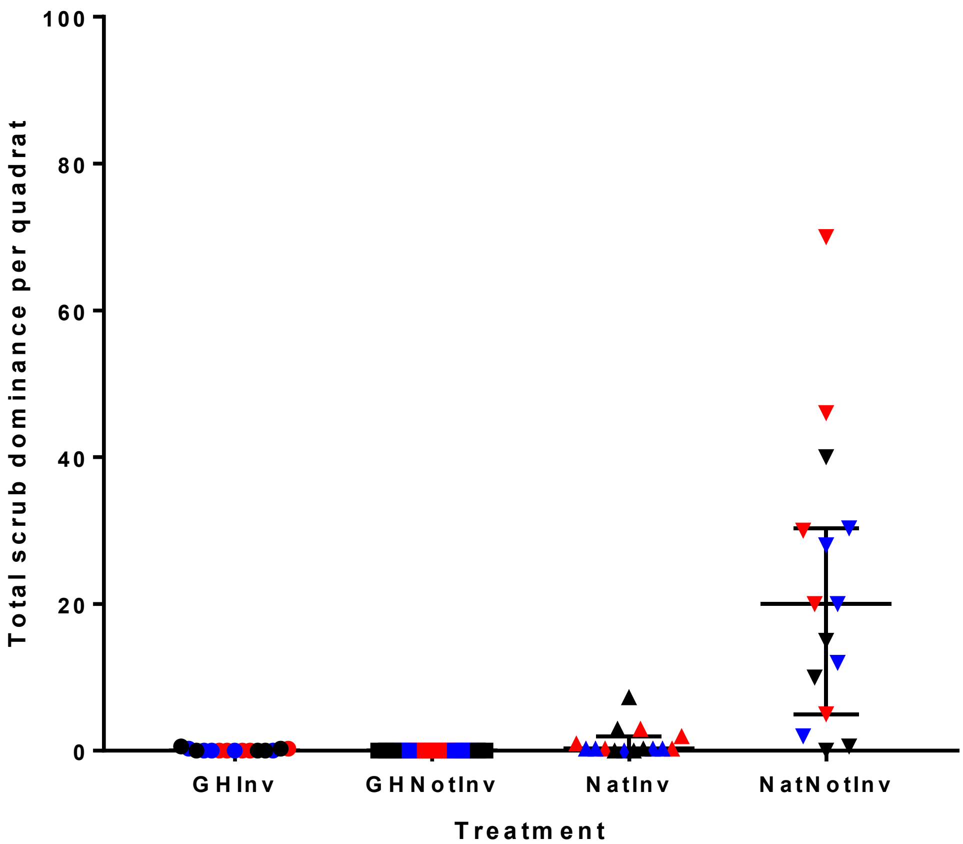


Figure 21. Scrub species dominance on the trial plots of experiment area 8, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 15 for each treatment. Dominance calculated as approximate proportion cover within quadrate area (i.e. 100 = 100% grass). Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: green hay inverted (GHInv), green hay not inverted (GHNotInv), natural recolonisation inverted (NInv) and natural recolonisation not inverted (Ninv). Bars represent the median with interquartile range.

In terms of scrub species dominance, the green hay plot recorded substantially lower dominance of scrub than the natural recolonisation plot. This was particularly evident for the non-inverted areas of the natural recolonisation plot, but the difference was not so substantial for the inverted areas of the same plot. A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to scrub dominance within quadrats ($p < 0.001$). Dunn's Multiple Comparison tests for post-hoc pairwise comparison resulted in no significant difference in terms of total number of squares in which scrub was recorded for the green hay inverted and non-inverted areas ($p > 0.99$), but there was for the natural recolonisation inverted and non-inverted areas ($p = 0.04$). No significant difference was recorded for the comparison of the inverted areas of the green hay plot and the natural recolonisation plot ($p = 0.08$). The non-inverted areas of the green hay and natural recolonisation plots were significantly different ($p < 0.001$).

3.2.4 Discussion

Vegetation redevelopment patterns in the latest scrub cleared area (experiment area 8) followed similar patterns to those recorded in previous years for green hay and natural recolonisation trials in the first year following green haying. Detailed comparative analysis of this redevelopment across experimental trials would be interesting to establish patterns between all four trials but was not within the scope of this current study.

Basic comparative analysis of the experiment area 8 results identified a similar trend of higher number of target forage species in green hayed areas compared to natural recolonisation plots (Table 5). The pattern in relation to overall diversity was less clear. For the latest trial, greater diversity was recorded in the green hay plot, but this has not always been the case for previous trials (Table 5). For experiment areas 1 and 5, diversity was greater in the natural recolonisation plot, for experiment area 4, the opposite was true.

In terms of available forage resource, total flower abundance patterns also mirrored those in previous experiments. Green haying was a significantly better method for generating higher total flower counts at peak foraging times for the conservation priority bumblebees. Whilst the difference was not significant, there was some evidence to indicate that flower head counts were slightly lower following soil profile inversion, than when the soil was not inverted. Further trials would be required to establish whether this was a trend that is consistently observed.

Table 5. Total floral diversity recorded during quadrat surveys at the green hay experiment, Hadleigh Park. Totals represent all floral species recorded during the survey. The number in brackets () represents the number of these species that were target forage species for the conservation priority bumblebees. For each survey area, thirty 1 x 1 m quadrats were surveyed. The exception being for experiment area 8 for which fifteen quadrats were surveyed on each inverted and non-inverted area respectively. Surveys were carried out the year following green haying.

	Treatment			
	Green hay		**Natural recolonisation**	
Trial	**Inverted**	**Not inverted**	**Inverted**	**Not inverted**
Expt 1	-	28 (7)	-	33 (5)
Expt 4	-	25 (6)	-	22 (5)
Expt 5	-	23 (6)	-	26 (2)
Expt 8	25 (7)	22 (7)	22 (3)	11 (2)

Green haying was also a significantly better method for abundance of the target forage species *Odontites verna* flowers. This also mimics results in previous years. Again, there was some evidence that non-inverted areas had higher counts but these differences were not statistically significant. Of the other flora species that have been recorded being frequently visited by the priority bumblebees only the Cirsium spp were recorded in sufficient quantities for comparisons to be made. Of these, *Cirsium arvense* was most abundant on the natural recolonisation plot with statistically significantly greater abundance of flowers on the non-inverted areas than the inverted areas, substantially so for the natural recolonisation plot. Whilst *Cirsium arvense* is a frequently visited forage source for the target bumblebees, in some situations this species can be considered undesirable. This result, in relation to soil inversion suppressing *Cirsium arvense* colonisation could, therefore, be interesting in terms of the green haying methodology and might warrant further research. Similar patterns were recorded for *Cirsium vulgare*, although counts were lower and no pairwise significant difference was recorded between treatments.

In part, this inversion study was established as a reaction to the dense grass swards that had developed following green haying in the areas to the west of the green hay donor area. As such, the grass cover and abundance results were of particular interest. For both grass cover and abundance, the green haying method created greater results. No significant difference was recorded for cover, but there was a significant difference for abundance. This reflected a more comprehensive cover following green haying compared to a consistent but sparse cover following natural recolonisation. There was a slight trend of lower grass dominance from inverted areas of the green hay plot, but this was not significantly different.

The other result of interest to the soil inversion experiment was the scrub re-encroachment. Previous experiments indicated that green haying had an effect on the re-colonisation of scrub with scrub counts generally being lower on green hay areas. This pattern was repeated in the latest experiment with scrub cover and dominance both greater on the natural recolonisation plot than the green hay plot. Soil inversion also appeared to impact scrub recolonisation, with significantly greater cover and abundance on the non-inverted areas than the inverted areas.

Longer term monitoring is required to establish whether these short-term recolonisation patterns are sustained, increase or decrease in future years. In the short-term however, the results from soil inversion were mixed. In terms of grass cover following green haying, the method did not seem to be the simple solution that was hoped to resolve the issue of grass dominance in the scrub clearance areas to the west of the hay cut area. Further trials and/or soil analysis would be an option for taking this study forward.

Also of note from the newly cleared area was the presence of hartwort (*Tordylium maximum*), within the recolonisation areas. Hartwort is a nationally scarce plant but can be found across Hadleigh Park. Whilst not a target species in the habitat creation programme, it is encouraging to see this species appearing spontaneously within a scrub cleared area for the second time (previously in experiment area 5). All quadrat records were from within the green hay treatment area.

3.3 May cut trial

3.3.1 Background

Management on the scrub clearance areas has successfully created suitable forage areas for the target conservation priority bumblebee species. However, previous surveys of subsequent floral development of these areas have identified two issues in relation to forage provision targets (Connop and Clough 2016):

i) *Providing a diverse forage source* - the older green hay experiment plots have been gradually transitioning from low swards of diverse wildflowers, including abundant target forage species, to *Centaurea nigra*-dominated tall swards with little floral diversity. *Centaurea nigra* is a good forage plant for honeybees and bumblebees, including the target bumblebee species. It is also of value to other pollinators. However, it is more typically males of the target species that are recorded foraging on it and it is not considered to be as important a forage resource for the target bumblebees as other species such as Lotus spp, *Odontites verna*, and Trifolium spp. As such, diverse swards containing this species, rather than dominated by this species, would be an ideal halted successional point for the habitat creation. A target of diverse habitat creation is also supported by 'the habitat heterogeneity hypothesis' that proposes that structurally diverse habitats provide a greater range of niches and resources, enhancing overall species diversity (MacArthur & MacArthur 1961).

ii) *Providing late forage* - by the time of the surveys, flowering has generally been observed to be coming to an end on the experimental plots with many plants going to seed (Connop and Clough 2016). This is a pattern that has been recorded across the park (Connop 2008a). Both *B. humilis* and *B. sylvarum* are categorised as being late emerging species and late foragers in the UK (Edwards and Jenner 2005). This means that they require a continuity of resources late into the summer season. Both species are commonly recorded still foraging late into September and early October in south Essex. In previous surveys it has been observed that few sites in the area contain suitable forage this late into the year, an exception being Two Tree Island (Connop 2008a).

In an attempt to address both of these issues, a new habitat management trial was established on the green hay experimental plots in 2017. Following the 8th year of the scrub clearance and green haying programme at the park, it was decided that sufficient forage was available to begin such a trial. This comprised a mosaic rotational May cut with the aim of enhancing the structural variation on the plots, creating areas of late forage, and increasing the floral diversity on the plots. It was intended that this would be carried out on experiment areas 1, 4 & 5. All of these areas were established as green hay experimental trials with green hay plots and comparative natural recolonisation plots. Each treatment plot of the experiment areas was divided into eight subplots and these were cut in a systematic pattern using a Rytec attached to a tractor (Figure 22).

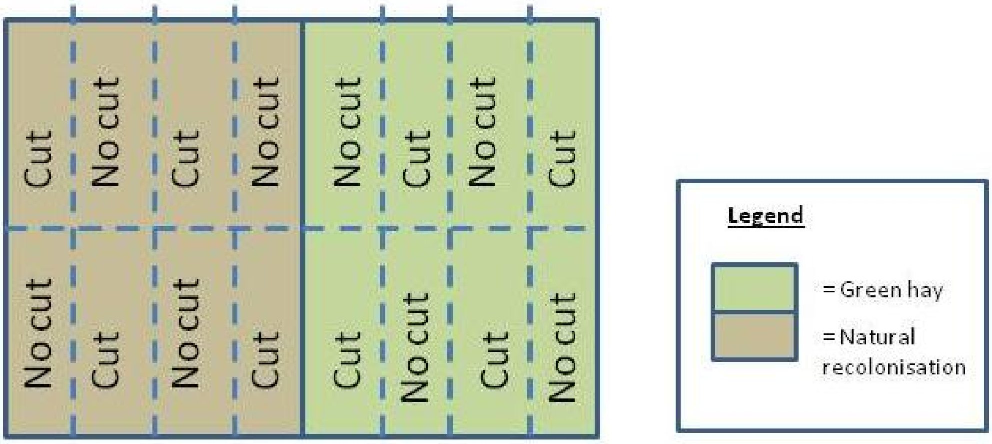


Figure 22. Plan of green hay experiment area mosaic May hay cut. Plan denotes areas that were cut and not cut during May 2017. May cuts were carried out on areas established by green haying or natural recolonisation following scrub clearance.

Whilst it was intended that experiment areas 1, 4 and 5 would be cut, the Rytec used for cutting broke during the process so only the first two of these areas were cut. For experiment areas 1 and 4, all cuttings were removed.

3.3.2 Methods

Floral surveys were carried out on the May cut and uncut areas during the peak foraging period for the target bees (late July/early August) to assess whether the management technique was effective for creating greater structural and floral diversity. The surveys were repeated in early September to investigate whether the technique was effective for providing late forage sources at the park.

Survey quadrat methodology was the same as for the inversion experiment (Section 3.2.2), but only flower counts were made as this was considered the key indicator in terms of performance. Three quadrats were surveyed in each of the cut and non-cut subplots. The quadrats were randomly placed in a systematic pattern (near top corner, centre and near bottom corner) in each of the experiment plots. In total, 96 quadrats were surveyed during each monitoring period (3 replicates on each of 8 subplots across the four green hay treatment experiment areas).

3.3.3 Results

3.2.3.1 August surveys

Sward height

Although no specific measure of sward height was carried out, photographic records taken at the time of the August surveys demonstrated the variation in sward height created by the mosaic May cut (Figure 23). This variation in sward height added greater habitat heterogeneity in terms structure of the experimental areas adding to the overall habitat mosaic.

Flower heads

Flower head count comparisons were made on the May cut and non-cut plots within each of the experiment treatment areas created during the original establishment experiment. During the August survey, a total of 18,285 flower heads were recorded across the 96 surveyed quadrats.

Comparison was made of the flower head counts on cut and un-cut areas with the same underlying treatment (Figure 24). In all four treatment areas of experiment areas 1 and 4, May hay cut plots appeared to record at least slightly higher flower head counts. This effect was more marked on the natural recolonisation areas.

ii)

i)

Figure 23. May hay cut areas at Hadleigh Park, 28th July 2017. Image shows the i) experiment area 1 and ii) the experiment area 4 plots on which a trial May cut were carried out in a mosaic pattern early in the year. A clear difference in sward characteristics was visible between the May cut and uncut areas. This included a difference in both dominant floral species and sward height.

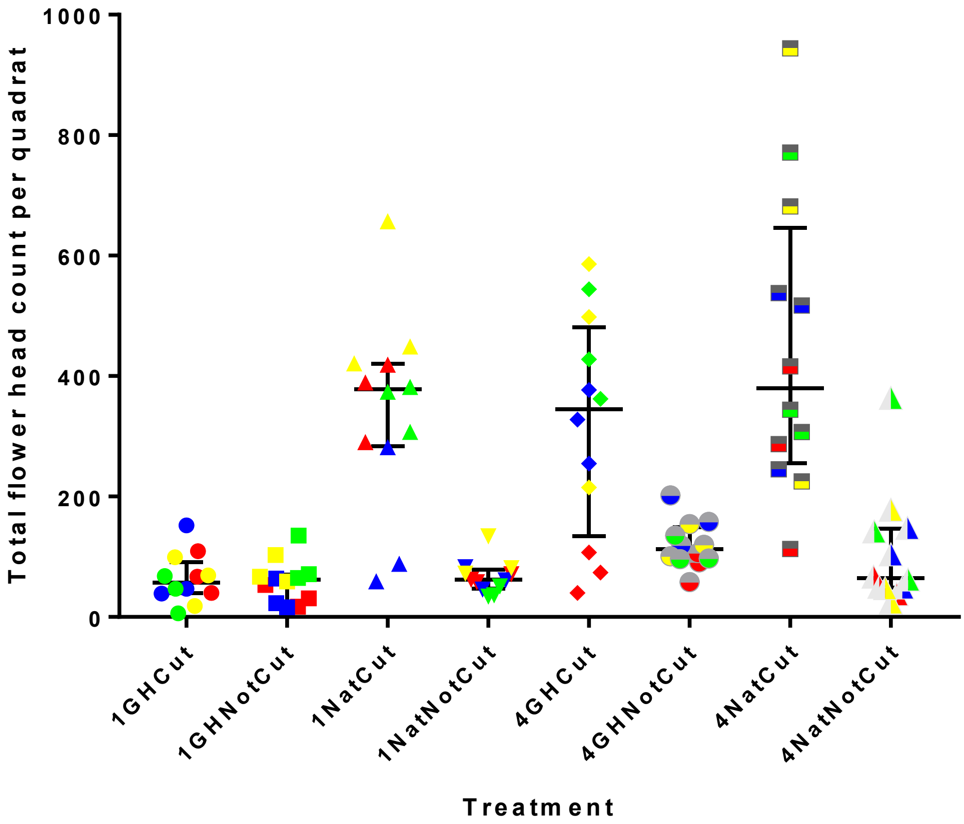


Figure 24. Total flower head counts following May hay cut trial, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 12 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: Experiment area 1 green hay cut (1GHCut), Experiment area 1 green hay not cut (1GHNotCut), Experiment area 1 natural recolonisation cut (1NatCut), Experiment area 1 natural recolonisation not cut (1NatNotCut), Experiment area 4 green hay cut (4GHCut), Experiment area 4 green hay not cut (4GHNotCut), Experiment area 4 natural recolonisation cut (4NatCut), Experiment area 4 natural recolonisation not cut (4NatNotCut). Bars represent the median with interquartile range.

