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Hadleigh Park priority species habitat assessment 2015

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Published by the University of East London

4-6 University Way

Docklands

London

E16 2RD

Cover photo: White-letter hairstreak on bramble © Stuart Connop

Printed in Great Britain at the University of East London, Docklands, London.

Connop, S. and Clough, J. 2016. Hadleigh Park priority species habitat assessment. London: University of East London.

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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 would be 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 are available in Harvey (2015).

Additional surveys were carried during the summer 2015 in order to create a baseline for 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. This report represents an overview of these additional surveys. The report is divided into three sections in order to document the three separate survey methodologies.

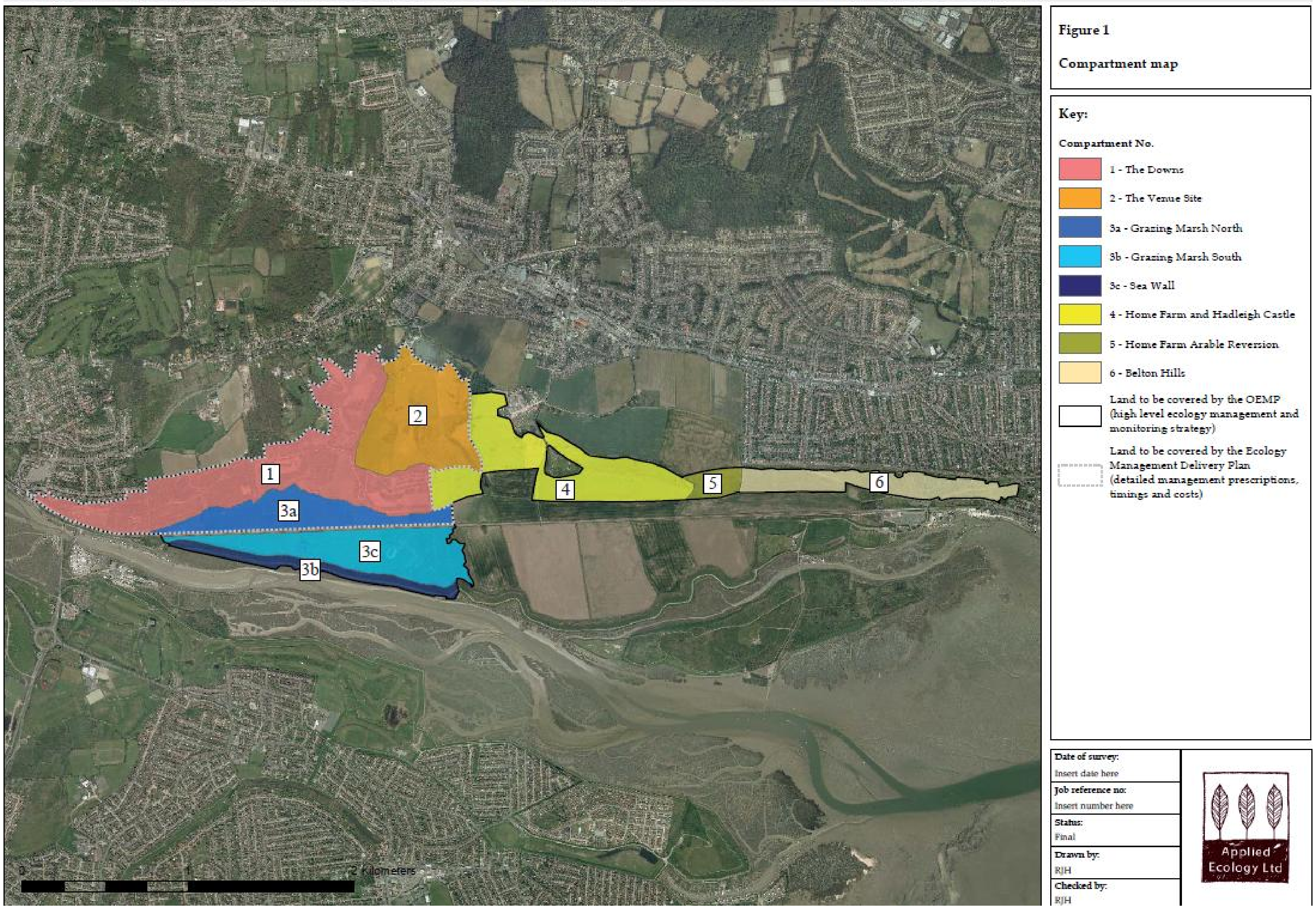

Figure 1. Hadleigh Park Compartment Map. Map displaying the habitat management compartments of Hadleigh Park. © ECC

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.

2.2 Survey Methodology

White-letter hairstreak adults are difficult to see because they spend so much time in the tree canopy, although they occasionally emerge to display an erratic, spiralling flight typical of the hairstreaks around elm tree tops or come to ground level to nectar on flowers near to elm trees (such as brambles and thistles) or scrub saplings (Butterfly Conservation 2016). This behaviour makes them an unsuitable species for standardised butterfly transect walking surveys (Pollard and Yates 1993). As such, a novel repeatable timed count was established at the park in order to monitor populations on the site over future years. The methods used were based on those developed by the Herts & Middlesex White-letter Hairstreak Monitoring Project (Goodyear and Middleton 2007) suitable for assessing arboreal habitats rather than standardised butterfly walks.

In order to generate standardised indices counts, it is necessary to count individuals where they can be reliably and repetitively found. This requires a particular focus on searching for male activity around the tree-tops and also individuals nectaring on bramble and thistles in close proximity to elm trees. To achieve this, a series of 17 observation points were established across the park at various elm 'hotspots' (Figure 2) rather than standardised transect walks. Each observation point was marked with a blue cross to ensure that the same location could be reliably found and a GPS reading of location was taken using a GPSmap 60CSx (Garmin, Hampshire, UK) to aid relocation of the blue crosses (Table 1). At each point, if elms or bramble were only present in a single direction, a bearing was recorded of this direction as a guide for the observer for the start of each survey (Table 1). A series of photographs were also taken from each observation point to document the location and type of vegetation being surveyed. Copies of some of these photos are included as Appendix A. The remaining photos will be held in an archive and can be obtained from the University of East London Sustainability Research Institute.

Once established, a ten minute observational survey was carried out from each of these points. 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 at one time 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.

The original number of monitoring points was designed to cover all of the main elm areas across the park. The number was also designed to be flexible with a view to the total being reduced following the first round of observations (i.e. some 'non-productive' monitoring points could be dropped, and others could be added based on observations whilst moving around the site). However, following the initiation of the monitoring rounds, it was decided