A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of flowerheads ($p < 0.001$). The relationship between flower head number and treatment type was further analysed using Dunn's Multiple Comparison test for post-hoc pairwise comparison. Selected pairwise comparisons were carried out to compare May cut and uncut plots on the same underlying treatment (i.e. experiment area 1 green hay cut vs experiment area 1 green hay not cut). P-values were adjusted to account for multiple comparisons. The quadrats for the experiment area 1 natural recolonisation plot did not appear to be independent, therefore the quadrat counts were combined to produce a total count for each plot for analysis. Graphpad Prism 7.03 software was used for all statistical analyses.

There was no significant difference in terms of total flower head counts between either of the green hay comparisons ($p > 0.99$ for 1GHCut vs. 1GHNotCut and $p = 0.44$ for 4GHCut vs. 4GHNotCut). There was, however, a significant difference in terms of total flower head counts between the cut and uncut plots of both natural recolonisation treatments ($p = 0.01$ for 1NatCut vs. 1NatNotCut and $p < 0.001$ for 4NatCut vs. 4NatNotCut).

In terms of diversity of flowers on the cut and uncut plots, the trend for overall diversity contrasted between the green hay plots and the natural recolonisation plots (Table 6). For the natural recolonisation plots the overall diversity of available flower heads was the same whether cut or not. For the green hay plots, the May cut plots recorded higher flower head diversity than the uncut plots.

Table 6. Presence/absence list of floral species recorded flowering on each experiment area treatment subplot type, August 2017. Twelve 1 x 1 m quadrats were surveyed in the cut and uncut plots of the green hay and natural recolonisation experiment areas. Floral species highlighted by shading are those that are considered to be target forage species for *Bombus humilis* and *Bombus sylvarum* (Connop 2008a). Total floral species for each experimental plot is given under 'Count'. The number in brackets represents the total number of target forage species.

	Experiment area 1				**Experiment area 4**			
	Green hay		**Natural recolonisation**		**Green hay**		**Natural recolonisation**	
Species	**Cut**	**Not cut**	**Cut**	**Not cut**	**Cut**	**Not cut**	**Cut**	**Not cut**
Agrimonia eupatoria	x	x	x		x	x	x	x
Centaurea nigra	x	x	x	x	x	x	x	x
Cerastium fontanum					x			
Geranium dissectum							x	
Galium verum		x		x		x		
Hypericum hirsutum								x
Lotus corniculatus	x	x	x	x	x	x	x	x
Lotus glaber							x	x
Medicago lupulina	x	x	x	x	x	x	x	x
Odontites verna			x	x	x		x	x
Picris echioides			x	x			x	x
Plantago lanceolata	x		x	x	x		x	x
Potentilla reptans			x	x			x	
Prunella vulgaris			x	x				
Ranunculus repens							x	x
Senecio squalidus				x				x
Stellaria graminea								x
Trifolium pratense	x	x	x	x	x	x	x	x
Trifolium repens	x		x		x		x	
Veronica chamaedrys					x			
Count	**7(4)**	**6(3)**	**11(5)**	**11(4)**	**10(5)**	**6(3)**	**13(6)**	**13(5)**

In terms flower head diversity for floral species considered to be target forage for the bumblebees, counts were consistently higher on the May cut plots than the uncut plots for each pair-wise comparison.

Target forage species

Further analysis was carried out to determine whether the May cut trials had led to increased abundance, in addition to diversity, of target forage for the bumblebees.

For *Odontites verna* flower heads, no clear pattern emerged in relation to the May cut (Figure 25).

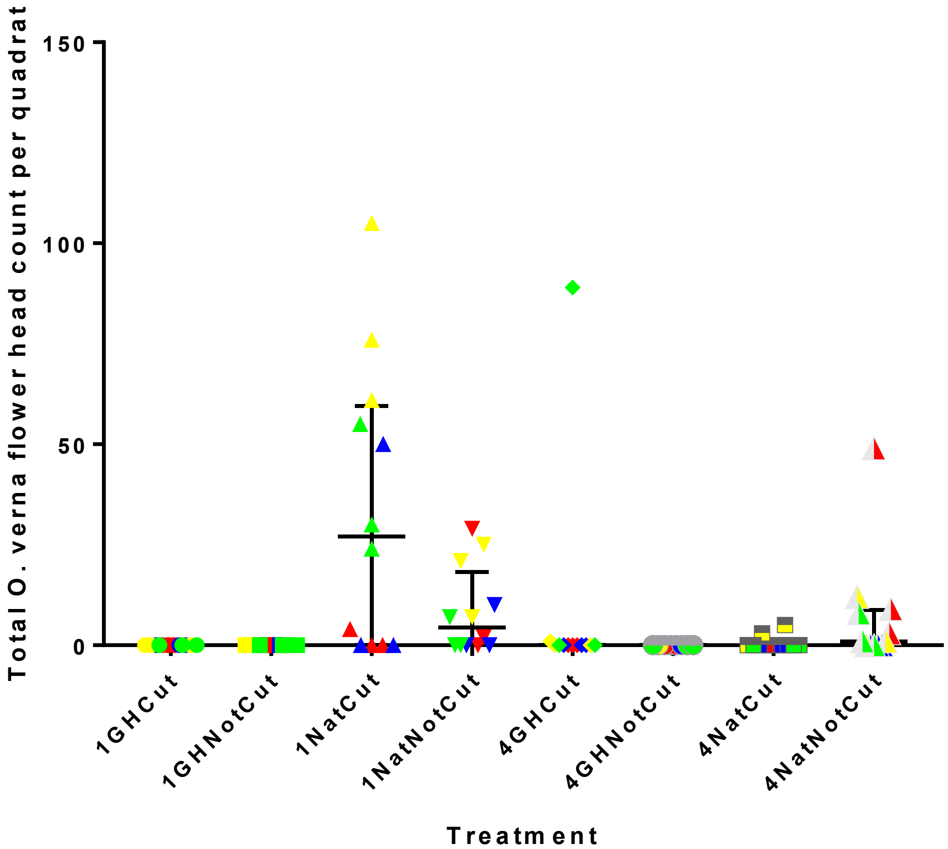


Figure 25. Total *Odontites verna* flower head counts following May hay cut trial, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 12 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: Experiment area 1 green hay cut (1GHCut), Experiment area 1 green hay not cut (1GHNotCut), Experiment area 1 natural recolonisation cut (1NatCut), Experiment area 1 natural recolonisation not cut (1NatNotCut), Experiment area 4 green hay cut (4GHCut), Experiment area 4 green hay not cut (4GHNotCut), Experiment area 4 natural recolonisation cut (4NatCut), Experiment area 4 natural recolonisation not cut (4NatNotCut). Bars represent the median with interquartile range.

The green hay treatment areas showed no increase in *O. verna* flower heads following cutting compared to corresponding uncut plots (with the exception of a single quadrat in a cut plot of experiment area 4). The pattern for natural recolonisation appeared to be location dependent, with experiment area 1 showing an increase following cutting compared to the uncut area and experiment area 4 showing a marginal decrease.

A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of *O. verna* flower heads ($p < 0.001$). The relationship between *O. verna* flower head number and treatment type was further analysed using Dunn's Multiple Comparison test for post-hoc pairwise comparison. Selected pairwise comparisons were carried out to compare May cut and uncut plots on the same underlying treatment (i.e. experiment area 1 green hay cut vs experiment area 1 green hay not cut). No significant difference in terms of total *O. verna* flower head counts were recorded for any of the comparisons ($p > 0.99$ for 1GHCut vs. 1GHNotCut, 1NatCut vs. 1NatNotCut and 4GHCut vs. 4GHNotCut, and $p = 0.14$ for 4NatCut vs. 4NatNotCut).

For *Centaurea nigra* flower heads, a consistent pattern emerged across all experimental area treatments in relation to the May cut (Figure 26). In all cases, a May cut reduced the abundance of *C. nigra* flower heads compared to each corresponding uncut area.

A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of *C. nigra* flower heads ($p < 0.001$). The relationship between *C. nigra* flower head number and treatment type was further analysed using Dunn's Multiple Comparison test for post-hoc pairwise comparison. Selected pairwise comparisons were carried out to compare May cut and uncut plots on the same underlying treatment (i.e. experiment area 1 green hay cut vs experiment area 1 green hay not cut).

For all four pairwise comparisons, a significantly greater *C. nigra* flower head count was recorded on the uncut plots than the corresponding May cut plots ($p = 0.008$ for 1GHCut vs. 1GHNotCut, $p = 0.005$ for 1NatCut vs. 1NatNotCut, $p < 0.001$ for 4GHCut vs. 4GHNotCut and $p = 0.01$ for 4NatCut vs. 4NatNotCut).

Lotus species flower head counts also followed a consistent pattern across all experimental area treatments in relation to the May cut (Figure 27). In contrast to *C. nigra* flower heads, a May cut increased the abundance of Lotus species flower heads compared to each corresponding uncut area.

A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of Lotus species flower heads ($p < 0.001$). The relationship between Lotus species flower head number and treatment type was further analysed using Dunn's Multiple Comparison test for post-hoc pairwise comparison.

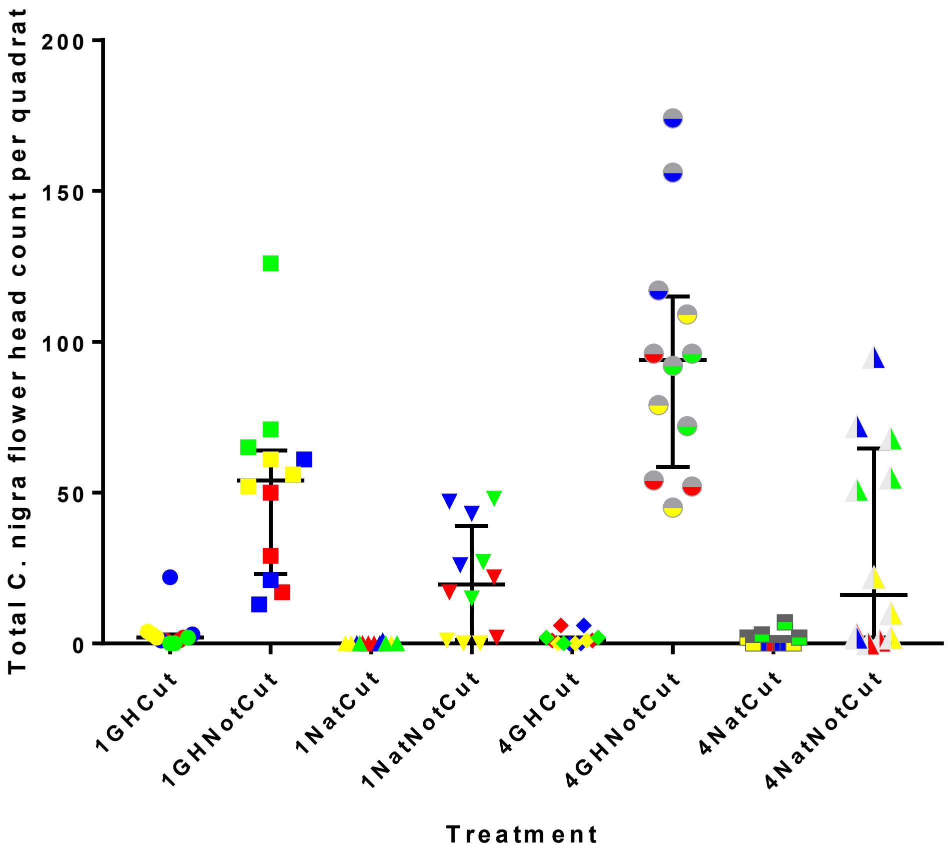


Figure 26. Total *Centaurea nigra* flower head counts following May hay cut trial, August 2017. Values calculated from 1 x 1 m quadrat surveys. $n = 12$ for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: Experiment area 1 green hay cut (1GHCut), Experiment area 1 green hay not cut (1GHNotCut), Experiment area 1 natural recolonisation cut (1NatCut), Experiment area 1 natural recolonisation not cut (1NatNotCut), Experiment area 4 green hay cut (4GHCut), Experiment area 4 green hay not cut (4GHNotCut), Experiment area 4 natural recolonisation cut (4NatCut), Experiment area 4 natural recolonisation not cut (4NatNotCut). Bars represent the median with interquartile range.

Selected pairwise comparisons were carried out to compare May cut and uncut plots on the same underlying treatment (i.e. experiment area 1 green hay cut vs experiment area 1 green hay not cut).

For all four pairwise comparisons, a significantly greater Lotus species flower head count was recorded on the May cut plots than the corresponding uncut plots ($p = 0.003$ for 1GHCut vs. 1GHNotCut, $p = 0.001$ for 1NatCut vs. 1NatNotCut, $p < 0.001$ for 4GHCut vs. 4GHNotCut and $p < 0.01$ for 4NatCut vs. 4NatNotCut).

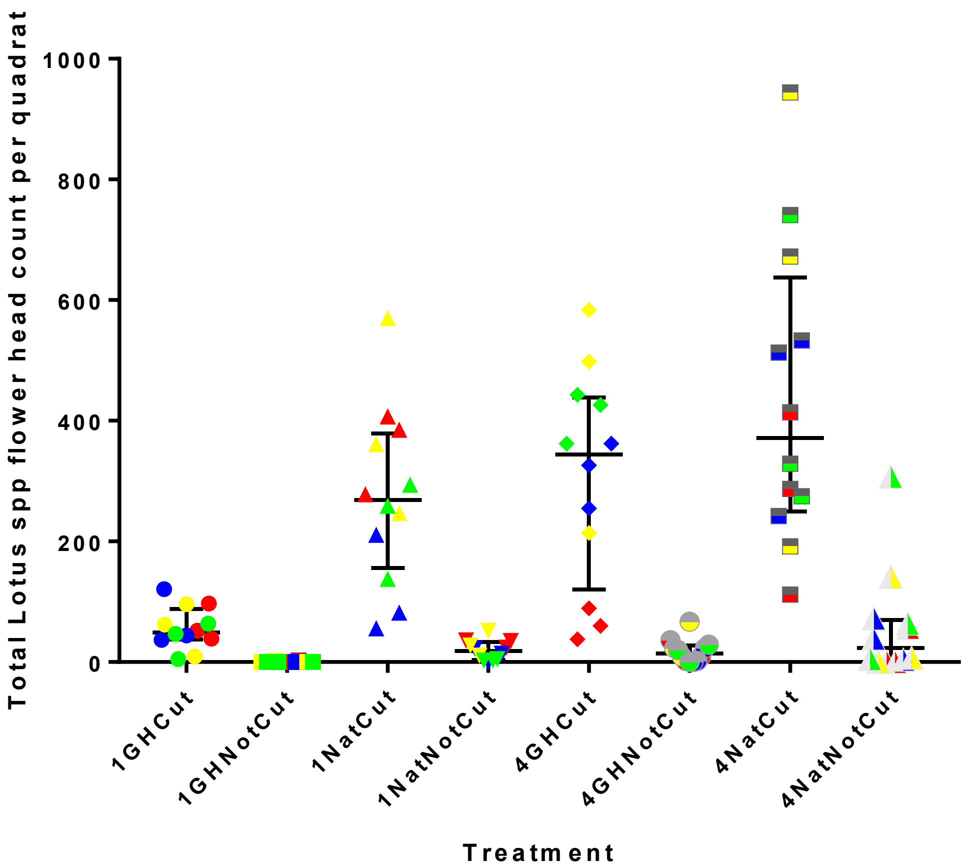


Figure 27. Total Lotus species flower head counts following May hay cut trial, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 12 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: Experiment area 1 green hay cut (1GHCut), Experiment area 1 green hay not cut (1GHNotCut), Experiment area 1 natural recolonisation cut (1NatCut), Experiment area 1 natural recolonisation not cut (1NatNotCut), Experiment area 4 green hay cut (4GHCut), Experiment area 4 green hay not cut (4GHNotCut), Experiment area 4 natural recolonisation cut (4NatCut), Experiment area 4 natural recolonisation not cut (4NatNotCut). Bars represent the median with interquartile range.