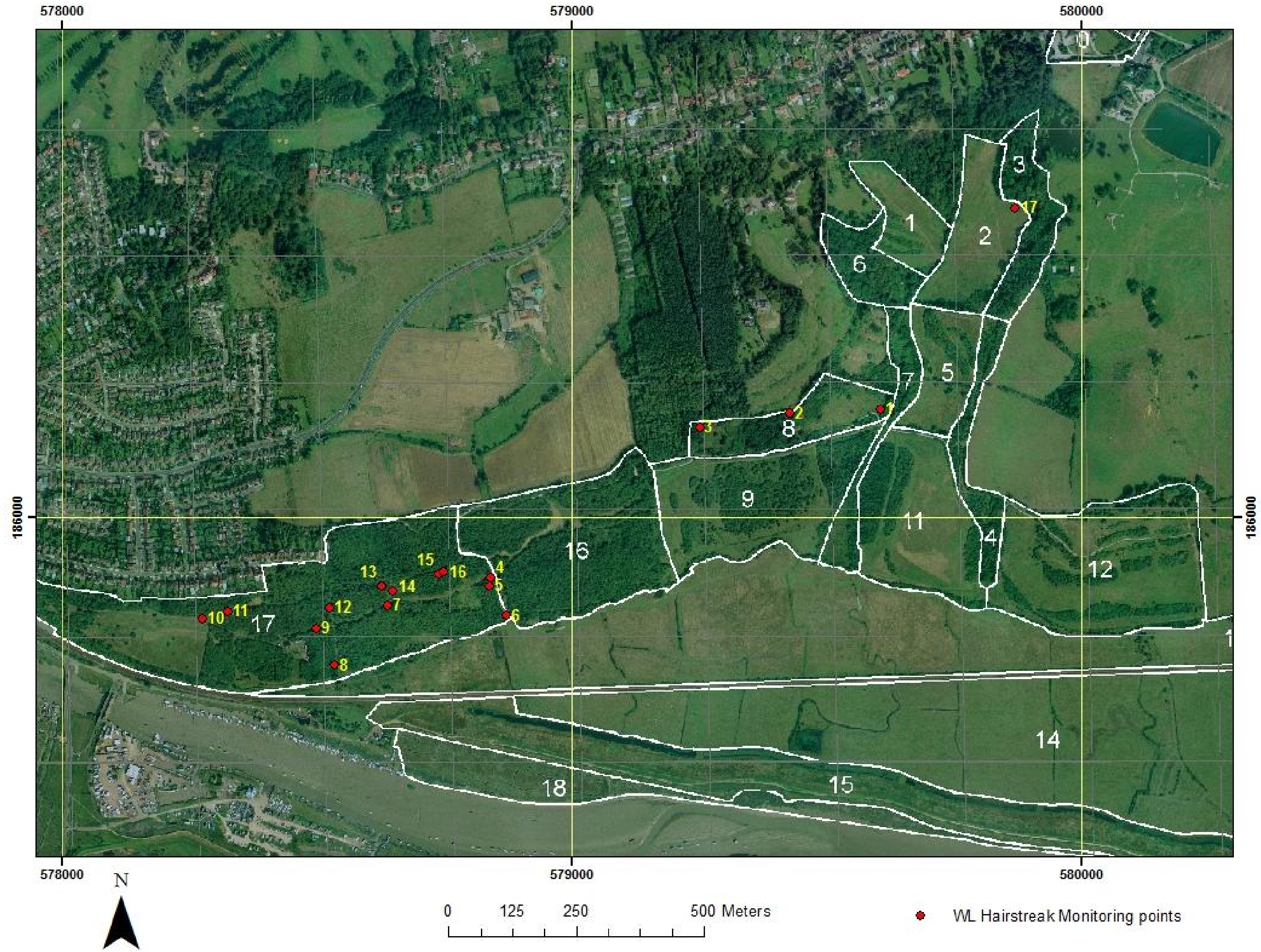

Figure 2. White-letter hairstreak observation points at Hadleigh Park. Observation points represent fixed-points used for timed white-letter hairstreak counts. Aerial Photo © ECC, Map prepared using ESRI ArcGIS.

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.

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
HP13	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

that all original monitoring points would be retained for subsequent monitoring rounds due to the distribution of white-letter hairstreaks at 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.

In addition to the baseline surveys carried out by University of East London researchers, surveys were also carried out by the conservation manager of Hadleigh Park, Andrew Woodhouse and by a butterfly surveyor that has been carrying out butterfly transects at Hadleigh Park for several years, David Chandler (Cambs & Essex Branch of Butterfly Conservation). Whilst Andrew was able to utilise the new monitoring methodology, David repeated the transects that he had established previously. As such, David's results were not directly comparable to those generated in the baseline survey and were thus treated separately. Nevertheless, they provide an interesting extra layer of data due to the continuity of methodology from his surveys in previous years.

2.3 Results

In total, five 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 22nd June to the 16th July 2015.

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 24 at HP4 on the 16th July. The maximum number of individuals observed in flight together was 8 recorded at HP7 and HP8 on the 30th June. The highest average score for total numbers observed was recorded at HP9 and the highest average maximum number of individuals was recorded at HP7. 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. In addition to these standardised fixed-point observation surveys, walked transect surveys were carried out by David Chandler. Results of these walks are displayed in Table 4.

Table 2. Average number of observations of white-letter hairstreaks at Hadleigh Park observation points, summer 2015. Observation 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).

Observation Point	Average	S.E.
HP1	0.25	0.25
HP2	5.00	2.71
HP3	0.50	0.50
HP4	8.50	5.68
HP5	3.25	2.93
HP6	5.00	2.61
HP7	2.50	1.66
HP8	6.75	1.49
HP9	11.00	4.97
HP10	3.50	2.53
HP11	0.50	0.50
HP12	5.50	2.40
HP13	5.75	3.15
HP14	5.75	2.75
HP15	2.50	1.66
HP16	3.25	2.93
HP17	2.00	1.35

Table 3. Maximum number of white-letter hairstreaks observed simultaneously at Hadleigh Park observation points, summer 2015. Observation made during a ten minute survey. Numbers represent the average of the total number of individuals observed at any one time during each of the ten minute surveys (*n = 5)*.

Observation Point	Average	S.E.
HP1	3.00	0.71
HP2	0.50	0.50
HP3	2.25	1.31
HP4	1.00	0.71
HP5	1.50	0.65
HP6	0.75	0.48
HP7	5.00	1.08
HP8	4.75	1.44
HP9	1.00	0.41
HP10	0.25	0.25
HP11	3.00	0.71
HP12	2.25	1.11
HP13	3.75	1.60
HP14	1.50	0.96
HP15	1.50	1.19
HP16	1.25	0.63
HP17	0.25	0.25

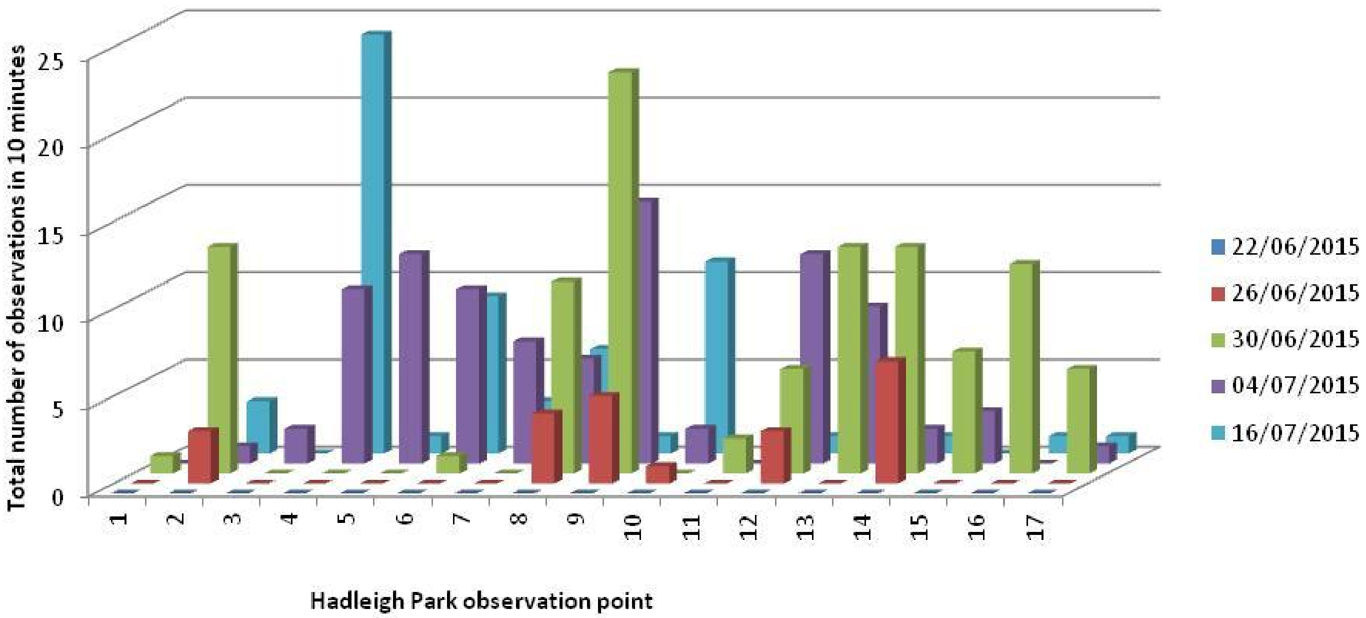

Figure 3. Total number of observations of white-letter hairstreaks at Hadleigh Park observation points, summer 2015. Observations were carried out at a series of fixed points. Each survey lasted ten minutes. Every individual observed during ten minutes was recorded. As such, values represent a measure of activity rather than actual population size.

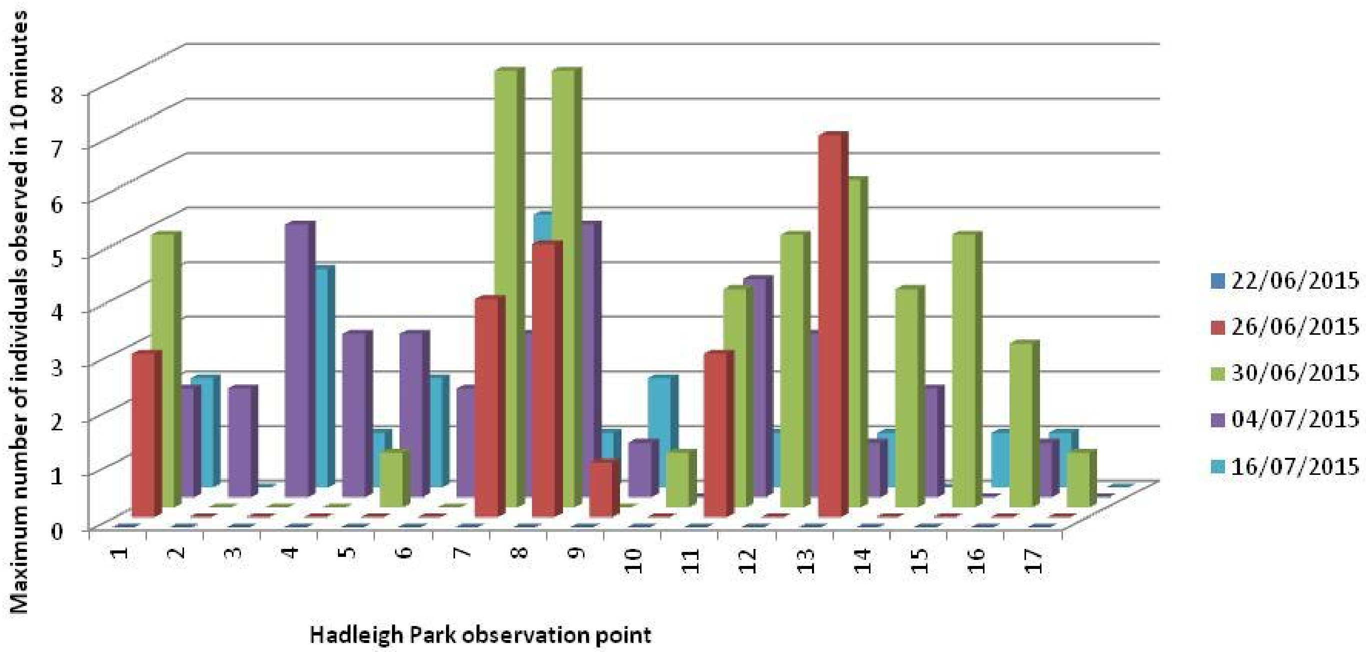

Figure 4. Maximum number of white-letter hairstreaks observed simultaneously at Hadleigh Park observation points, summer 2015. Observations were carried out at a series of fixed points. Each survey lasted ten minutes. maximum number of individuals observed together at one time during ten minutes was recorded. As such, values represent a minimum measure of population size.

Table 4. Number of white-letter hairstreak individuals observed during fixed-length butterfly transect walks at Hadleigh Park, summer 2015. Walks carried out by David Chandler. All WLH individuals observed during walks were recorded (Total observations) and the maximum observed at any one time at each section along the transect (Maximum observed).

Date	Total observations	Maximum observed
11/06/2015	0	0
18/06/2015	0	0
25/06/2015	14	6
01/07/2015	40	19
10/07/2015	5	4
16/07/2015	4	3
27/07/2015	1	1
01/07/2015	2	2
08/07/2015	0	0

2.4 Discussion

White-letter hairstreak fixed point observation surveys were successful with substantial numbers being recorded at Hadleigh Park by all recorders. As expected, 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. Highest average absolute counts and average maximum number of individuals counts were distributed across several of the observation points (Figures 5 and 6) and the location of highest counts varied on different survey dates (Figures 3 and 4). Indeed at least one white-letter hairstreak was seen at all 17 of the established observation points.

The 2015 survey has established a standardised and repeatable methodology for assessing white-letter hairstreak numbers and distributions within the park for the future. 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 2015. Observations were carried out at a series of fixed points. Each survey lasted ten minutes (*n = 5)*. 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 ESRI ArcGIS.

Figure 6. Distribution of average maximum number of white-letter hairstreak butterflies observed simultaneously at Hadleigh Park observation points, summer 2015. Observations were carried out at a series of fixed points. Each survey lasted ten minutes (*n = 5)*. 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.

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 7). 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 particular, 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) and to other species 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 (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 provide an opportunity to re-visit the site and repeat the baseline surveys established as part of the original experimental research. By doing this it was possible to investigate:

- whether management of the scrub cleared areas has been successful in retaining the bumblebee forage;
- whether *B. humilis* and *B. sylvarum* are still present on the site in substantial numbers;

- whether *B. humilis* and *B. sylvarum* are still utilising the scrub cleared areas;
- any effects of planned changes to the management of these areas through a shift from an annual cut to a return to low-level grazing.

Figure 7. Plan of Hadleigh Park green hay plots (Aerial photo © Hadleigh Park). Areas 1-5 represent areas of scrub within management unit 9 (Figure 2) that have been cleared for bumblebee forage habitat creation. Area 5 represents green hay experiment area 5, green hayed in 2010. Area 6 represents the area that was planned to be cleared in 2011.

Management on the experimental areas has consisted of a single annual cut late in September/early October after flowering has ceased and when no more *B. humilis* or *B. sylvarum* were observed foraging. The cleared areas were cut by Ryetec flail mower and the cuttings were removed from all of the areas. Both the natural recolonisation and green hayed trial plots of each experiment area were managed in the same way. This was to ensure that the development of bumblebee forage on the plots could be monitored to assess whether initial green hay management continued to produce more suitable forage for *B. sylvarum* and *B. humilis* annually.

Throughout the duration of the initial monitoring programme for this experiment the management appeared to have been successful, with *Odontites verna* flower heads remaining abundant on the green hay plots and increasing on the natural recolonisation plots.

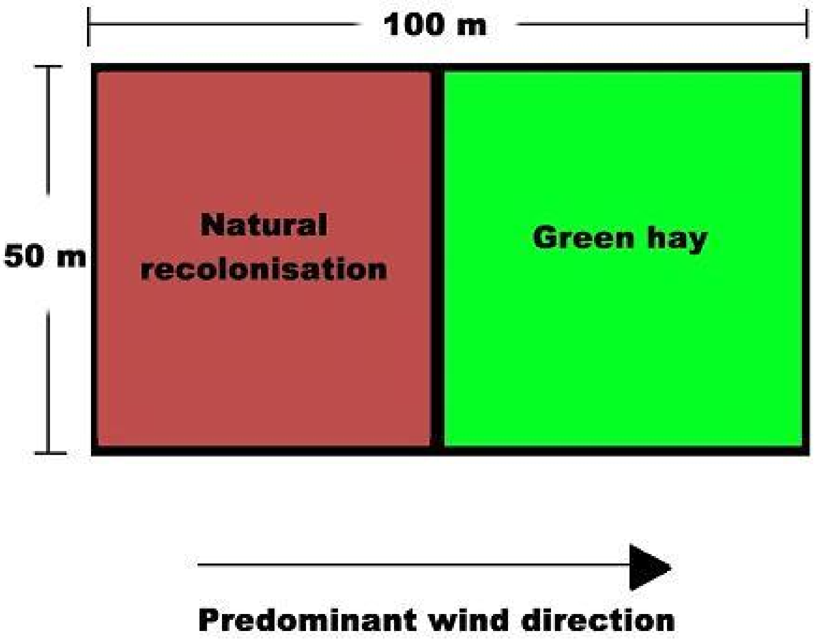

Figure 8. Plan of scrub removal forage patch creation experiment at Hadleigh Park.

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.

The following sections document the methods and results of the repeated floral surveys to assess the floral availability for foraging bumblebees.

3.2 Floral survey methods

Thirty 1 x 1 m quadrats (Figure 10) were randomly placed across each treatment plot of each of the experiment areas. In total 6 plots were surveyed (3 green hay plots and 3 natural recolonisation plots). 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).

Figure 10. 1 x 1 m quadrat used for floral surveys at Hadleigh Park.

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 made and so that a measure of vegetation cover was recorded.

3.3 Results

3.3.1. Floral and habitat feature diversity

Records of the floral species and habitat features recorded on the green hay plot and natural recolonisation plot of each experiment area during the August 2015 vegetation surveys are listed in Tables 5 to 7.

For experiment area 1 (established in 2006), the natural recolonisation plot recorded the highest diversity of floral species. In contrast, the green hay plot recorded the highest diversity of target species for the conservation priority bumblebees.

For experiment area 4 (established in 2009), the natural recolonisation plot and green hay plot recorded the same diversity of floral species, although they were not all the same species. Nevertheless the natural recolonisation plot recorded the highest diversity of target species for the conservation priority bumblebees.

For experimental area 5 (established in 2010), the natural recolonisation plot recorded the highest diversity of floral species and the highest diversity of target species for the conservation priority bumblebees.

Table 5. Presence/absence list of floral species for experiment area 1 recorded during 2015 floral surveys. Thirty 1 x1 m quadrats were surveyed in each experimental plot (green hay plot and natural recolonisation plot). Floral species highlighted by shading are those that are considered to be target forage species for *Bombus humilis* and *Bombus sylvarum* (Connop 2008). Total floral species for each experimental plot is given under 'Count'. The number in brackets represents the total number of target forage species.