For Trifolium species flower heads, no consistent pattern emerged across the experimental area treatments in relation to the May cut (Figure 28). On plots with a May cut and no cut Trifolium species flower head numbers were low.

A Kruskal Wallace test indicated that there was no significant difference between the treatment types in relation to total number of Trifolium species flower heads ($p = 0.12$).

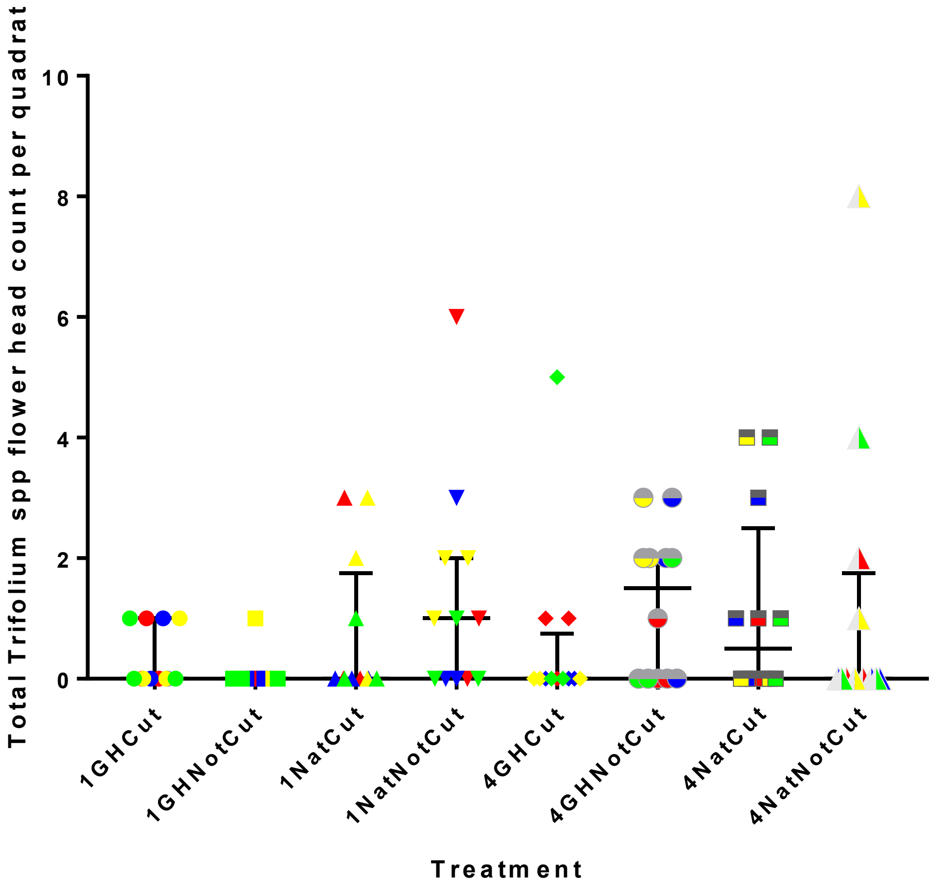


Figure 28. Total Trifolium species flower head counts following May hay cut trial, August 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 12 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: Experiment area 1 green hay cut (1GHCut), Experiment area 1 green hay not cut (1GHNotCut), Experiment area 1 natural recolonisation cut (1NatCut), Experiment area 1 natural recolonisation not cut (1NatNotCut), Experiment area 4 green hay cut (4GHCut), Experiment area 4 green hay not cut (4GHNotCut), Experiment area 4 natural recolonisation cut (4NatCut), Experiment area 4 natural recolonisation not cut (4NatNotCut). Bars represent the median with interquartile range.

3.2.3.2 September surveys

In addition to the peak foraging period of August for both bumblebee species. Flower head counts were also carried out in mid-September on the May cut and comparison plots to assess whether the May cut management was effective in extending the forage availability season.

Sward height

Similarly to the August surveys, no specific measure of sward height was carried out. However, photographic records taken at the time of the mid-September surveys (Figure 29) demonstrated that the variation in sward height evident during the August survey (Figure 23) had persisted.

ii)

i)

Figure 29. May hay cut areas at Hadleigh Park, 12th September 2017. Image shows the i) experiment area 1 and ii) the experiment area 4 subplots on which a trial May cut were carried out in a mosaic pattern earlier in the year. A clear difference in sward characteristics was visible between the May cut and uncut areas. This included a difference in both dominant floral species and sward height.

Flower heads

Flower head count comparisons were made on the May cut and non-cut plots within each of the experimental treatment areas created during the original establishment experiment. During the mid-September survey, there were fewer flower heads, so it was possible to survey a greater number of quadrats. As such 5 quadrats were place in each survey plot. A total of 1657 flower heads were recorded across the 160 surveyed quadrats. This represented a reduction of greater than 90% in terms of available flower heads for pollinators since the August survey.

Comparison was made of the flower head counts on cut and un-cut areas with the same underlying treatment (Figure 30). In all four treatment areas of experiment areas 1 and 4, May hay cut plots appeared to record at least slightly higher flower head counts. This effect was more marked on experiment area 4 than 1.

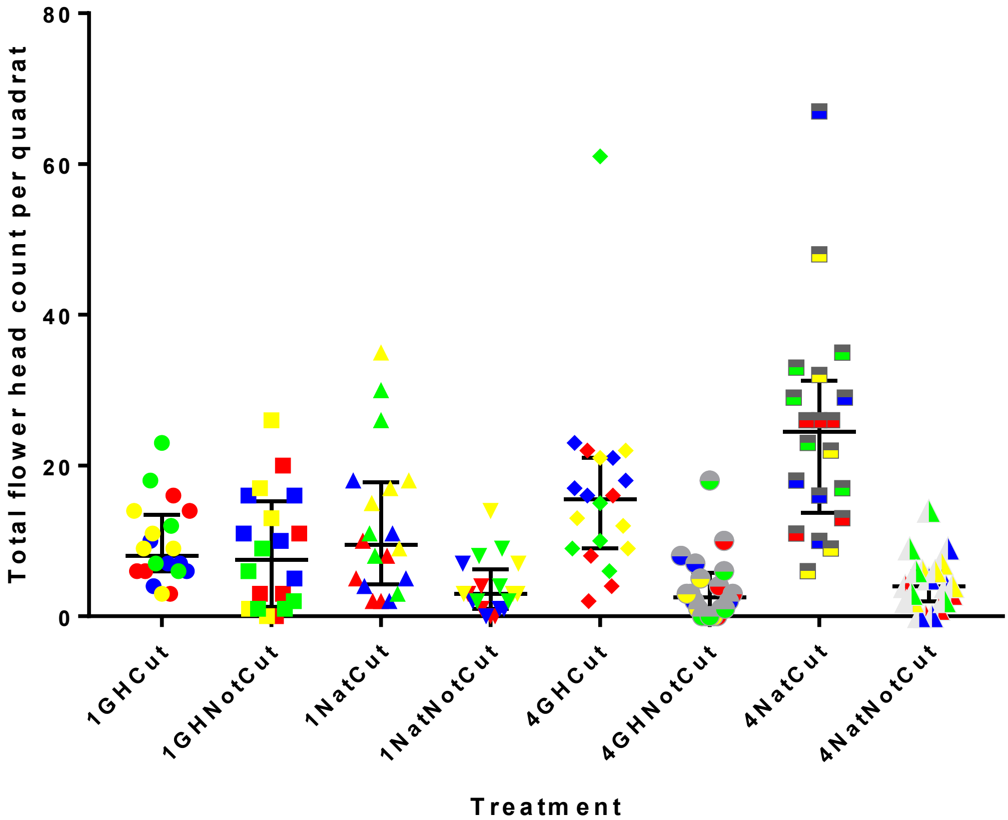


Figure 30. Total flower head counts following May hay cut trial, September 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 12 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: Experiment area 1 green hay cut (1GHCut), Experiment area 1 green hay not cut (1GHNotCut), Experiment area 1 natural recolonisation cut (1NatCut), Experiment area 1 natural recolonisation not cut (1NatNotCut), Experiment area 4 green hay cut (4GHCut), Experiment area 4 green hay not cut (4GHNotCut), Experiment area 4 natural recolonisation cut (4NatCut), Experiment area 4 natural recolonisation not cut (4NatNotCut). Bars represent the median with interquartile range.

A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of flower heads ($p < 0.001$). The relationship between flower head number and treatment type was further analysed using Dunn's Multiple Comparison test for post-hoc pairwise comparison. Selected pairwise comparisons were carried out to compare May cut and uncut plots on the same underlying treatment (i.e. experiment area 1 green hay cut vs experiment area 1 green hay not cut). P-values were adjusted to account for multiple comparisons.

There was no significant difference in terms of total flower head counts between the May cut and uncut subplots of the green hay plot of experiment area 1 ($p > 0.99$). There was, however, a significant greater total flower head count on the May cut subplots of all of the other trial areas ($p = 0.004$ for 1NatCut vs. 1NatNotCut, and $p < 0.001$ for 4GHCut vs. 4GHNotCut and 4NatCut vs. 4NatNotCut respectively).

Overall, flower head diversity was consistently higher on the May cut subplots compared with the corresponding uncut subplots (Table 7). A similar pattern was also observed for the diversity of target forage species for the bumblebees. All May cut subplots recorded either higher diversity or the same diversity as the corresponding uncut subplot.

Table 7. Presence/absence list of floral species recorded flowering on each experiment area treatment plot, September 2017. Twenty 1 x 1 m quadrats were surveyed in the cut and uncut subplots of the green hay and natural recolonisation experiment areas. Floral species highlighted by shading are those that are considered to be target forage species for *Bombus humilis* and *Bombus sylvarum* (Connop 2008a). Total floral species for each experimental plot is given under 'Count'. The number in brackets represents the total number of target forage species.

	Experiment area 1				Experiment area 4			
	Green hay		Natural recolonisation		Green hay		Natural recolonisation	
Species	**Cut**	**Not cut**	**Cut**	**Not cut**	**Cut**	**Not cut**	**Cut**	**Not cut**
Agrimonia eupatoria	x	x			x		x	x
Centaurea nigra	x	x	x	x	x	x	x	x
Cirsium arvense					x			x
Galium verum	x				x			
Jacobaea vulgaris			x			x	x	x
Lathyrus pratensis						x		
Lotus corniculatus	x	x	x	x	x	x	x	x
Lotus glaber					x	x	x	
Medicago lupulina		x	x	x	x	x	x	x
Odontites verna			x					
Picris echioides			x	x	x	x	x	x
Plantago lanceolata	x		x	x	x	x	x	x

Prunella vulgaris			x					
Ranunculus repens			x		x		x	
Rubus fruticosus						x		
Senecio squalidus	x	x		x				
Trifolium pratense	x	x	x	x	x	x	x	x
Count	**7 (3)**	**6 (3)**	**10 (4)**	**7 (3)**	**11 (5)**	**10 (4)**	**10 (4)**	**9 (4)**

Of the target forage species, only *Centaurea nigra*, *Lotus* species and *Trifolium pratense* flower were sufficiently abundant for further analysis to be worthwhile.

For *Centaurea nigra* flower heads, a consistent pattern emerged across all experimental area treatments in relation to the May cut (Figure 31). In all cases, a May cut increased the abundance of late *C. nigra* flower heads compared to each corresponding uncut area.

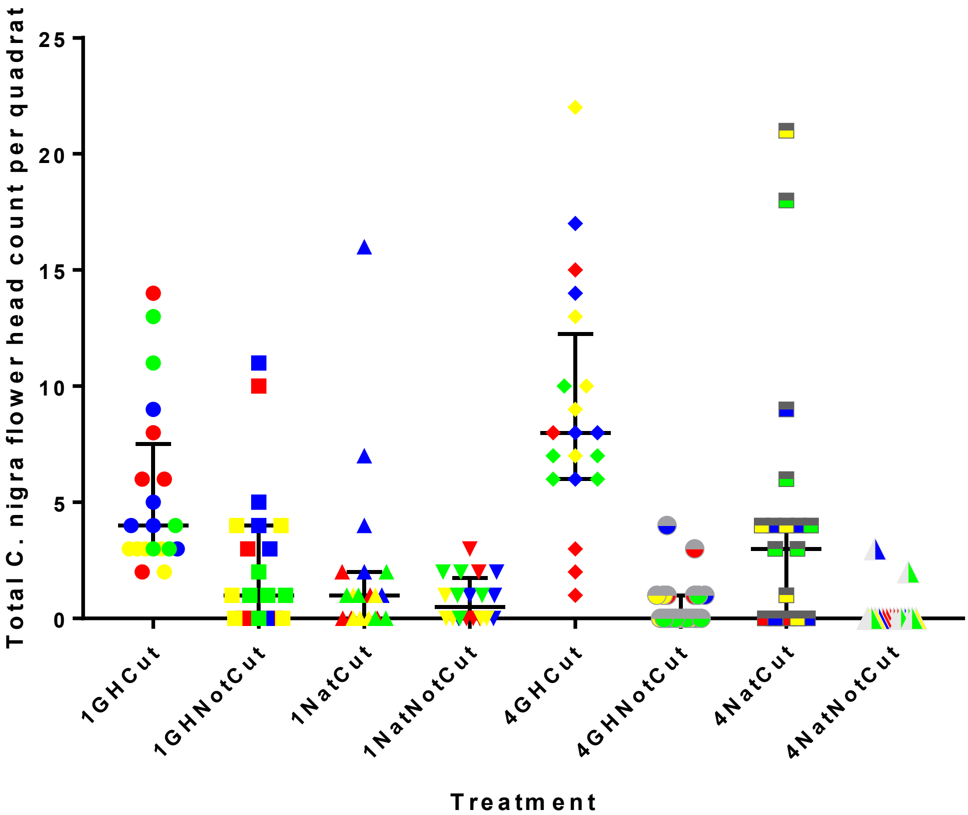


Figure 31. Total *Centaurea nigra* flower head counts following May hay cut trial, September 2017. Values calculated from 1 x 1 m quadrat surveys. *n* = 12 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: Experiment area 1 green hay cut (1GHCut), Experiment area 1 green hay not cut (1GHNotCut), Experiment area 1 natural recolonisation cut (1NatCut), Experiment area 1 natural recolonisation not cut (1NatNotCut), Experiment area 4 green hay cut (4GHCut), Experiment area 4 green hay not cut (4GHNotCut), Experiment area 4 natural recolonisation cut (4NatCut), Experiment area 4 natural recolonisation not cut (4NatNotCut). Bars represent the median with interquartile range.

A Kruskal Wallace test indicated that there was a significant difference between the treatment types in relation to total number of late *C. nigra* flowerheads ($p < 0.001$). The relationship between *C. nigra* flower head number and treatment type was further analysed using Dunn's Multiple Comparison test for post-hoc pairwise comparison. Selected pairwise comparisons were carried out to compare May cut and uncut plots on the same underlying treatment (i.e. experiment area 1 green hay cut vs experiment area 1 green hay not cut).

There was no significant difference in terms of late *C. nigra* flower head count for the natural recolonisation plots of experiment area 1 ($p > 0.99$). For the other plots there were significantly greater late *C. nigra* flower head counts on the May cut plots than the uncut plots ($p = 0.02$ for 1GHCut vs. 1GHNotCut, $p < 0.001$ for 4GHCut vs. 4GHNotCut and $p = 0.003$ for 4NatCut vs. 4NatNotCut).