Floral species/habitat feature	Green hay	Natural recolonisation
Agrimonia eupatoria	X	X
Ballota nigra	X	
Centaurea nigra	X	X
Cirsium arvense	X	X
Cirsium vulgare	X	X
Crataegus monogyna	X	X
Galium verum	X	
Geranium molle		X
Hypericum hirsutum		X
Lotus corniculatus	X	X
Lotus glaber		X
Medicago lupulina	X	X
Odontites verna	X	X
Papaver rhoeas		X
Picris echioides	X	X
Plantago lanceolata	X	X
Potentilla reptans	X	X
Prunella vulgaris	X	X
Ranunculus repens		X
Rosa canina		X
Rubus fruticosus		X
Senecio vulgaris	X	
Stachys officinalis		X
Trifolium pratense	X	X
Trifolium repens	X	
Count	**17 (8)**	**21 (7)**
Bare ground	X	X
Grass/dead grass	X	X
Deadwood		X

Table 6. Presence/absence list of floral species for experiment area 4 recorded during 2015 floral surveys. Thirty 1 x1 m quadrats were surveyed in each experimental plot (green hay plot and natural recolonisation plot). Floral species highlighted by shading are those that are considered to be target forage species for *Bombus humilis* and *Bombus sylvarum* (Connop 2008). Total floral species for each experimental plot is given under 'Count'. The number in brackets represents the total number of target forage species.

Floral species/habitat feature	Green hay	Natural recolonisation
Agrimonia eupatoria	X	X
Centaurea nigra	X	X
Cirsium arvense	X	X
Cirsium vulgare		X
Clinopodium vulgare		X
Crataegus monogyna	X	X
Epilobium tetragonum		X
Galium verum	X	
Geranium molle	X	
Hypericum hirsutum	X	X
Lotus corniculatus	X	X
Malva moschata	X	X
Malva sylvestris	X	
Medicago lupulina	X	X
Odontites verna	X	X
Picris echioides	X	X
Plantago lanceolata	X	X
Potentilla reptans		X
Prunella vulgaris	X	X
Ranunculus repens	X	X
Rosa canina	X	X
Rubus fruticosus	X	X
Senecio vulgaris		X
Trifolium pratense	X	X
Trifolium repens		X
Vicia spp.	X	
Count	**21 (6)**	**21 (7)**
Bare ground	X	X
Grass/dead grass	X	X

Table 7. Presence/absence list of floral species for experiment area 5 recorded during 2015 floral surveys. Thirty 1 x1 m quadrats were surveyed in each experimental plot (green hay plot and natural recolonisation plot). Floral species highlighted by shading are those that are considered to be target forage species for *Bombus humilis* and *Bombus sylvarum* (Connop 2008). Total floral species for each experimental plot is given under 'Count'. The number in brackets represents the total number of target forage species.

Floral species/habitat feature	Green hay	Natural recolonisation
Agrimonia eupatoria	X	X
Acer campestre		X
Ballota nigra		X
Centaurea nigra	X	X
Convolvulus arvensis		X
Crataegus mongyna	X	X
Crataegus monogyna		X
Daucus carota		X
Dipscus fullonum	X	
Hypericum hirsutum	X	
Lotus corniculatus	X	X
Medicago lupulina		X
Odontites verna		X
Picris echioides		X
Plantgo lanceolata		X
Potentilla reptans		X
Rosa canina	X	X
Rubus fruticosus	X	X
Rumex crispus	X	
Trifolium pratense		X
Count	**9 (2)**	**18 (5)**
Bare		X
Grass/dead grass	X	X

3.3.2 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. Figures 11 to 13 show the average flower head numbers on each of the trial plots of experimental areas 1, 4 and 5.

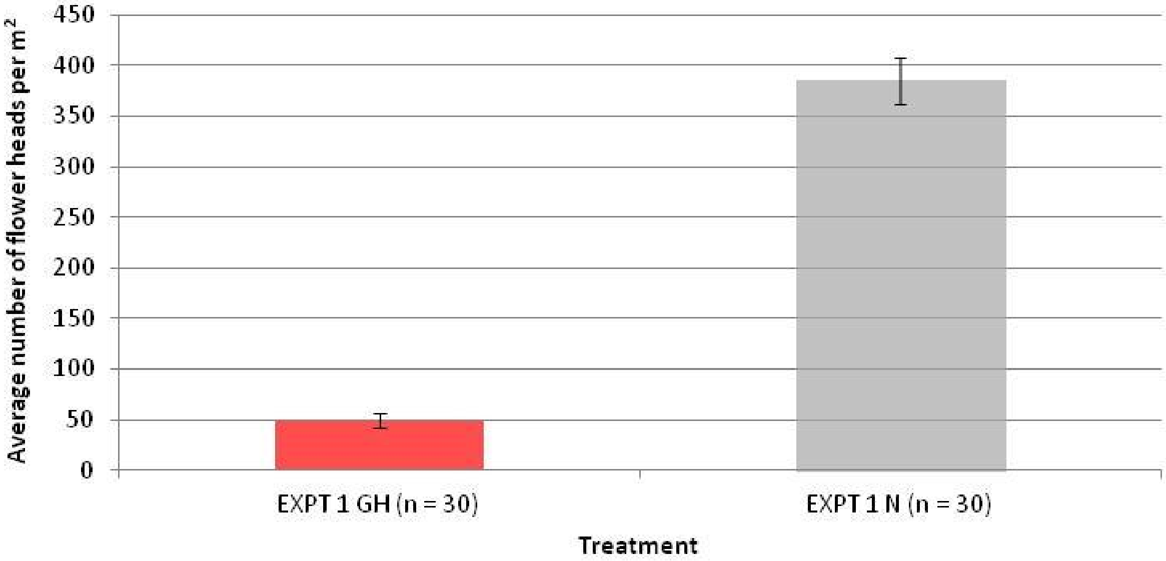

Figure 11. Average number of all flower heads on the trial plots of experiment area 1, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

Average number of flower heads available to pollinators on experiment area 1 differed considerably between the two treatment plots (Figure 11). Substantially greater numbers were recorded on the natural recolonisation plot than on the green hay plot. Mann-Whitney U 2-tailed exact tests indicated that the difference in average flower heads was significant ($p < 0.001$).

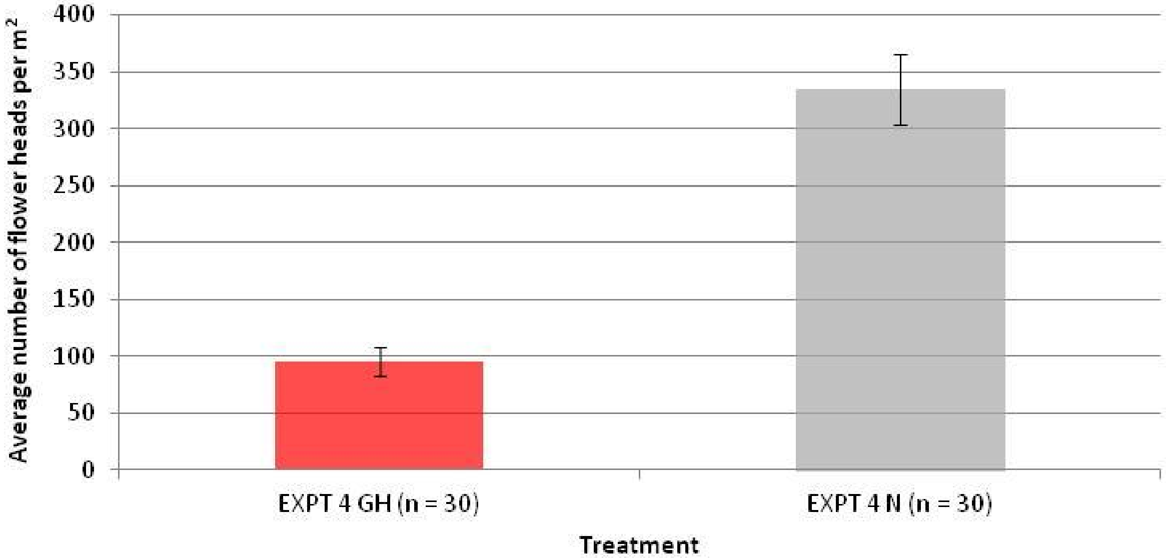

Figure 12. Average number of all flower heads on the trial plots of experiment area 4, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

Average number of flower heads available to pollinators on experiment area 4 differed considerably between the two treatment plots (Figure 12). Substantially greater numbers were recorded on the natural recolonisation plot than on the green hay plot. Mann-Whitney U 2-tailed exact tests indicated that the difference in average flower heads was significant ($p < 0.001$).