Lotus species flower head counts followed no consistent pattern across the experimental area treatments in relation to the May cut (Figure 32).

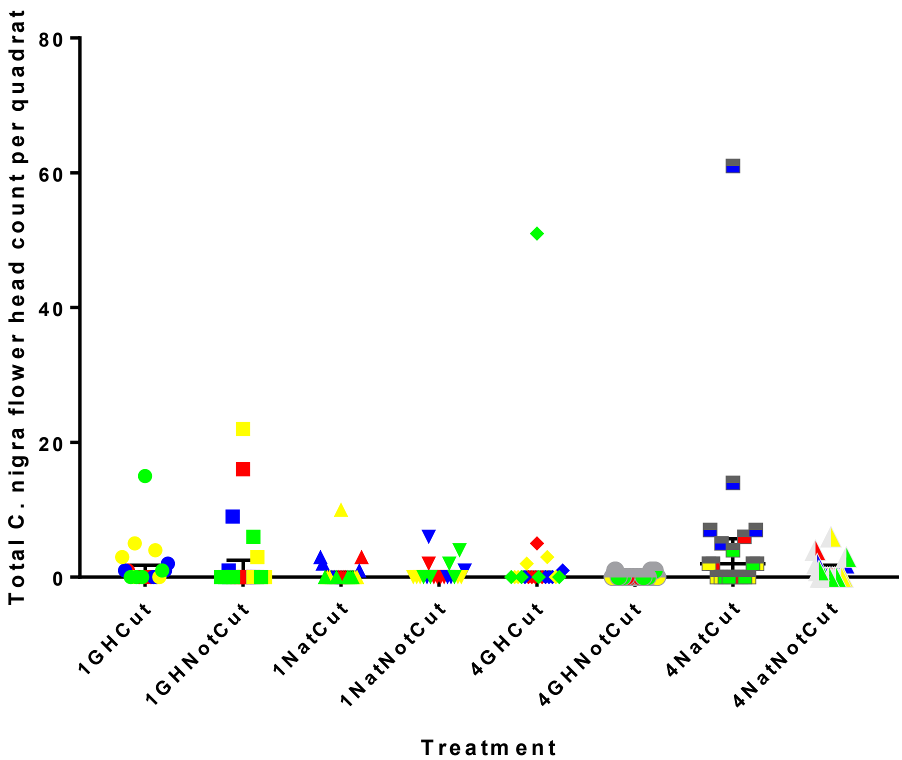


Figure 32. Total Lotus species flower head counts following May hay cut trial, September 2017. Values calculated from 1 x 1 m quadrat surveys. $n = 12$ for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: Experiment area 1 green hay cut (1GHCut), Experiment area 1 green hay not cut (1GHNotCut), Experiment area 1 natural recolonisation cut (1NatCut), Experiment area 1 natural recolonisation not cut (1NatNotCut), Experiment area 4 green hay cut (4GHCut), Experiment area 4 green hay not cut (4GHNotCut), Experiment area 4 natural recolonisation cut (4NatCut), Experiment area 4 natural recolonisation not cut (4NatNotCut). Bars represent the median with interquartile range.

There were occasional high counts on individual quadrats, typically associated with May cut subplots, but overall numbers were low with no distinct pattern. A Kruskal Wallace test indicated that there was no significant difference between the treatment types in relation to total number of Lotus species flowerheads (p = 0.08).

Trifolium pratense flower head counts also followed no consistent pattern across the experimental area treatments in relation to the May cut (Figure 33). On some of the plots it appeared that cutting led to higher counts, but this was not consistent across all plots. A Kruskal Wallace test indicated that there was significant difference between the treatment types in relation to total number of *T. pratense* flowerheads (p = 0.004).

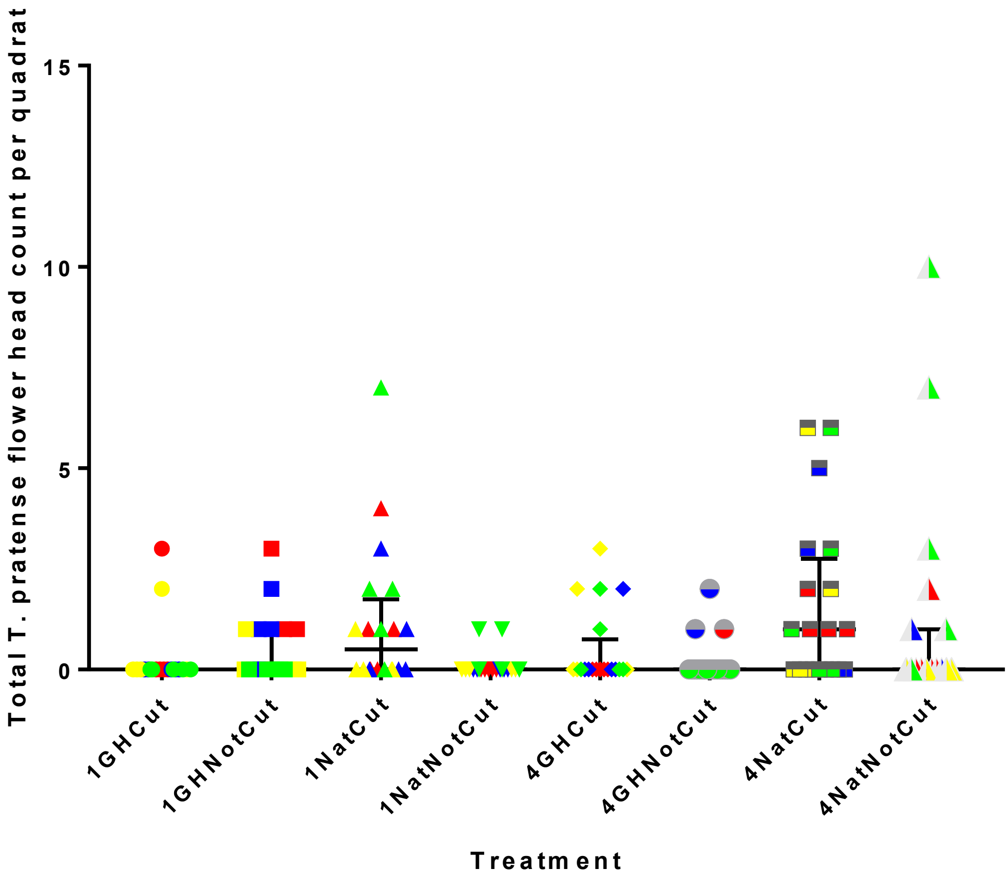


Figure 33. Total *Trifolium pratense* flower head counts following May hay cut trial, September 2017. Values calculated from 1 x 1 m quadrat surveys. n = 12 for each treatment. Quadrat surveys were carried out on three replicate subplots for each treatment. Quadrats from the same subplot within each treatment are grouped by colour. Treatments comprised: Experiment area 1 green hay cut (1GHCut), Experiment area 1 green hay not cut (1GHNotCut), Experiment area 1 natural recolonisation cut (1NatCut), Experiment area 1 natural recolonisation not cut (1NatNotCut), Experiment area 4 green hay cut (4GHCut), Experiment area 4 green hay not cut (4GHNotCut), Experiment area 4 natural recolonisation cut (4NatCut), Experiment area 4 natural recolonisation not cut (4NatNotCut). Bars represent the median with interquartile range.

The relationship between late *T. pratense* flower head number and treatment type was further analysed using Dunn's Multiple Comparison test for post-hoc pairwise comparison. Selected pairwise comparisons were carried out to compare May cut and uncut plots on the same underlying treatment (i.e. experiment area 1 green hay cut vs experiment area 1 green hay not cut).

There were significantly more late *T. pratense* flower heads on the natural recolonisation subplots of experiment area 1 following a May cut than the corresponding uncut subplots ($p = 0.02$). For the other plots there was no significant difference ($p = 0.6$ for 1GHCut vs. 1GHNotCut, $p > 0.99$ for 4GHCut vs. 4GHNotCut and $p = 0.34$ for 4NatCut vs. 4NatNotCut).

3.3.4 Discussion

Initial results from the first year of the May cut trial were very positive with the subplots adding to the habitat heterogeneity of the experimental bumblebee forage creation areas by:

- diversifying habitat structure;
- creating greater and more diverse forage, including target flora, in August at the peak forage time of both *B. humilis* and *B. sylvarum*;
- enhancing late forage availability in mid-September.

In August, during the peak forage activity of both target bumblebee species, evidence from the surveys identified greater structural diversity across the forage plots. Based on the 'habitat heterogeneity hypothesis' (MacArthur & MacArthur, 1961), this should provide benefits to biodiversity, beyond just the target bumblebees by providing a greater diversity of niches to exploit.

May cuts also increased overall flower head numbers and diversity, most notably on the natural recolonisation plots for total numbers and the green hay plots for floral diversity. In terms of target forage species favoured by *B. humilis* and *B. sylvarum*, number of species were all higher on the May cut subplots than corresponding uncut areas indicating that the management intervention had a positive impact on target flora.

In relation to individual key target species, in the short-term, the May cut had no significant impact on *Odontites verna* or *Trifolium* species flower heads. However, corresponding with one of the aims of the trial hay cut, the number of flower heads (and thus dominance in the sward) of *Centaurea nigra* reduced on the May cut subplots compared to the corresponding uncut areas. In previous years, these areas had become almost entirely dominated by this species. Reducing the abundance was an underlying aim with the hope being that it would enable other target forage species to develop. This appeared to be the case based on the August surveys as Lotus species flower head counts indicated that this species was significantly more abundant on all May cut subplots than each corresponding uncut subplot.

One key ambition of the May cut management trial was to extend the flowering season as *B. humilis* and *B. sylvarum* are late foragers. In previous years, very little forage has been available in mid/late September for these bumblebees to forage on. As such, very few individuals have been observed at the park at this time of year, whilst substantial numbers have been recorded on neighbouring sites such as Two Tree Island (Connop 2008a). The mid-September survey was designed to investigate whether the May cut management was successful in promoting late forage for the bumblebees. Whilst flower head numbers were substantially lower than those recorded during the August survey, there was some evidence to suggest that this method had been successful, at least in the short-term.

Overall, the variation in sward height observed at the time of the August survey persisted through to the September survey period. During this later survey, flower head counts on May cut subplots were generally higher than on corresponding uncut subplots. This difference was significant on three of the four treatment plots. Moreover, diversity of flowering species was also up on the subplots that were cut in May. A similar pattern was also observed for diversity of target flora flower heads.

Of these target flora, significantly greater *C. nigra* flower heads were recorded on 3 of the 4 May cut subplots compared to corresponding uncut subplots. No consistent pattern was recorded for either Lotus species or *Trifolium pratense*, but numbers of flower heads of these two species were low.

In addition to this target performance data, anecdotal evidence of the benefits of the May cut mosaic approach was generated incidentally during the quadrat survey process:

- Solitary bee nest cavities were observed during floral quadrat surveys in hay cut areas, indicating that the shorter sward might be more favourable for ground nesting species. As this was not a comprehensive searching methodology, it is possible that these cavities were also present in the uncut areas but were not observed due to the taller vegetation sward. However, evidence from a separate nesting study at Hadleigh Park indicated that once ground cover is comprehensive, nesting behaviour ceases (personal communications, James McGill), so it is likely that the shorter sward would favour such ground nesting behaviour.
- During the September quadrat survey, several bumblebee species were observed foraging in the experiment areas. Whilst no formal standardised timed survey was carried out, all incidental bumblebee foraging observations were recorded and the time spent surveying quadrats in each treatment area was relatively similar. In total, ten individuals were recorded: 2 x *B. pascuorum* on *Picris echioides*; 1 x *B. pascuorum* on *C. nigra*; 4 x *B. humilis* on *C. nigra*; and 3 x *B. sylvarum* on *C. nigra*. Of these ten sightings, nine were on May cut subplots, including all of the *B. humilis* and *B. sylvarum* sightings.

3.4 Timed bumblebee counts

3.4.1 Background

As part of the bumblebee monitoring and habitat creation programme established at Hadleigh Park, counts of bumblebees utilising the most forage-rich areas of the site have been carried out. The purpose of these surveys was to provide long-term monitoring of population size so that an assessment could be made of the 'health' of the bumblebee populations in the park including any effects of the habitat creation programme. Such monitoring enables park managers to understand whether bumblebees are locating and exploiting the new forage resources and, as such, whether habitat management efforts are having a beneficial effect on the target bumblebees. The monitoring programme also provides a barometer for the populations of conservation priority bumblebee species at the park revealing long-term population trends from which the stochastic effects of good and poor climatic years can be disregarded.

3.4.2 Methodology

Bumblebee population baseline surveys were established at Hadleigh Park in 2003. These comprised of standardised timed walking surveys on approximately equal areas of the most forage-rich patches of the site (Figure 34). In 2007, following the establishment of the first experimental green hay and natural recolonisation plots in experiment area 1, these walking surveys were expanded to included the newly created plots. Additional experimental plots were added to these timed survey walks in subsequent years.

The bee walks comprised of a modified version of the bee walk transects used by Banaszak (1980) and Saville et al. (1997). Modification of the method was necessary as the shapes and forage distribution of the forage-rich areas of the park were too patchy and discontinuous for single straight-line transect walks to be effective. Thus, non-linear walks were used which covered the whole of each area including the main flowering patches. The approximate walking routes and duration were replicated with and between each year. Bee walks were conducted between 9:30 and 17:00 BST and during warm weather favourable to bumblebee activity (temperatures greater than 15°C). Observations were made approximately 2 m either side of the observer and walking speed was about 10 m per minute. Timed walking surveys were carried out at the end of July/early August each year. The survey dates corresponded with the peak flight periods for a range of bumblebee species in southern England as reported by Edwards and Jenner (2005) and based on observed peak timings from previous surveys in the region (Connop et al. 2010).

Figure 34. Bumblebee forage-rich areas of Hadleigh Park. Yellow areas represent the most forage-rich areas within Hadleigh Park supporting the highest numbers of *B. humilis* and *B. sylvarum* when surveys began in 2003 to 2005. The red dot represents the location of the first scrub clearance area for the green hay experiment. Aerial Photo © ECC, Map prepared using ESRI ArcGIS.

Identification of bumblebees observed followed Prŷs-Jones and Corbet's key (1987). Bumblebees which could not be identified whilst foraging were captured using queen bee marking plunger cages (Kwak, 1987) and were identified by species morphology using a field lens. Where workers of *B. humilis* and *B. pascuorum* were old and worn making it impossible to use abdomen hair colouration to differentiate between the two species, individuals were recorded as *B. pascuorum* to avoid overestimating numbers of the target species *B. humilis*. For non-target species for which use of a field lens was insufficient to separate individuals, species were grouped together (e.g. *B. terrestris/lucorum* aggregate). Despite thorough searching by the authors and Peter Harvey (personal communications) *Bombus muscorum* has not been recorded in this area of the Thames Corridor in recent years. As such this species has been disregarded during the timed bee walks making differentiation of the 'brown' bumblebees more straightforward.

Ten replicate counts of fifteen minutes each were carried out on each of the original survey areas. Ten replicate counts were also carried out in experiment areas 1 and 4. Due to the new May cut management, the distinction in flora between the original green hay treatments and natural recolonisation treatments were no longer as obvious. As such the timed counts were combined across the green hay and natural recolonisation plots for both of these areas. In addition to these pre-established areas, the new trial experiment area 8 was also included in the timed surveys.

Unless observed bees are collected or marked it is impossible to know whether the same bees have been counted twice, but marking or collecting was considered an impractical technique for these surveys due to the time it would take impacting surveying time. For this reason the bee walks were carried out in a slow and methodical manner in an attempt to avoid counting the same bee twice. It was considered that this combination of avoidance of counting the same individual and repeated methodology both within and between patches would generate accurate comparative counts rather than actual counts. The technique therefore created an accurate comparison of the relative value of the forage areas in terms of the relative number of bumblebees they supported. This created a comparable indices of bumblebee numbers at each survey area within the park that could be compared between areas and across different years.

3.4 3 Results

Results were analysed to assess the abundance and diversity of bumblebees on the green hay plot and natural recolonisation plot of experiment areas 8. Forage preferences on each area were also analysed. Numbers and diversity on all of the originally established forage-rich areas and the cleared experiment areas were also compared.