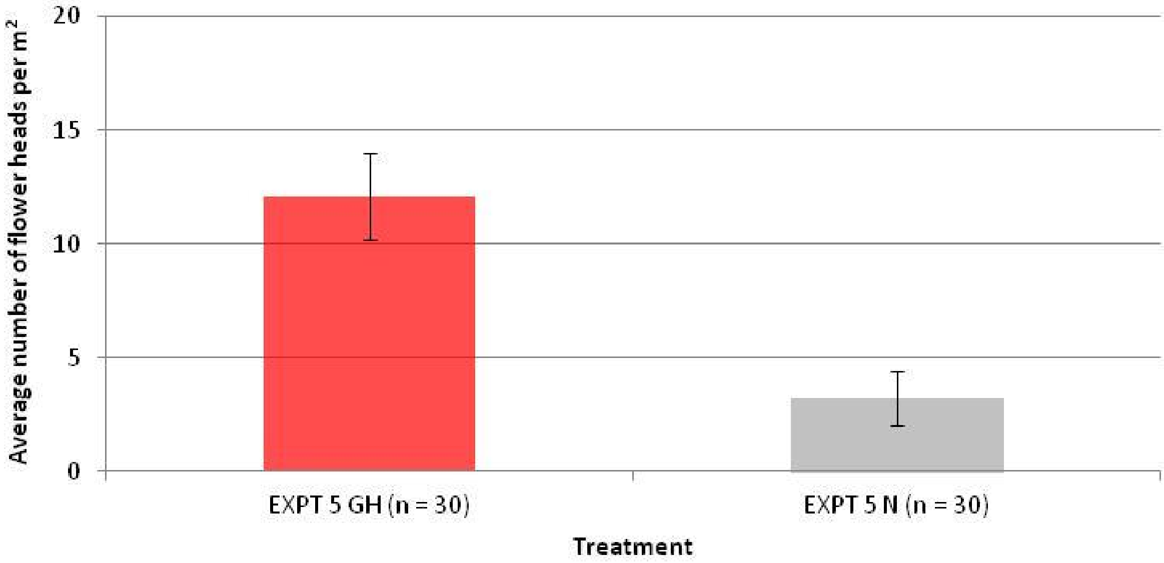

Figure 13. Average number of all flower heads on the trial plots of experiment area 5, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

Average number of flower heads available to pollinators on experiment area 5 was substantially lower than on the other two experiment areas (Figure 13). Greater numbers were recorded on the green hay plot than on the natural recolonisation plot. Mann-Whitney U 2-tailed exact tests indicated that the difference in average flower heads was significant ($p < 0.001$).

3.3.3 Target forage species

Key forage species for *Bombus humilis* and *Bombus sylvarum* at Hadleigh Park are *Odontites verna*, *Lotus glaber*, *Lotus corniculatus*, *Trifolium pratense*, *Trifolium repens*, *Centaurea nigra*, *Cirsium vulgare*, *Cirsium arvense* and *Ballota nigra*.

Odontites verna

Average numbers of *Odontites verna* flowers varied considerably between experimental areas and comparative treatment plots. Results for each experimental area are presented in Figures 14 to 16. For all three experimental areas, the average number of *Odontites verna* flower heads per quadrat was larger on the natural recolonisation areas than the green hayed areas. Mann-Whitney U 2-tailed exact tests indicated that the difference in average *Odontites verna* flower heads was significant for experiment areas 1 and 4 ($p < 0.001$ respectively) but was not significant for experiment area 5 ($p = 0.24$).

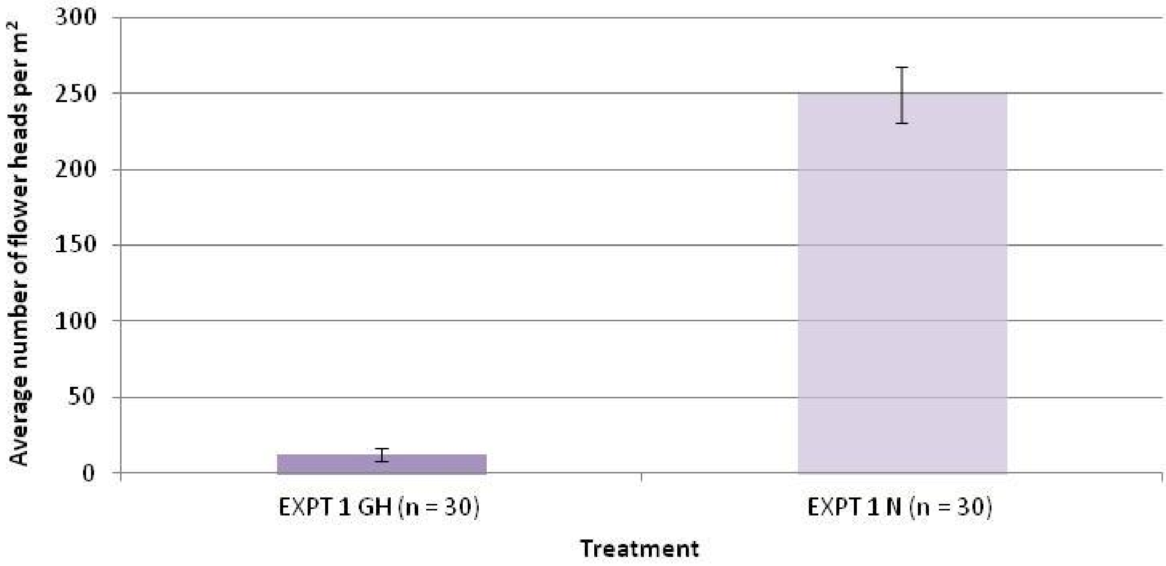

Figure 14. Average number of *Odontites verna* flower heads on the trial plots of experiment area 1, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

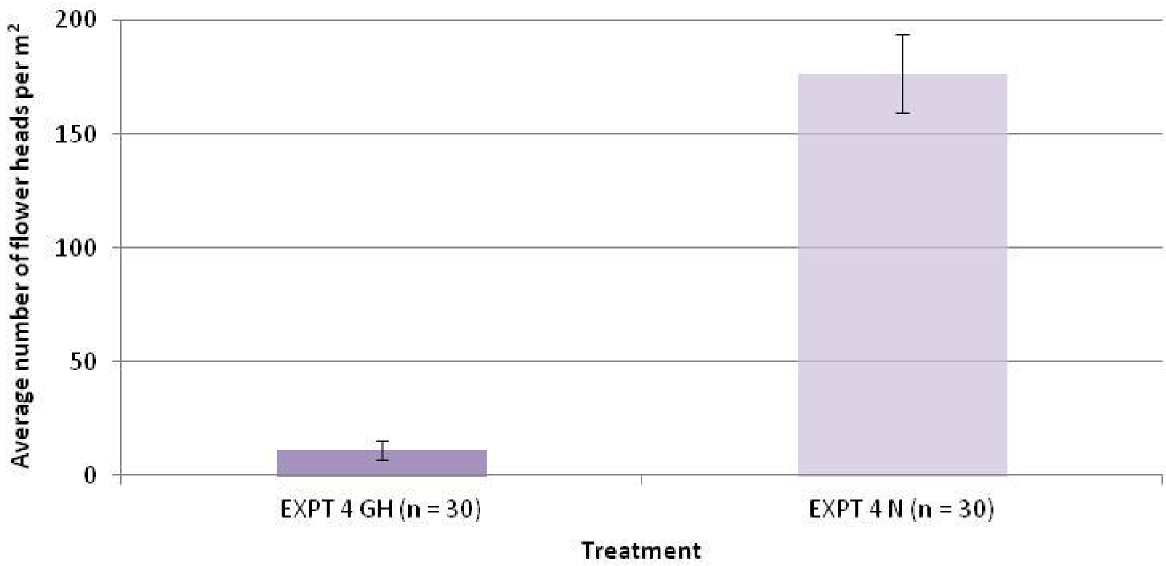

Figure 15. Average number of *Odontites verna* flower heads on the trial plots of experiment area 4, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