Comparison between green hay and natural recolonisation areas of experiment area 8

Timed bumblebee counts in experiment area 8 green hay plot recorded higher counts for all *Bombus* species than the corresponding natural recolonisation plot (Figure 35). A Mann-Whitney U Exact test identified this difference to be significant ($p < 0.001$). Counts of *B. humilis* individuals were also higher on the green hay plot than the natural recolonisation plot (Figure 36). A Mann-Whitney U Exact test also identified this difference to be significant ($p < 0.02$). Only a single *B. sylvarum* individual was recorded on the treatment plots of experiment area 8. It was recorded on the green hay plot.

Whilst the repeated counts within the same plot provided a representation of how 'attractive' each plot was in terms to available forage to bumblebees. Treating each result as an independent replicate for statistical analysis could constitute pseudoreplication. As such, the use of statistics to compare statistical difference could be questioned as this replies upon interdependence of replicates. Following the completion of the surveys on experiment area 8, there were comparative green hay vs recolonisation experiments from four different replicate areas (experiment areas 1, 4, 5 and 8). This enabled a paired comparison of results

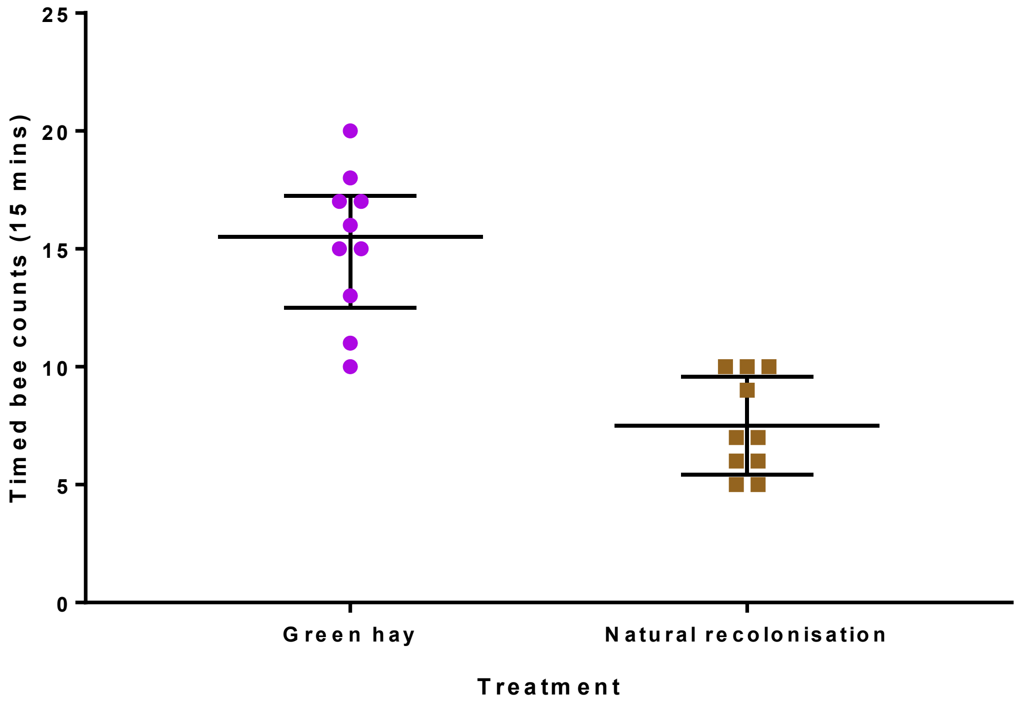


Figure 35. Median bumblebee counts on experiment area 8, August 2017. Medians calculated based on number of individuals observed on the green hay and natural recolonisation plots during a fifteen minute walked survey (*n* = 10). Medians given for all bumblebee species (All *Bombus*) [Bars denote median and interquartile range]

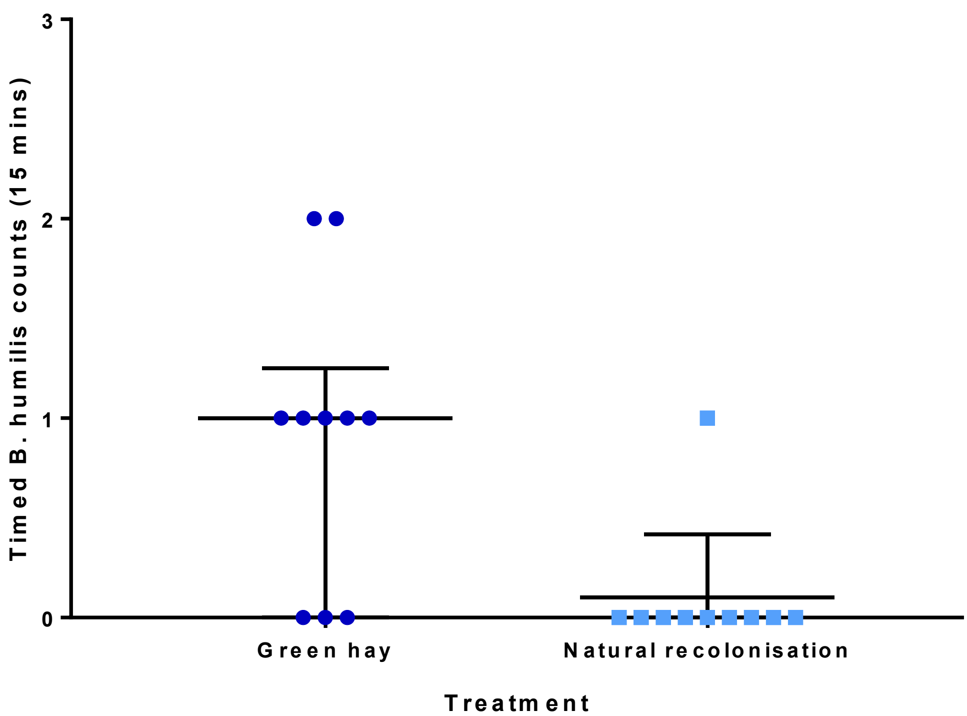
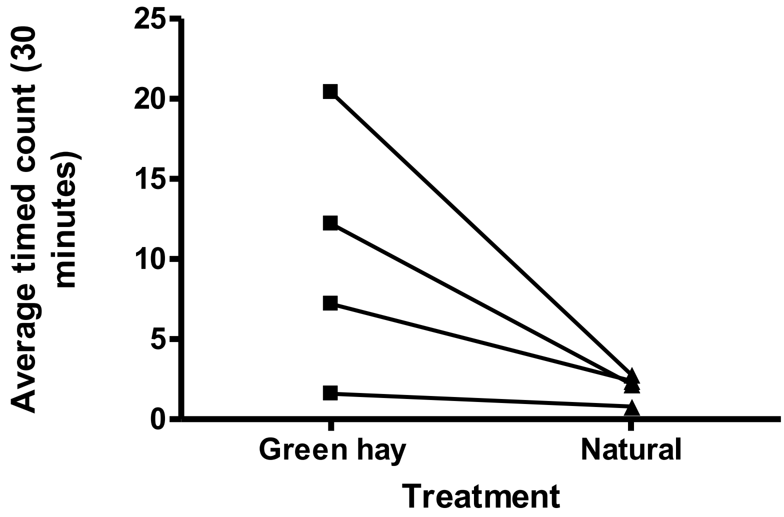
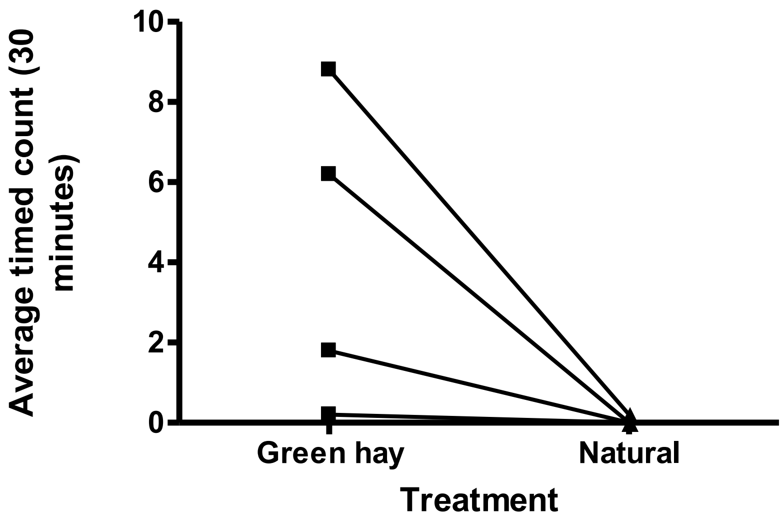


Figure 36. Median i) *Bombus humilis* counts on experiment area 8, August 2017. Medians calculated based on number of individuals observed on the green hay and natural recolonisation plots during a fifteen minute walked survey (*n* = 10). [Bars denote median and interquartile range]

to be carried out. For the purpose of this, average counts from all of the ten replicated bee walks were compared for each green hay and natural recolonisation plot. Graphs of these counts for *B. humilis* and *B. sylvarum* are presented below (Figure 37).



i)



ii)

Figure 37. Comparison of timed i) *Bombus humilis* and ii) *Bombus sylvarum* counts on the green hay and natural recolonisation plots of experiment areas 1, 4,5 and 8 at Hadleigh Park. For each average count, ten replicate counts were carried out. Values are paired for each experiment area. In each case, counts were carried out in the year following the experimental habitat creation.

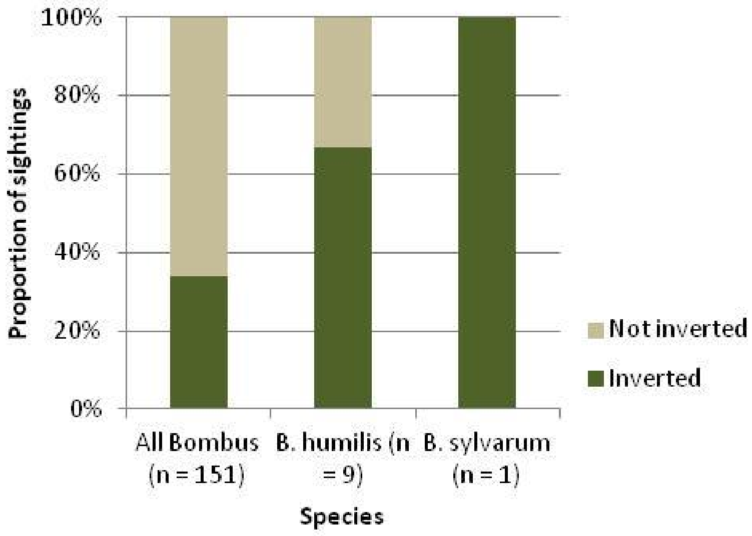
For all four experiment treatment areas, counts of *B. humilis* and *B. sylvarum* were higher on the green hay plot than the corresponding natural recolonisation plot. However, if a comparison of all green hay plots was made to all natural recolonisation plots, the green hay plot counts were not consistently greater than natural recolonisation counts. This indicated that there were natural variations in either floral redevelopment or target bumblebees between the different years and locations. Whilst it is possible to speculate what may have driven this variation (e.g. underlying substrate, difference in green hay crop, annual population fluctuations of target bees), this effect meant that comparison of statistical significance could not be carried out using Mann-Whitney analysis and a paired statistical comparison was necessary instead.

For this analysis a Wilcoxon signed rank test was used. For a Mann-Whitney test, a sample size of four is sufficient to achieve statistical significance. This is not the case for a a Wilcoxon signed rank test, with six being the lowest number of replication that can achieve significant confidence at the $p < 0.05$ significance level. With four replicates the highest significance level that can be achieved with the a Wilcoxon signed rank test is $p = 0.125$. For both *B. humilis* and *B. sylvarum* counts this $p = 0.125$ significance level was achieved.

Comparison between inverted and non-inverted areas of experiment area 8

When a bumblebee was observed within the green hay and natural recolonsation plots of experiment 8, a note was also made of the spatial location of the bee in terms of in terms of whether the soil of the subplot had been inverted or not. Proportional results are presented in Figure 38.

Only a single *B. sylvarum* was observed during the timed surveys meaning that interpretation of patterns in relation to soil inversion was not possible. For *B. humilis* and all *Bombus* species a contrasting pattern in relation to the underlying treatment was recorded. For all *Bombus* species on both the green hay and natural recolonisation plots, substantially greater numbers were recorded on the non-inverted subplots compared to the inverted subplots. However, the opposite was true for *B. humilis* on the green hay plot. Only a single *B. humilis* was recorded on the natural recolonisation plot, so insufficient to represent an interpretable pattern.



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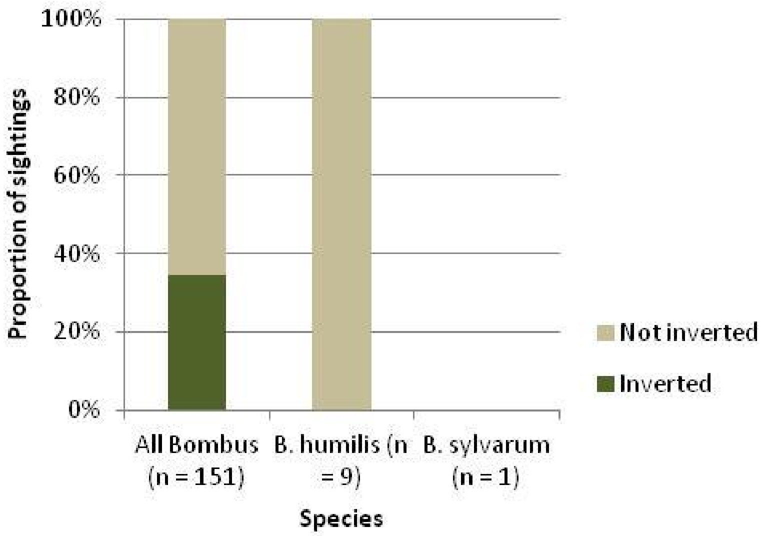


i)

Figure 38. Spatial distribution of bumblebee counts in relation to soil inversion trial, experiment area 8 2017. Bumblebee counts were carried out on i) a green hay plot, and ii) a natural recolonisation plot. Ten counts of fifteen minute duration were carried out on each plot. Observations were recorded relative to inverted and non-inverted soil profile subplots.

Comparative forage use on the green hay and natural recolonisation plots of experiment area 8.

Proportional forage use was also assessed for the green hay and natural recolonisation plots (Figure 39). Similarly to previous years, *Odontites verna* recorded the most visits on the green hay plot for all *Bombus* species.