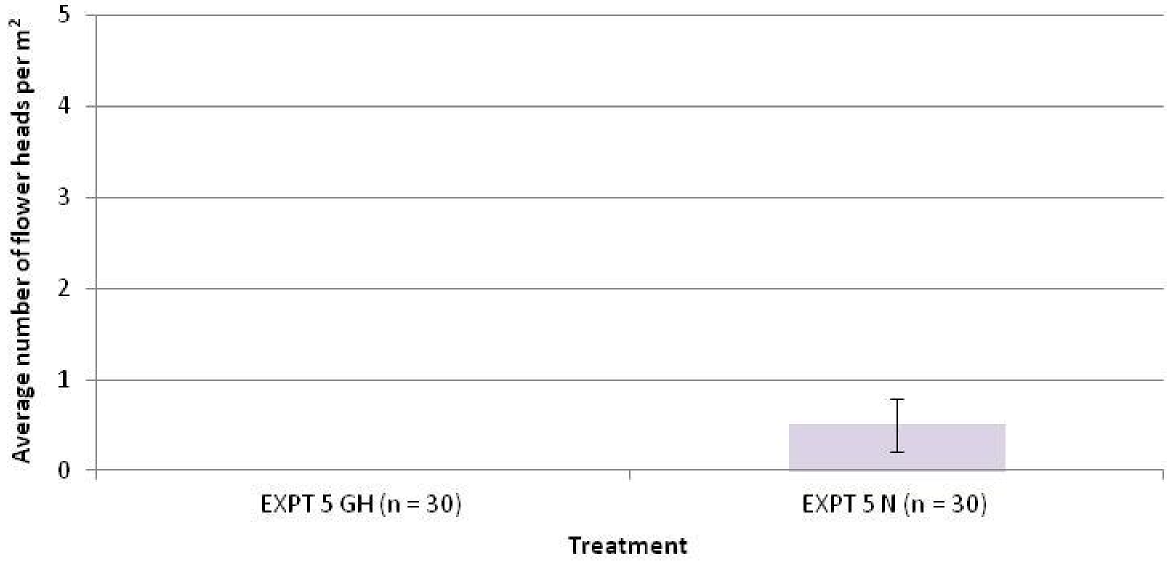

Figure 16. Average number of *Odontites verna* flower heads on the trial plots of experiment area 5, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

Lotus species

Due to the small number of *Lotus glaber* flower heads recorded, *Lotus glaber* and *Lotus corniculatus* were combined for flower head counts. Average numbers of *Lotus* species flowers varied considerably between experimental areas and comparative treatment plots. Results for each experimental area are presented in Figures 17 to 19.

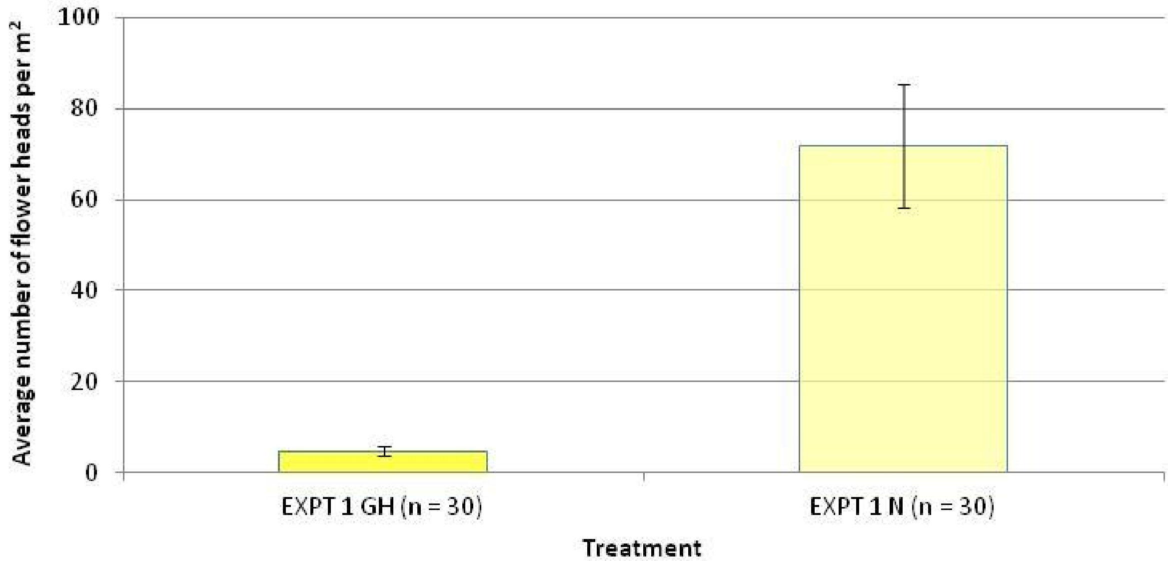

Figure 17. Average number of *Lotus* species flower heads on the trial plots of experiment area 1, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

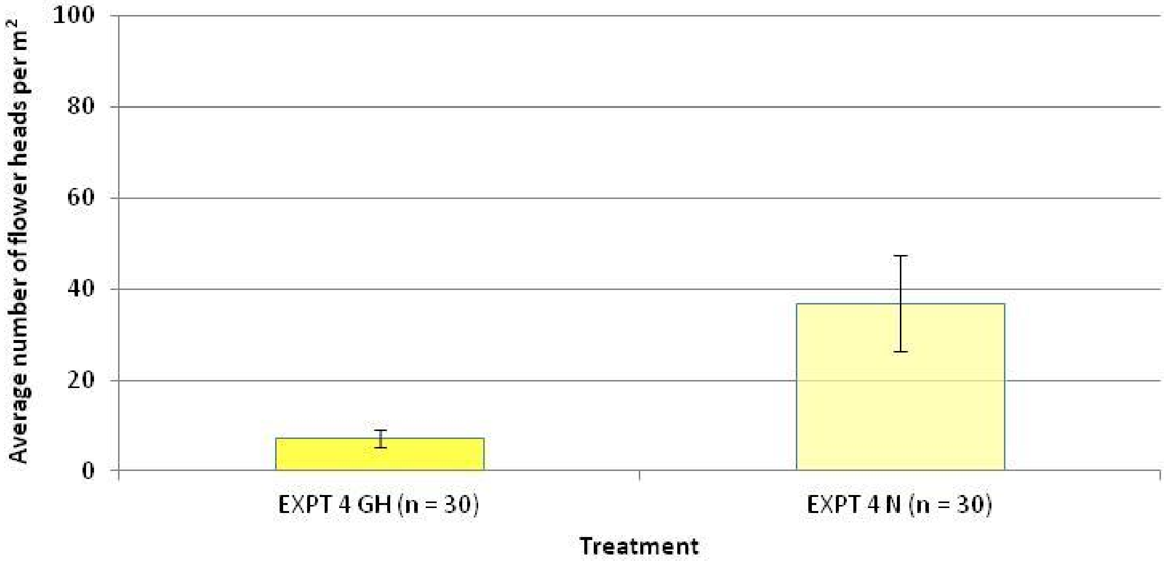

Figure 18. Average number of *Lotus* species flower heads on the trial plots of experiment area 4, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

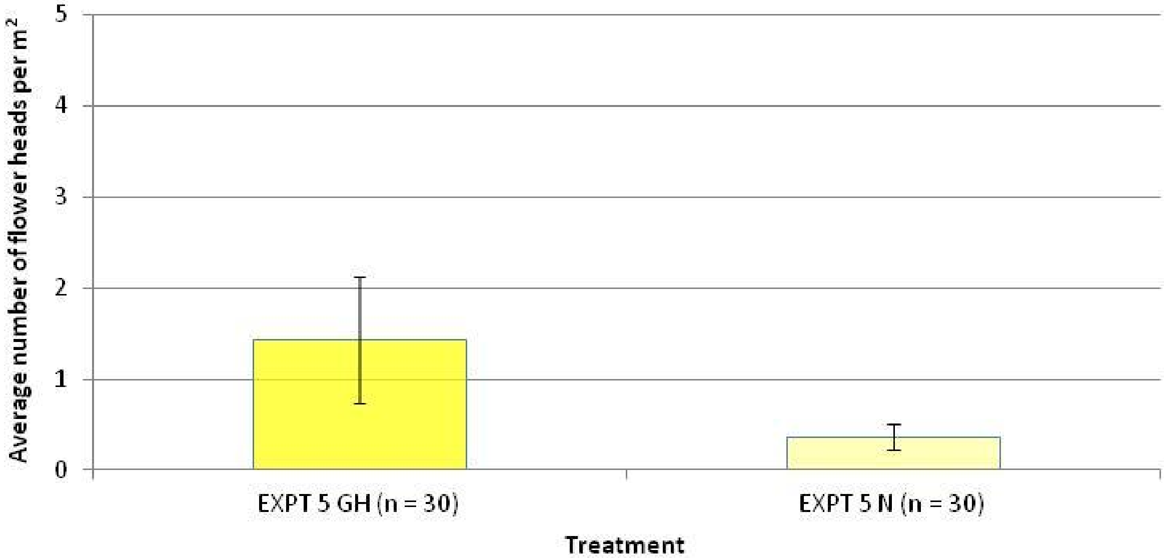

Figure 19. Average number of *Lotus* species flower heads on the trial plots of experiment area 5, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

For experimental areas 1 and 4, the average number of *Lotus* species flower heads per quadrat was larger on the natural recolonisation plots than the green hayed plots. For experimental area 5 the opposite was true. Mann-Whitney U 2-tailed exact tests indicated that the difference in average *Lotus* species flower heads was significant for experiment area

1 ($p < 0.001$) but was not significant for experiment areas 4 and 5 (p = 0.54 and 0.55 respectively).