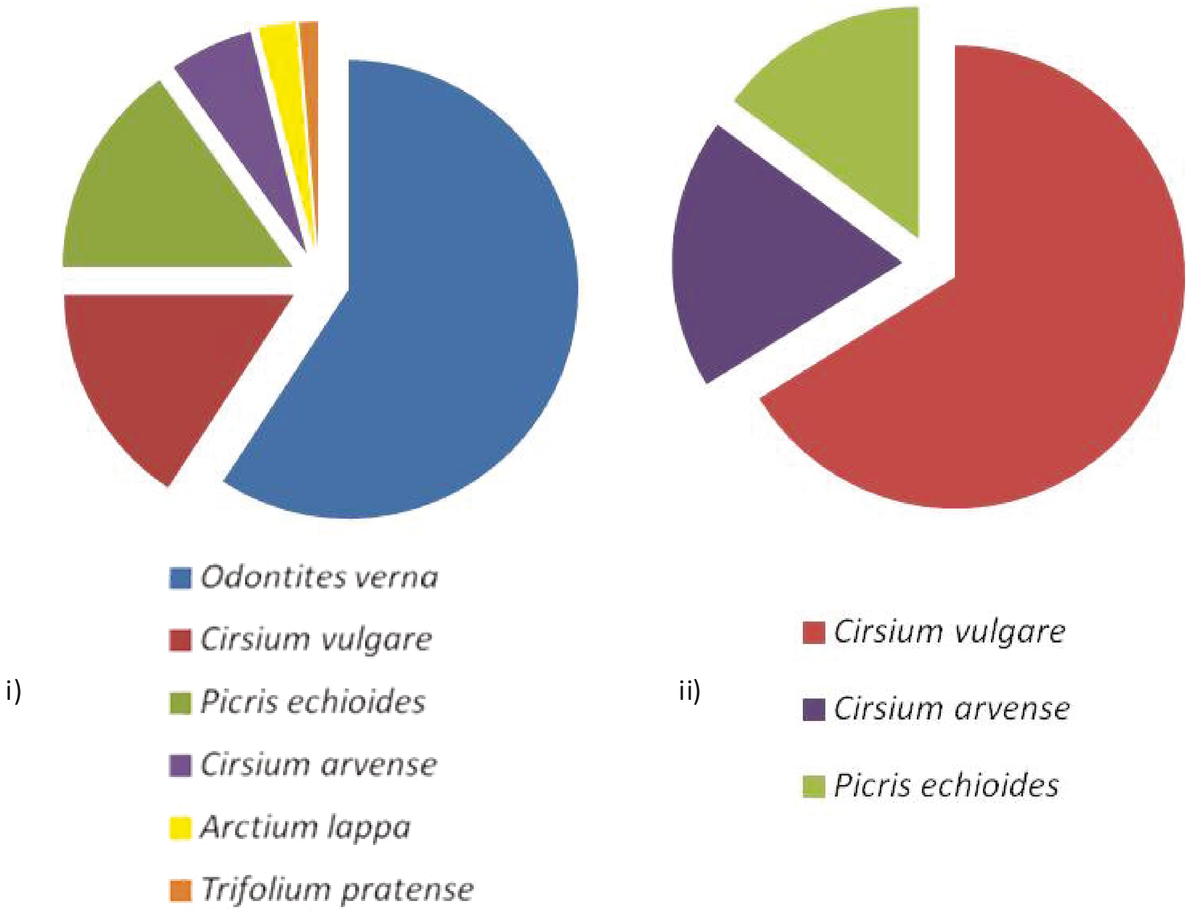


Figure 39. All Bombus species floral use on experiment area 8, Hadleigh Park 2017. Proportions are based on bumblebees observed foraging during ten bee walks each of fifteen minutes. Comparison is presented between individuals observed on the i) green hay (*n* = and ii) natural recolonisation plots (*n* =75) of the experiment area.

Odontites verna also comprised the majority of visits for *B. humilis* (67%) on the green hay area, the other 33% being to *Cirsium vulgare* (*n* = 9). The single *B. humilis* recorded foraging on the natural regeneration plot was observed on *Cirsium vulgare*. The single *B. sylvarum* recorded foraging on experiment area 8 was observed on the green hay plot on *Odontites verna.*

Counts across the park.

In addition to the counts on experiment area 8, timed counts of bumblebees were made across the park. The purpose of these was to enable within year comparisons of numbers on different forage patches and also to enable between year comparisons.

In 2017, patterns across the park were quite varied (Figure 40). Highest mean count for all *Bombus* species was recorded on the green hay donor area. With similarly high counts on all other areas with the exception of the rear of the marsh and the natural recolonisation plot of experiment area 8.

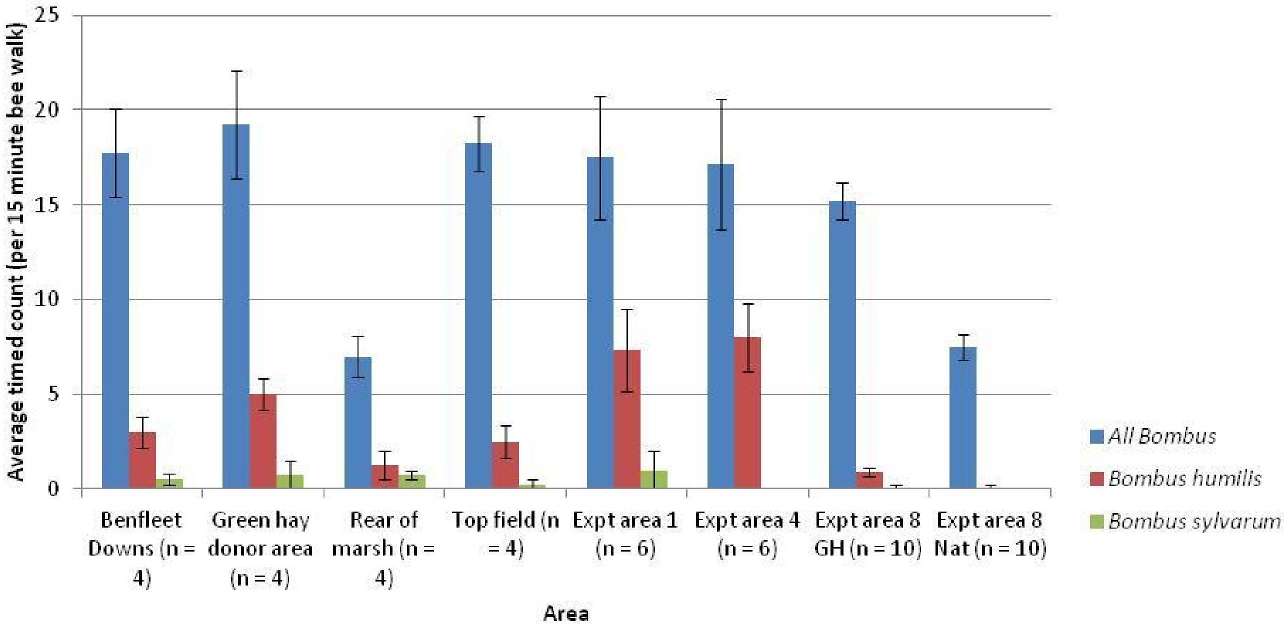


Figure 40. Timed bumblebee counts across the best forage areas of Hadleigh Park, August 2017. Timed counts comprised a 15 minute standardised walk through forage rich areas. All *Bombus* species totals are presented along with target species *Bombus humilis* and *Bombus sylvarum* numbers

Bombus humilis numbers were highest on the green hay experiment areas 1 and 4, with lowest numbers on the natural recolonisation plot of experiment area 8. Similarly to results from nearly all of the previous years, *B. sylvarum* numbers were consistently lower than *B. humilis* counts. Highest *B. sylvarum* counts were recorded at experiment area 1, the green hay donor area and the rear of the marsh. Lowest counts were on experiment area 4 and the green hay and natural recolonisation plots of experiment area 8.

Comparison of the 2017 counts of the two target bumblebee species with those in previous years (Figure 41) highlighted several patters. *Bombus humilis* numbers on forage patches that were the best at the site when monitoring was initiated at Hadleigh Park, revealed a pattern of 2017 being some of the lowest counts. However, in sharp contrast to this, counts for this species on the green hay experiment areas 1 and 4 were some of the highest.

Bombus sylvarum counts on the best forage patches at the site when surveying began showed some signs of recovery in 2017 after particularly low counts in the previous year. Numbers remained very low compared to some of the highest previous counts at the site though. In contrast, numbers of *B. sylvarum* on the green hay experiment areas 1 and 4 were the lowest recorded on the experiment areas.

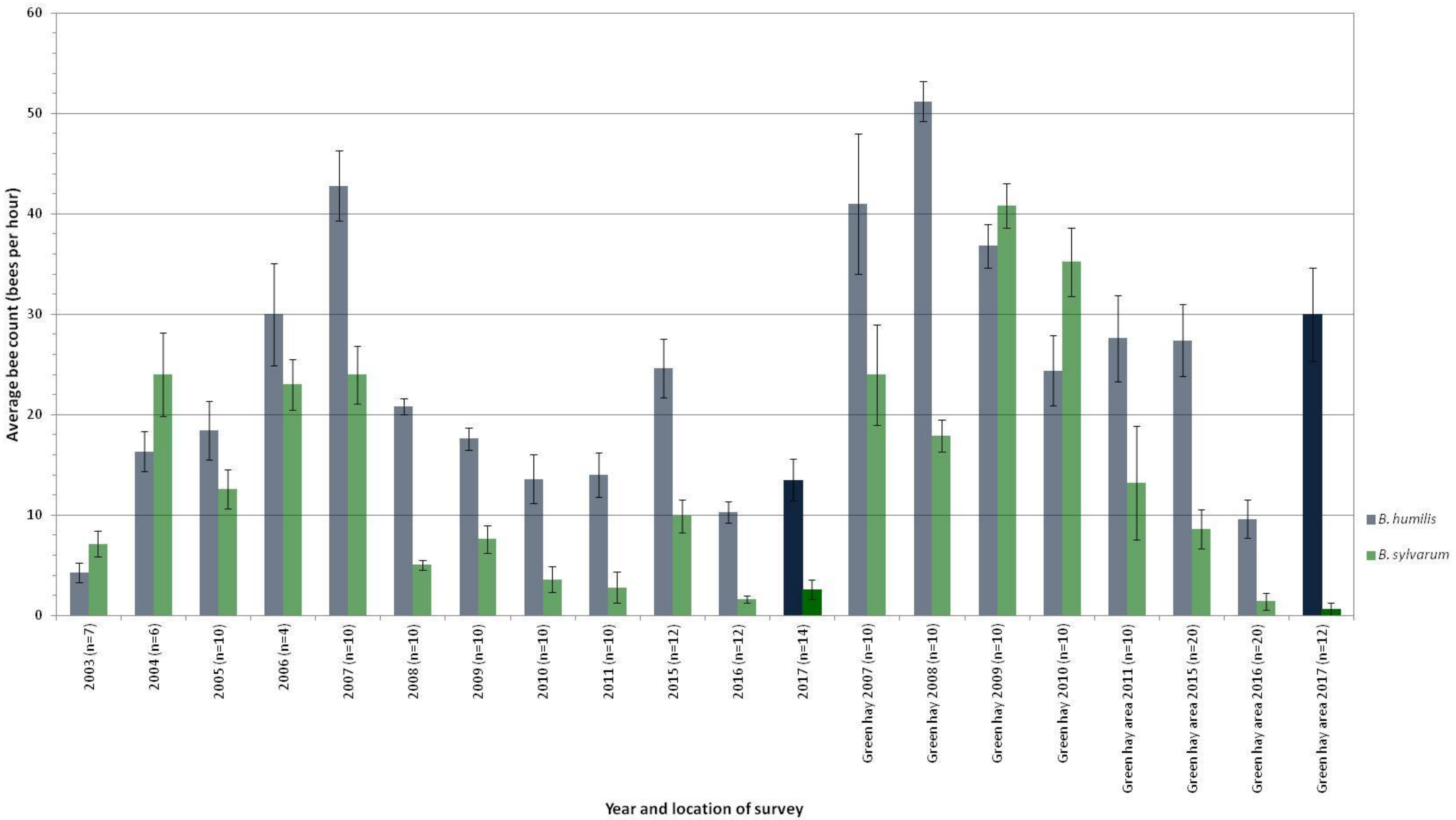


Figure 41. Average annual *Bombus humilis* and *Bombus sylvarum* counts at Hadleigh Park, 2003-2017. Counts were all conducted during August and September, the main foraging period for workers of the two species, over approximately equal areas. n = the number of timed surveys the average is based on. Averages are based on all surveys across the key forage patches at Hadleigh Park and those carried out on green hay plots. Green hay plot counts and key forage patch counts are kept separate for comparison. For the 2017 counts, colours are presented in bold to highlight the latest survey results. [Error bars represent the standard error of the mean]

3.4.4 Discussion

Similarly to previous years, the scrub removal and forage creation programme was successful in attracting bumblebees onto the habitat created area. Of the two experimental techniques on experiment area 8, the green haying plot consistently recorded greater numbers of bumblebees than the natural recolonisation plot. This was the case for all Bombus species combined and for *B. humilis*. Only a single *B. sylvarum* individual was recorded during the bee walk surveys on experiment area 8. This too was recorded on the green hay plot.

Comparison across the four experiment areas on which this comparative trial has been carried out at Hadleigh Park confirmed that this pattern of green haying outperforming natural recolonisation was a consistent trend. At least in the short term, green haying was the better technique for creating forage for target bumblebees following scrub clearance.

Overall, in contrast to all Bombus species, *B. humilis* and *B. sylvarum* counts on the newly created area were low when compared to other forage-rich areas on the site. This was presumably linked to the high proportion of grasses and low proportion of *Odontites verna* flowers that have typified the experiment areas since the experiment area 5 creation. Whilst *Odontites verna* flower heads were available, particularly on the green hay plot, it is possible that *B. humilis* and *B. sylvarum* prefer to forage on more open, high-density stands of their most frequently visited forage and this was reflected in these counts on these new areas. This pattern of foraging densities reflecting forage availability is certainly something that has been experienced anecdotally by the authors.

In terms of bumblebee counts in relation to inverted and non-inverted treatments, no clear pattern emerged. Despite slightly higher *O. verna* counts on the non-inverted sub-plots of the green hay plot, greater numbers of *B. humilis* were recorded on the inverted plots. The opposite pattern was observed for all Bombus species on both the natural recolonisation and green hay plots. As in previous years, *Odontites verna* appeared to be the key forage source, making up the majority of visits on the green hay plot, the majortiy of other visits on the plot being to *Cirsium vulgare* and *Picris echioides*. The absence of *O. verna* on the natural recolonisation plot meant that *C. vulgare* recorded the majority of the forage visits.

Counts from the treatment plots of experiment area 8 were also compared to those from other forage-rich areas across the site. In 2017, counts for all Bombus species from the green hay plot of experiment area 8 were comparable to the best counts from most of the other forage-rich areas. In comparison to the area to the rear of the marsh, counts on the experiment area 8 green hay plot were higher. This pattern was not the same for *B. humilis* and *B. sylvarum*. Counts for both species on both treatment plots of experiment area 8 were the lowest of all of the areas surveyed. It is impossible to conclude whether this was to do with the 'quality' of the forage, or an ability of these target species to find/exploit these new resources. It would be interesting to keep monitoring these areas in future years though, to monitor whether these patterns change.

Annual counts indicated that *B. humilis* numbers were relatively high on the green hay plot and were fairly average on the other forage-rich patches at Hadleigh Park compared to previous years. In contrast, *B. sylvarum* numbers continued to be low with numbers on the green hay plot the lowest recorded since they were created. Numbers on the forage-rich patches across the rest of the park were also fairly low, but higher than in the previous year.

Overall, there remained positive indications that the green hay habitat creation areas were delivering what was aimed for in terms of providing suitable forage that the target bumblebees were able to exploit. Low numbers for *B. sylvarum* continue to be a concern though, with perhaps a broader conservation effort across the landscape important to conserve this species in the region. It is hoped that the new national Bank from the Brink project will be a mechanism to achieve this (https://naturebftb.co.uk/the-projects/shrill-carder-bee/).

4. Bumblebee habitat management recommendations

Based on the results of the summer 2017 green hay vegetation monitoring and timed-bumblebee count surveys, a series of conclusions could be drawn in relation to legacy habitat management plans:

- Green haying at the park and the subsequent late cut management seemed to be an effective and fast method for creating forage areas suitable for bumblebees;
- In the short-term, such habitat creation provided suitable foraging for the conservation priority bumblebee species *B. humilis* and *B. sylvarum.*
- May hay cut on established forage areas in a mosaic pattern was an effective method for both providing more diverse forage during the peak foraging period in July/August and for creating more abundant forage late into the foraging season (September).
- This combination of May hay cut on half of the experiment plots and standard cuts on the other half should be continued.
- It is important to monitor the effects of this new cutting regime long-term to investigate whether is it successful in increasing forage abundance and diversity in future.

- Soil inversion led to some interesting results. Whilst not statistically significant, there was a general trend of greater *O. verna* abundance and lower grass abundance on inverted areas within the green hay plots.
- Further inversion trials, potentially including larger areas, would be beneficial in order to clarify these trends.
- Whilst inversion did appeared to have some effect on recolonisation following green haying, the effect was not significant and grass recolonisation on inverted green hay areas remained more abundant than had been observed on the previously created experiment areas to the east of the hay cut donor area. As such, it might be worth carrying out soil analysis to investigate whether there is a physical/chemical difference in the soil to the east and west of the green hay donor area that would explain the differing results of the green haying in both areas.
- Inversion also appeared to have a beneficial effect in terms of reducing scrub encroachment following clearance.
- Long-term monitoring of scrub re-encroachment would be beneficial for understanding whether this effect persists in future.
- Future management should target the creation of both flower-rich areas for foraging and mature grass swards for nesting.
- Similarly to the previous year, no evidence was provided of a significant detrimental effect of the introduction of grazing on the experiment plots. However, there remained no substantial evidence of any effect of the new grazing in the green hay experiment areas. In particular, there was still no evidence that the new management intervention was delaying or reversing the observed trend of shift from short open vegetation dominated by *O. verna* and Lotus species to taller more closed swards dominated by *C. nigra*.
- Further monitoring of floral development and timed bee counts is necessary to assess the long-term effects of initiating the new disturbance trial and May hay cuts. Continuing monitoring would also be of benefit in terms of understanding the long-term patterns of the target bumblebee numbers at the park. This is particularly of value in light of the new Back from the Brink national conservation project for *B. sylvarum* which has been developed in response to the continued declines of this species nationally.
- As recommended in previous years, one of the key forage areas - rear of marsh, should also be targeted for habitat management. The value of this area has reduced significantly in relation to foraging bumblebees but it still records proportionately higher visits by the target conservation priority bumblebee species than the more ubiquitous bumblebees at the park. The majority of *B. humilis* and *B. sylvarum* sightings in this area have been on *Lotus glaber* in a secluded area surrounded by scrub and on *O. verna* along the edges of the path running east-west to the north of the grazing marsh. Abundance of both of these forage sources was substantially reduced by the time of the 2017 surveys. *Lotus glaber* generally needs winter wet

conditions to develop (personal communications - Peter Harvey) and it is possible that this area at the rear of the marsh is one of the few areas within the park to provide such conditions. A small scrape could be trialled here and/or heavy equipment driven in the area during winter to assess whether disturbance management is a potential method for re-establishing the comprehensive *Lotus glaber* forage that was found here previously. More intensive cutting along the path edges, or creation of wider path edges could also be instigated to encourage *O. verna* re-development.

5. Pantheon

2.1 Background

Following the 2015 common standards monitoring at Hadleigh Park, the ISIS invertebrate analysis programme (2010 version) was used to identify the habitat associations of the invertebrate assemblages (Harvey 2015). ISIS was developed by Natural England as a tool to define and recognise invertebrate assemblages in the UK. Assemblages which qualify as in favourable condition in ISIS are ones which exceed threshold scores whereby assemblages qualify as nationally important. The ISIS analysis was carried out to provide an indication of the habitat types and conditions of these habitats present in the park at the time of survey. Since the production of the baseline report, an additional invertebrate assemblage analysis tool has been developed by Natural England and the Centre for Ecology and Hydrology - PANTHEON (Webb at al 2017). Pantheon is an online tool (http://www.brc.ac.uk/pantheon/) adapted from ISIS which supports improved understanding of the resources and structures used by invertebrates within a sample locations to aid their conservation. In order to assess the status of such resources at Hadleigh Park, the original species lists generated by Peter Harvey (Harvey 2015) and additional species recorded by James McGill and Stuart Connop were inputted into the PANTHEON online programme. The results of this are presented below (Tables 8 to 15 and Figure 42).

Table 8. Summary of taxanomic output for Hadleigh Park invertebrates. Data generated from species list for Hadleigh Park. Data analysed using Natural England and the Centre for Ecology and Hydrology online invertebrate assemblage analysis tool - PANTHEON (http://www.brc.ac.uk/pantheon/).

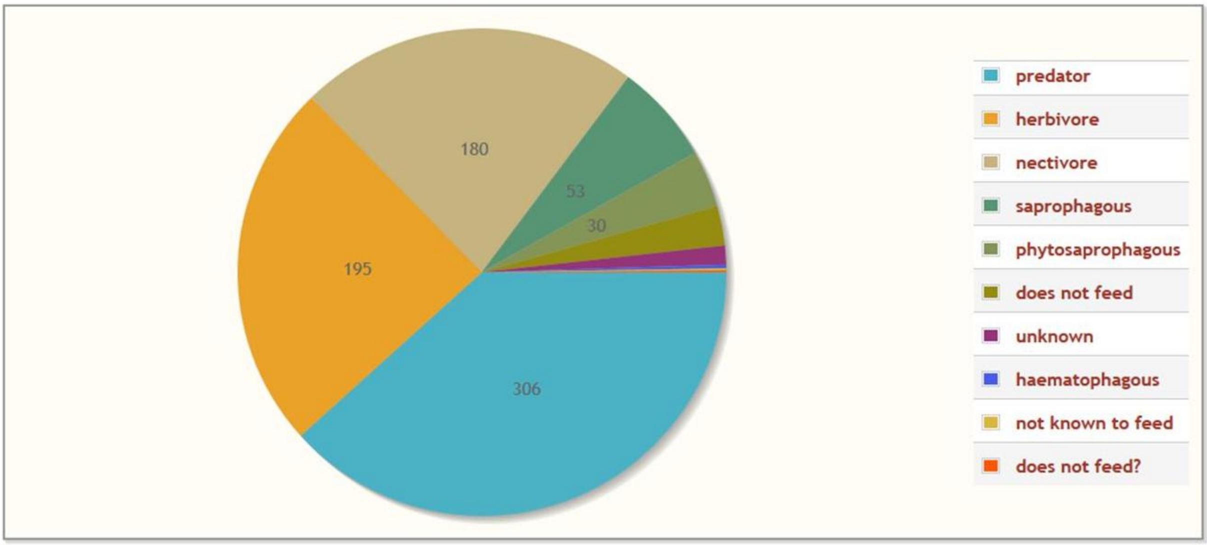
Taxonomic output	Number	Proportion
insect - beetle (Coleoptera)	319	31%
insect - true fly (Diptera)	204	20%
insect - true bug (Hemiptera)	130	12%
spider (Araneae)	126	12%
insect - hymenopteran	92	9%
insect - butterfly	14	1%
insect - orthopteran	9	0%
harvestman (Opiliones)	9	0%
insect - moth	7	0%
insect - dragonfly (Odonata)	4	0%
insect - scorpion fly (Mecoptera)	2	0%
crustacean	2	0%
insect - earwig (Dermaptera)	2	0%
millipede	1	0%

Table 9. Summary of feeding guilds for Hadleigh Park invertebrates. Data generated from species list for Hadleigh Park. Data analysed using Natural England and the Centre for Ecology and Hydrology online invertebrate assemblage analysis tool - PANTHEON (http://www.brc.ac.uk/pantheon/).

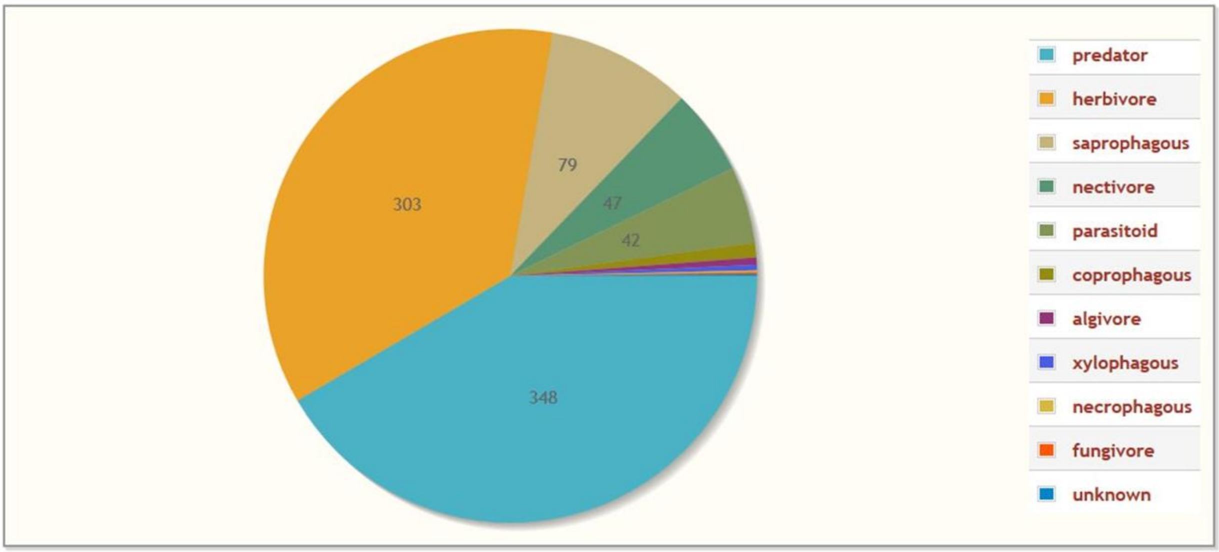
Stage	Guild	No. of spp	Proportion (%)
adult	predator	306	30
adult	herbivore	195	19
adult	nectivore	180	17
adult	saprophagous	53	5
adult	phytosaprophagous	30	2
adult	does not feed	21	2
adult	unknown	10	0
adult	haematophagous	2	0
adult	not known to feed	1	0
adult	does not feed?	1	0
larva	predator	348	34
larva	herbivore	303	29
larva	saprophagous	79	7
larva	nectivore	47	4
larva	parasitoid	42	4
larva	coprophagous	8	0
larva	algivore	4	0
larva	xylophagous	3	0
larva	necrophagous	1	0
larva	fungivore	1	0

Table 10. Summary of biotope associations for Hadleigh Park invertebrates. Data generated from species list for Hadleigh Park. Data analysed using Natural England and the Centre for Ecology and Hydrology online invertebrate assemblage analysis tool - PANTHEON (http://www.brc.ac.uk/pantheon/).

Broad biotope	No. of spp	% representation	Species Quality Index (SQI)	Species with conservation status	Conservation status
open habitats	604	14	131	61	18 NSi; 1 RDB 2; 17 Nb; 1 CR; 1 NRi; 7 RDB 3; 5 Notable; 7 Na; 6 Section 41 Priority Species; 1 (LR); 2 NTi; 1 RDB K; 1 Section 41 Priority Species - research only
tree-associated	149	4	141	17	3 Nb; 2 NRi; 4 Na; 5 NSi; 1 RDB 3; 1 RDB K; 1 Notable; 1 pNT
wetland	134	5	119	7	2 NSi; 1 RDB I; 2 Notable; 1 Nb; 1 RDB 2
coastal	17	4	265	6	1 Notable; 4 NSi; 1 RDB 3



ii)



i)

Figure 42. Distribution of feeding guilds for Hadleigh Park i) larval and ii) adult invertebrates. Data generated from species list for Hadleigh Park. Data analysed using Natural England and the Centre for Ecology and Hydrology online invertebrate assemblage analysis tool - PANTHEON (http://www.brc.ac.uk/pantheon/).

Table 11. Summary of habitat associations for Hadleigh Park invertebrates. Data generated from species list for Hadleigh Park. Data analysed using Natural England and the Centre for Ecology and Hydrology online invertebrate assemblage analysis tool - PANTHEON (http://www.brc.ac.uk/pantheon/).

Broad biotope	Habitat	No. of spp	% representation	Species Quality Index (SQI)	Species with conservation status	Conservation status
open habitats	tall sward & scrub	425	16	124	28	4 Notable; 9 Nb; 9 NSi; 1 CR; 1 NRi; 3 RDB 3; 3 Section 41 Priority Species; 1 Section 41 Priority Species - research only
open habitats	short sward & bare ground	170	13	141	30	4 Na; 3 Section 41 Priority Species; 4 RDB 3; 8 Nb; 2 Notable; 9 NSi; 1 (LR); 1 RDB 2; 2 NTi
tree-associated	arboreal	74	6	130	6	3 NSi; 1 Nb; 1 Na; 1 NRi
wetland	marshland	67	8	120	3	1 RDB 2; 1 NSi; 1 RDB I
wetland	peatland	65	6	115	3	2 Notable; 1 NSi
tree-associated	shaded woodland floor	46	4	144	5	1 RDB 3; 1 Nb; 1 NRi; 1 pNT; 1 Notable; 1 NSi
tree-associated	decaying wood	33	3	168	7	2 NSi; 3 Na; 1 RDB K; 1 Nb
coastal	saltmarsh	17	6	265	6	1 RDB 3; 4 NSi; 1 Notable
wetland	running water	16	2	100		
coastal	brackish pools & ditches	8	7	175	2	2 NSi
tree-associated	wet woodland	7	3	100		
wetland	wet woodland	7	3	100		
open habitats	upland	3	2	100		
coastal	rocky shore	1	3	800	1	1 RDB 3
coastal	sandy beach	1	<1	100		

Table 12. Summary of habitat scores for Hadleigh Park invertebrates. Data generated from species list for Hadleigh Park. Data analysed using Natural England and the Centre for Ecology and Hydrology online invertebrate assemblage analysis tool - PANTHEON (http://www.brc.ac.uk/pantheon/).

Habitat Scores	
Number of species	1014
Number of species with habitat scores	892
Conservation statuses	
GB Conservation Status (old & new)	9 Na; 20 Nb; 1 Not native; 1 Not reviewed; 13 Notable; 3 NR; 32 NS; 1 RDB 1; 2 RDB 2; 10 RDB 3; 2 RDB I; 2 RDB K
GB Red List	2 (LR); 1 CR; 28 LC; 2 NA; 1 NE; 2 NT; 19 pLC; 1 pNT
Section 41 Priority Species	6 Section 41 Priority Species
Section 41 Priority Species - research only	1 Section 41 Priority Species - research only
Scores	
acid mire	1 acid mire specialists
calcareous grassland	3 High, 31 Moderate, 1 Moderate to low, 22 Low
coarse woody debris	4 facultative xylophages, 2 probable xylophages/non xylophages
ERS (Coleoptera)	2 ERS associated
ERS (Diptera)	1 moderate fidelity
grazing marsh - salinity	12 Freshwater species tolerant of only mildly brackish water, 1 Species tolerant of mildly brackish conditions
grazing marsh - status	1.54
peat bog spiders	6 indicator species
seepage (calcareous)	1 seepage obligates, 2 seepage specialists, 1 seepage associates
seepage (soft rock cliff)	1 seepage associates
soft rock cliff	6 Grade 3

Table 13. Summary of resource associations for Hadleigh Park invertebrates. Data generated from species list for Hadleigh Park. Data analysed using Natural England and the Centre for Ecology and Hydrology online invertebrate assemblage analysis tool - PANTHEON (http://www.brc.ac.uk/pantheon/).