Centaurea nigra

Average numbers of *Centaurea nigra* flowers varied considerably between comparative experimental plots. Results for each experimental area are presented in Figures 20 to 22.

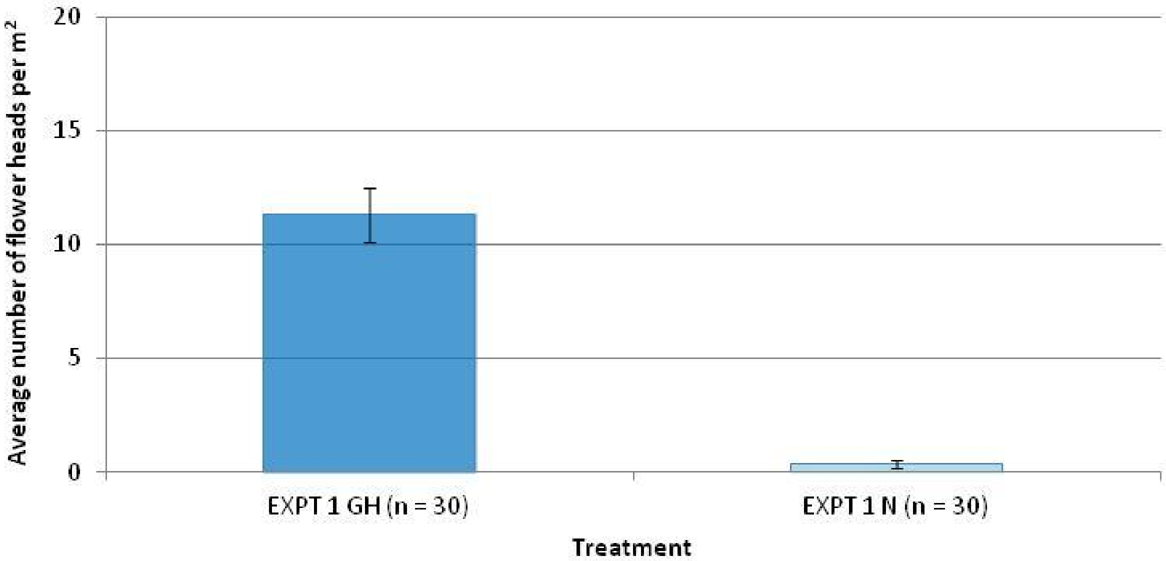

Figure 20. Average number of *Centaurea nigra* flower heads on the trial plots of experiment area 1, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

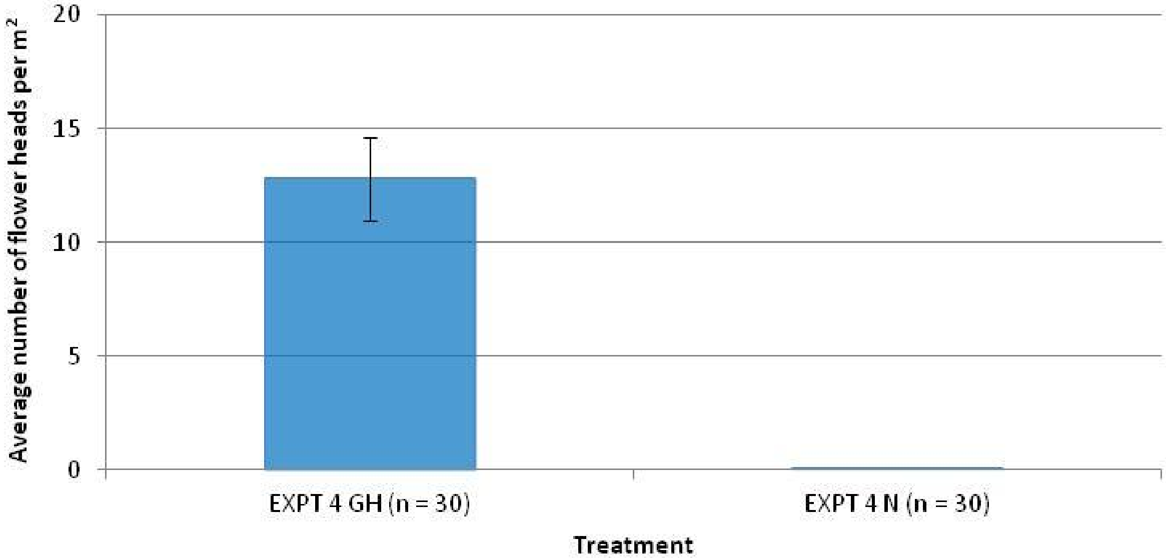

Figure 21. Average number of *Centaurea nigra* flower heads on the trial plots of experiment area 4, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

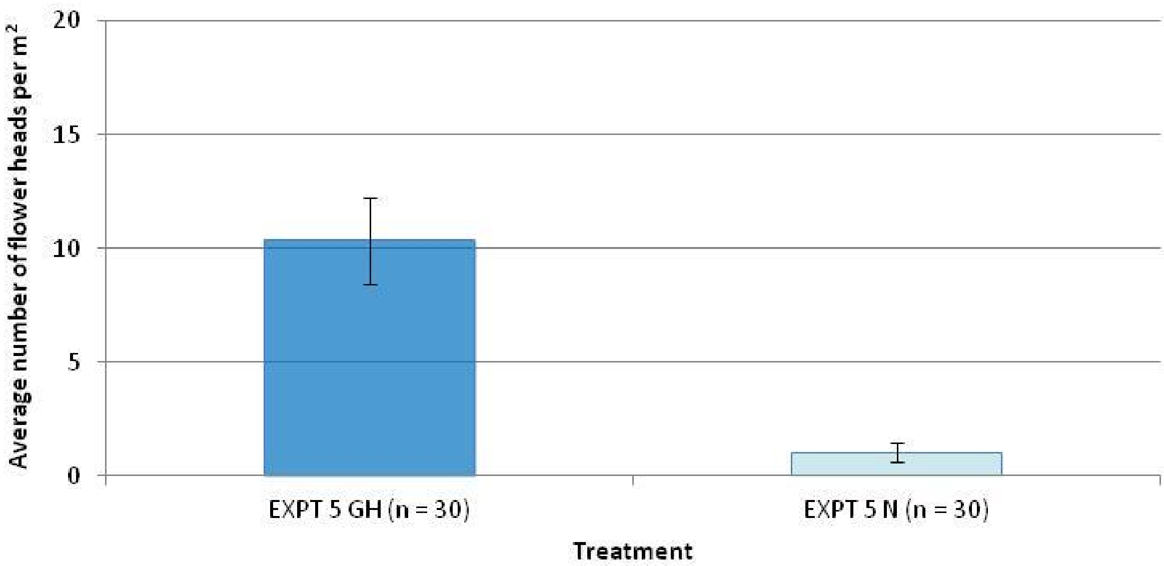

Figure 22. Average number of *Centaurea nigra* flower heads on the trial plots of experiment area 5, August 2015. Values calculated from 1 x1 m quadrat surveys. [Error bars represent the standard error of the mean]

In contrast to *Lotus* species and *Odontites verna* flowers, *Centaurea nigra* flowers were consistently more abundant on green hay plots than natural recolonisation plots. Mann-Whitney U 2-tailed exact tests indicated that the difference in average *Centaurea nigra* flower heads was significant for all experiment areas ($p < 0.001$ *for* 1, 4 and 5 respectively).

Trifolium pratense

*A*verage numbers of *Trifolium pratense* flowers varied considerably between experiment areas and comparative treatment plots. Results for experimental areas 1 and 4 are presented in Figures 23 and 24. Results for experimental area 5 are not included as only a single quadrat recorded any *Trioflium pratense* flowers in this area. For the two areas where *Trioflium pratense* flowers were recorded in substantial numbers, they were consistently more abundant on green hay plots than natural recolonisation plots. Mann-Whitney U 2-tailed exact tests indicated that the difference in average *Trifolium pratense* flower heads was significant for both experiment areas ($p < 0.001$ *for* 1 and 4 respectively).