Broad biotope	Habitat	Resource type	Resource sub-type	No. of species	% representation	Species Quality Index (SQI)	Species with conservation status	Conservation status
open habitats	tall sward & scrub	habitats	sward/field layer	251	16	123	22	RDB 3|Section 41 Priority Species|RDB 3|Nb|Nb|Section 41 Priority Species|Notable|NS|RDB 3|NS|NS|Nb|Nb|Notable|Nb|NS|Nb|NS|Notable|Nb|Nb|Section 41 Priority Species|Notable|Section 41 Priority Species - research only
open habitats	tall sward & scrub	soil humidity	dry	151	21	126	15	RDB 3|Notable|Section 41 Priority Species|Notable|Notable|Nb|Notable|Nb|NS|Section 41 Priority Species|Nb|RDB 3|Nb|Section 41 Priority Species|Nb|NS|NS
open habitats	tall sward & scrub	habitats	litter & ground layer	147	22	110	5	Nb|NS|NS|NS|NS
open habitats	short sward & bare ground	soil humidity	dry	141	14	140	27	Nb|Notable|NS|NS|NS|RDB 3|Section 41 Priority Species|Nb|RDB 2|Section 41 Priority Species|NT|Nb|Na|RDB 3|Nb|Nb|RDB 3|RDB 3|NT|Section 41 Priority Species|Nb|NS|Na|NS|(LR)|NS|NS|Notable|Nb|Na|Nb
open habitats	short sward & bare ground	habitats	sward/field layer	124	16	143	25	Na|Nb|Na|NS|RDB 2|NS|Notable|Nb|Section 41 Priority Species|NT|Nb|Na|RDB 3|Nb|Nb|RDB 3|RDB 3|NS|Nb|Nb|Na|Section 41 Priority Species|NT|Section 41 Priority Species|RDB 3|Nb|NS|Notable
open habitats	tall	soil	variable	120	27	113	6	NS|NS|NS|NS|Nb|Nb

	sward & scrub	humidity	humidity					
tree-associated	arboreal	canopy		69	5	128	5	Nb|NS|Na|NS|NR
open habitats	short sward & bare ground	habitats	exposed sand	68	12	143	15	Na|Na|NS|Nb|NS|Na|RDB 3|Section 41 Priority Species|NS|Nb|Na|RDB 2|RDB 3|Nb|RDB 3|Nb
open habitats	tall sward & scrub	soil humidity	damp	62	15	169	3	RDB 3|NS|CR|NR
open habitats	short sward & bare ground	soil type	sand	49	10	153	12	Na|RDB 3|RDB 2|RDB 3|Na|Nb|Section 41 Priority Species|RDB 3|NS|Na|NS|NS|Nb
tree-associated	arboreal	conifer or broadleaved	broadleaved only	49	5	140	5	NS|Nb|Na|NS|NR
open habitats	short sward & bare ground	habitats	litter & ground layer	44	20	121	3	NS|NS|NS
tree-associated	shaded woodland floor	conifer or broadleaved	broadleaved only	43	4	147	5	NS|NR|pNT|Notable|RDB 3|Nb
tree-associated	arboreal	foliage		40	8	133	3	NR|NS|NS
open habitats	tall sward & scrub	habitats	soil & roots	39	20	187	2	NR|NS|CR
wetland	marshland	drawdown zone: mud/shallow litter		34	10	136	3	RDB I|RDB 2|NS
wetland	peatland	wetland vegetation		31	8	109		

tree-associated	shaded woodland floor	shadiness		28	4	126	3	RDB 3|Nb|NS
tree-associated	decaying wood	sapwood & bark decay		27	4	156	5	Nb|RDB K|Na|Na|NS
tree-associated	decaying wood	sapwood & bark decay	dead trunks & branches	25	5	160	5	NS|Na|Nb|RDB K|Na
wetland	marshland	wetland vegetation		23	15	133	1	RDB 2
wetland	marshland	shallow freshwater pond		23	6	100		
tree-associated	shaded woodland floor	woodland habitat	woodland litter	22	7	194	4	NR|pNT|Notable|RDB 3|NS
tree-associated	shaded woodland floor	shadiness	heavy shade	20	4	137	1	RDB 3
tree-associated	arboreal	canopy	scrub at wood edge/glade	19	8	132	2	NS|NS
tree-associated	decaying wood	conifer or broadleaved	broadleaved only	18	2	135	2	Na|NS
tree-associated	decaying wood	flowers (adult)		18	10	150	3	Na|Na|RDB K
wetland	marshland	shallow freshwater pond	aquatic: well vegetated	15	9	100		
wetland	peatland	shallow freshwater pond		15	5	100		

open habitats	tall sward & scrub	dung & carrion		14	9	100		
open habitats	short sward & bare ground	soil humidity	damp	13	19	182	2	Na|NS
tree-associated	shaded woodland floor	humidity	damp	13	4	227	2	RDB 3|pNT|NR
open habitats	tall sward & scrub	base status	base rich	13	11	200	5	NS|Notable|NS|Nb|Notable
wetland	peatland	shallow freshwater pond	aquatic: well vegetated	12	5	100		
open habitats	short sward & bare ground	soil humidity	variable humidity	10	20	127	1	NS
wetland	peatland	deep litter		9	7	133	1	Notable
wetland	running water	drawdown zone: mud/shallow litter		9	4	100		
open habitats	tall sward & scrub	soil type	calcareous substrates	8	9	143	2	NS|Nb
wetland	peatland	wet/damp peat		8	3	100		
tree-associated	shaded woodland floor	shadiness	light shade	8	4	100	2	Nb|NS
open habitats	tall sward &	habitats	unknown	8	13	100		

	scrub							
tree-associated	shaded woodland floor	humidity	wet	7	3	100		
open habitats	short sward & bare ground	soil type	clay	7	25	186		
open habitats	tall sward & scrub	dung & carrion	dung	7	10	100		
tree-associated	shaded woodland floor	woodland habitat	undergrowth	7	6	100	1	Nb
tree-associated	decaying wood	sapwood & bark decay	bark & cambium	6	2	100		
tree-associated	decaying wood	heartrot		5	2	300	2	Na|NS
tree-associated	arboreal	foliage	leaves and/or stems	5	2	100		
open habitats	tall sward & scrub	soil type	sand	5	11	220	2	Nb|NS
open habitats	short sward & bare ground	habitats	soil & roots	5	7	160	1	NS
tree-associated	shaded woodland floor	humidity	dry	5	4	160	2	NS|Notable
coastal	saltmars	saline		5	5	160	1	NS

	h	silt						
wetland	running water	wetland vegetation		4	7	100		
wetland	marshland	shallow freshwater pond	temporary water dependant	4	16	100		
coastal	brackish pools & ditches	pond/seepage edge		4	33	250	2	NS|NS
open habitats	tall sward & scrub	base status	acidic	4	4	175	1	NS
coastal	saltmarsh	tidal litter		4	9	250	2	NS|Notable
open habitats	short sward & bare ground	base status	base rich	4	4	250	1	Notable
tree-associated	arboreal	terrestrial aspect	pupate in foliage on ground	3	4	100		
tree-associated	arboreal	trunk & branches		3	4	200	1	NS
tree-associated	arboreal	terrestrial aspect	larvae ground active/pupate in soil	3	6	100		
tree-associated	decaying wood	heartrot	decaying wood	3	2	400	2	NS|Na
wetland	peatland	shallow freshwater pond	aquatic: sparsely vegetated	3	5	100		

open habitats	upland	habitats	litter & ground layer	3	4	100		
open habitats	tall sward & scrub	habitats	exposed sand	3	11	100		
open habitats	tall sward & scrub	habitats	scrub	3	7	100		
coastal	saltmarsh	saltmarsh vegetation		3	6	200	1	NS
tree-associated	arboreal	trunk & branches	bark predator	3	12	200	1	NS
wetland	peatland	sphagnum/moss lawn		2	1	100		
tree-associated	decaying wood	heartrot	wet hollows	2	3	100		
open habitats	tall sward & scrub	habitats	exposed chalk	2	29	100	1	Nb
open habitats	tall sward & scrub	dung & carrion	carrion	2	8	100		
tree-associated	arboreal	flowers (adult)		2	1	100		
open habitats	short sward & bare ground	habitats	nests	2	10	100	1	RDB 3
tree-associated	arboreal	carr/wet woodland		2	3	250	1	Nb
open habitats	short sward & bare	habitats	stones, boulders, shingle	2	10	100	1	RDB 3

	ground		and scree						
open habitats	tall sward & scrub	habitats	nests	2		6	100	1	Nb
tree-associated	decaying wood	sapwood & bark decay	roots & underground wood	2		6	100		
open habitats	upland	soil humidity	variable humidity	2		22	100		
open habitats	short sward & bare ground	soil type	calcareous substrates	2		3	100	1	Nb
open habitats	short sward & bare ground	dung & carrion		2		10	100		
tree-associated	arboreal	canopy	mature tree canopy	2		2	450	1	NR
tree-associated	decaying wood	fungal fruiting bodies		1	<1		100		
tree-associated	arboreal	conifer or broadleaved	conifer only	1	<1		100		
tree-associated	arboreal	canopy	understorey	1		1	100		
open habitats	upland	soil humidity	dry	1		6	100		
tree-associated	arboreal	honeydew & sap runs	honeydew (adult)	1		14	100		

		(adult)					
tree-associated	arboreal	foliage	inflorescence	1	<1		100
tree-associated	shaded woodland floor	dung & carrion		1		3	
tree-associated	arboreal	honeydew & sap runs (adult)		1		3	100
open habitats	tall sward & scrub	soil humidity	wet	1		2	100
wetland	peatland	shallow freshwater pond	temporary water dependant	1		20	100
wetland	marshland	shallow freshwater pond	aquatic: sparsely vegetated	1	<1		100
wetland	running water	exposed riverine sediments	riparian sand	1	<1		100
coastal	brackish pools & ditches	brackish dune slacks		1		11	100
wetland	running water	seepages	unshaded seepage	1	<1		100
wetland	running water	seepages	neutral/acid seepage	1		3	100
coastal	sandy beach	freshwater seepages		1		17	100
wetland	running	unmodified fast		1	<1		100

	water	flowing streams							
open habitats	short sward & bare ground	habitats	exposed clay	1		25	400	1	Nb
open habitats	short sward & bare ground	habitats	exposed chalk	1		17	100	1	Nb
open habitats	tall sward & scrub	habitats	stones, boulders, shingle and scree	1		3	400	1	NS
tree-associated	shaded woodlan d floor	dung & carrion	dung	1		6			
wetland	running water	exposed riverine sediments		1	<1		100		
wetland	running water	seepage s		1	<1		100		
tree-associated	decaying wood	heartrot	woodmo uld	1		1	100		
tree-associated	decaying wood	heartrot	hollow tree cavities	1	<1		400	1	Na
open habitats	tall sward & scrub	soil type	clay	1		33	100		

Table 14. Summary of Specific Assemblage Type (SAT) associations for Hadleigh Park invertebrates. Data generated from species list for Hadleigh Park. Data analysed using Natural England and the Centre for Ecology and Hydrology online invertebrate assemblage analysis tool - PANTHEON (http://www.brc.ac.uk/pantheon/).

Broad biotope	Habitat	SAT	No. of spp	% rep.	SQI	Species with conserv. status	Conservation status	Code	Reported condition
open habitats		rich flower resource	53	22	134	15	Nb|Nb|Na|RDB 3|Nb|Nb|Na|RDB 3|Na|RDB K|Nb|Na|Section 41 Priority Species|Nb|Nb|Section 41 Priority Species	F002	Favourable
open habitats		scrub edge	30	13	140	4	Na|Na|Nb|Notable	F001	Favourable
open habitats	short sward & bare ground	bare sand & chalk	27	6	185	9	NS|NS|Section 41 Priority Species|RDB 3|NS|(LR)|NS|NS|Na|NS|Nb	F111	Favourable
tree-associated	decaying wood	bark & sapwood decay	21	4	157	4	Na|Nb|RDB K|Na	A212	Favourable
open habitats	short sward & bare ground	open short sward	18	9	150	5	NS|Nb|NT|Section 41 Priority Species|Section 41 Priority Species|Nb|NT	F112	Favourable
open habitats		scrub-heath & moorland	16	5	138	3	Na|NS|RDB 3	F003	Favourable
coastal	saltmarsh	saltmarsh & transitional brackish marsh	4	4	425	3	NS|RDB 3|Notable	M311	Unfavourable
tree-associated	decaying wood	heartwood decay	3	2	300	2	NS|Na	A211	Unfavourable
wetland	marshland	undisturbed fluctuating marsh	2	5	250	1	RDB I	W221	Unfavourable

wetland	peatland	reed-fen & pools	2		2	100	W314	Unfavourable
tree-associated	decaying wood	epiphyte fauna	1		5	100	A215	Unfavourable
wetland	peatland	Sphagnum bog	1	<1		100	W312	Unfavourable

Table 15. Summary of associations for Hadleigh Park invertebrates. Data generated from species list for Hadleigh Park. Data analysed using Natural England and the Centre for Ecology and Hydrology online invertebrate assemblage analysis tool - PANTHEON (http://www.brc.ac.uk/pantheon/).

Animal			
Associated taxon	Species count	Species with conservation status	Conservation status
Animalia	2		

Animalia			
Associated taxon	Species count	Species with conservation status	Conservation status
Arthropoda	195	16	2 NR; 1 pNT; 13 NS; 1 Notable
Aphididae	37	3	1 Nb; 1 CR; 1 NR; 1 Na
Apidae	13	4	2 Na; 1 RDB 2; 1 Nb
Diptera	10		
Mammalia	9		
Mollusca	5		
Araneae	4		
Adelgidae	3		
Ceratopogonidae	2		
Coccidae	2		
Formicidae	2	1	1 NS
Psychodidae	2		
Bombus	1		
Bombus (Melanobombus) lapidarius	1	1	1 Nb
Bos	1		
Cerceris	1	1	1 RDB 3
Chorthippus	1	1	1 Notable
Cicadellidae	1	1	1 (LR); 1 NS
Colletes	1		
Delia antiqua	1		
Discus	1		
Gorytes quadrifasciatus	1	1	1 Nb
Gyraulus	1		
Halictus	1		
Isopoda	1		
Lepidoptera	1		
Lumbricidae	1		
Miridae	1		
Omocestus	1	1	1 Notable
Orthoptera	1		
Oxybelus	1		
Pemphigus (Pemphigus) spyrothecae	1		
Psocoptera	1		

Sphecidae	1		
Succinea	1		
Tachysphex pompiliformis	1		
Tetranychus	1		

Fungi			
Associated taxon	Species count	Species with conservation status	Conservation status
Fungi	1		

Plantae			
Associated taxon	Species count	Species with conservation status	Conservation status
Fagales	76	6	2 Nb; 1 RDB K; 1 Notable; 1 Na; 1 NS
Asteraceae	49	6	1 RDB 3; 1 RDB K; 3 Nb; 2 Section 41 Priority Species
Poaceae	37	4	2 Section 41 Priority Species; 2 NT; 1 Nb; 1 NS
Quercus	29	5	4 NS; 1 NR
Spermatophytina	23	3	1 RDB 3; 2 Nb
Trifolium	14	1	1 Section 41 Priority Species - research only
Brassicaceae	11	2	2 NS
Cirsium	10	1	1 Na
Phragmites australis	7	2	1 Notable; 1 Nb
Urtica dioica	7		
Rumex	6		
Senecio	6	1	1 Notable
Vicia	6		
Centaurea nigra	5	1	1 Notable
Crataegus	5		
Ononis repens	5		
Urtica	5		
Apiaceae	4	1	1 RDB 3; 1 Section 41 Priority Species
Lathyrus	4		
Malvaceae	4	1	1 NS
Ulmus	4	2	1 Na; 1 Nb
Betula	3		
Brachypodium	3		
Carduus	3		
Cirsium arvense	3		
Lotus	3		
Plantago	3		
Polygonaceae	3		
Rosaceae	3		

Alnus	2		
Artemisia	2		
Aster tripolium	2	1	1 RDB 3
Centaurea	2		
Corylus	2		
Epilobium	2		
Fabaceae	2		
Fagus	2	1	1 NR
Geranium	2	2	1 NS; 1 Nb
Heracleum sphondylium	2	2	2 Na
Juncus	2		
Lamiaceae	2	1	1 NS
Malus	2		
Poales	2		
Prunus	2		
Prunus spinosa	2		
Rubus	2	2	2 Na
Ulex	2		
Acer	1		
Alliaria petiolata	1		
Anthemis	1		
Azolla	1		
Ballota nigra	1		
Bolboschoenus maritimus	1		
Bromus	1	1	1 Notable
Bryophyta	1		
Calamagrostis	1		
Campanula	1		
Capsella bursa-pastoris	1		
Carex rostrata	1		
Carpinus	1		
Chenopodium	1		
Chenopodium album	1		
Coincya wrightii	1		
Convolvulaceae	1		
Cornus	1		
Dactylis	1		
Elytrigia repens	1		
Epilobium hirsutum	1		
Fraxinus	1		
Galium	1		
Glyceria	1		
Hedera helix	1		
Helianthemum	1		
Hordeum	1		
Humulus lupulus	1		
Hyacinthoides non-scripta	1		
Ilex	1		

Ilex aquifolium	1		
Inula crithmoides	1	1	1 RDB 3
Lactuca	1		
Laurus	1		
Leucanthemum	1		
Linum	1		
Lolium	1		
Lotus corniculatus	1		
Lythrum salicaria	1		
Matricaria	1		
Medicago	1		
Medicago sativa	1	1	1 Section 41 Priority Species - research only
Narcissus	1		
Odontites vernus	1	1	1 Nb
Ononis	1		
Persicaria	1		
Persicaria maculosa	1		
Pinus	1	1	1 NS
Populus	1		
Populus nigra 'Italica'	1		
Pulicaria	1	1	1 RDB 3
Pulicaria dysenterica	1	1	1 Na
Ranunculaceae	1		
Ranunculus	1		
Ranunculus repens	1		
Reseda	1	1	1 Nb
Rosa	1	1	1 Na
Rumex acetosa	1		
Rumex acetosella	1		
Scirpus	1		
Smyrnium olusatrum	1		
Solanum	1		
Sonchus	1		
Stachys sylvatica	1		
Taraxacum	1		
Tripleurospermum	1		
Typha	1		
Ulmus procera	1	1	1 Nb

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