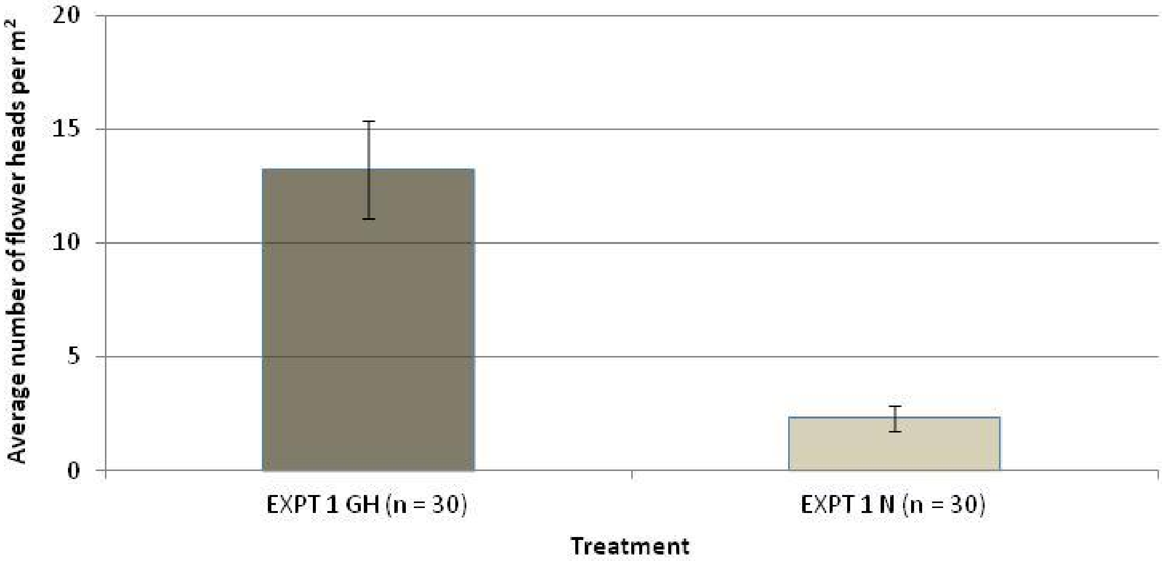

Figure 23. Average number of *Trifolium pratense* flower heads on the trial plots of experiment area 1, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

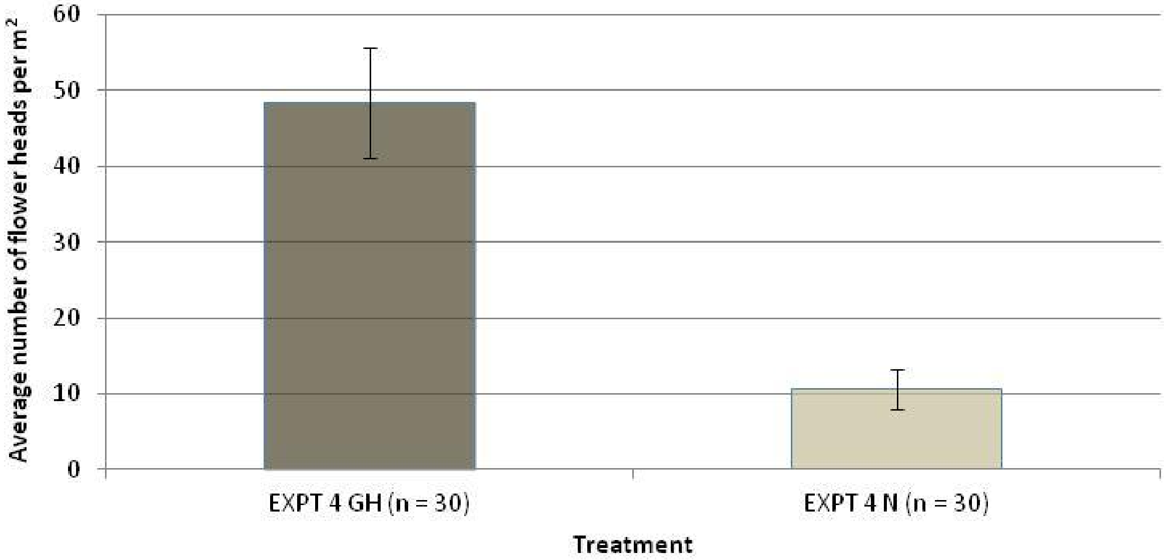

Figure 24. Average number of *Trifolium pratense* flower heads on the trial plots of experiment area 4, August 2015. Values calculated from 1 x 1 m quadrat surveys. [Error bars represent the standard error of the mean]

Other key forage species

Whilst the other key forage species for *Bombus humilis* and *Bombus sylvarum* at Hadleigh Park (*Trifolium repens*, *Cirsium vulgare*, *Cirsium arvense* and *Ballota nigra*) were recorded within the quadrat surveys, flowers of these species were rare and infrequent across the experimental plots. As such, no detailed analysis of comparative abundance of flower heads was made.

3.3.4 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 2008);
- abundance of recolonising scrub species that were targeted for removal by the original habitat management programme.

Table 8 provides a summary of the direction of average abundance (i.e. more abundant on green hay plot or natural recolonisation plot) and the level of statistical significance for this difference using Mann-Whitney U 2-tailed exact tests. Values are based on counts of all squares that the species was recorded in within each quadrat. The exception to this is grass/dead grass for which an additional measure of 'the number of squares it was the dominant vegetation in' is given. This was due to the almost ubiquitous nature of grass in terms of presence/absence within survey quadrats across all survey plots causing presence/absence counts to not provide meaningful data on the abundance of grasses.

Species presented are separated into target forage species for *Bombus humilis* and *Bombus sylvarum*, grasses, and scrub species. Target forage species can be viewed as a measure of successful habitat creation. Whilst dominant grasses are not a target of forage creation, grassy swards are important as nesting areas for the conservation priority bumblebees and so can be viewed as a neutral result in terms of habitat management. Recolonisation by scrub can be viewed as a negative result as this would lead to an increased need for management intervention for scrub removal to prevent the habitat loss which was the original target of the habitat management.

Table 8. Summary of the abundance and the level of statistical significance between target and non-target floral species on green hay plots and natural recolonisation plots at Hadleigh Park, August 2015. Statistical difference was measured using Mann-Whitney U 2-tailed exact tests at a p = 0.05 threshold for significance. Values are based on counts of all squares that the species was recorded in within each 1 x 1 m quadrat (n = 30 within each green hay plot and natural recolonisation plot). Where differences between treatment plots were significant, cells are shaded pink. Floral species are divided into target forage species for *Bombus humilis* and *Bombus sylvarum* foraging, grasses, and scrub. Due to the ubiquitous nature of grasses across the quadrat subunits (very few subunits recorded no grass at all) a dominance measure was also compared for grasses (i.e. number of squares where grass/dead grass was the dominant plant/feature).

		Experiment area 1		Experiment area 4		Experiment area 5	
	Species/group	**Highest average count**	**Significance**	**Highest average count**	**Significance**	**Highest average count**	**Significance**
Target forage	*Odontites verna*	Natural	$p < 0.001$	Natural	$p < 0.001$	Natural	$p = 0.24$
	Lotus spp.	Green hay	$p = 0.013$	Green hay	$p < 0.001$	Green hay	$p = 0.98$
	Centaurea nigra	Green hay	$p < 0.001$	Green hay	$p < 0.001$	Green hay	$p < 0.001$
	Trifolium pratense	Green hay	$p < 0.001$	Green hay	$p < 0.001$	Natural	$p = 1.00$
Grass/ dead grass	Presence/absence	Green hay	$p = 0.05$	Natural	$p = 1.00$	N = GH	$p = 1.00$
	Dominant squares	Natural	$p = 0.001$	Natural	$p < 0.001$	Natural	$p = 0.05$
Scrub	*Crataegus monogyna*	Natural	$p < 0.001$	Natural	$p < 0.001$	Natural	$p < 0.001$
	Rosa canina	Natural	$p = 0.001$	Green hay	$p = 0.10$	Natural	$p = 0.35$
	Rubus fruticosus	Natural	$p < 0.001$	Green hay	$p = 0.04$	Natural	$p < 0.001$

With the exception of *Odontites verna*, significantly greater vegetation coverage was recorded on the green hay plots of experimental areas 1 and 4 for all target forage species. For experiment area 5 this was also the case with the exception of *Trifolium pratense* for which there was no significant difference. For *Odontites verna*, coverage was significantly greater on the natural recolonisation areas than the green hay areas for experiment areas 1 and 4. No significant difference was recorded for experiment area 5.

In terms of number of squares that grass and/or dead grass was recorded, significantly more was recorded in the green hay plot of experiment area 1 than the corresponding natural recolonisation plot, and no significant difference was recorded for experiment areas 4 and 5. Comparison of grass dominance, however, recorded significantly greater grass dominance on all three natural recolonisation plots than corresponding green hay plots.

The scrub species *Crataegus monogyna* was recorded with significantly greater cover on the natural recolonisation plots of all three experimental areas. *Rubus fruticosus* was recorded with significantly greater cover on the natural recolonisation plots of experiment areas 1 and 5 but was the opposite was true for experiment area 4. The third scrub species present in any number, *Rosa canina,* was recorded with significantly greater cover on the natural recolonisation plot of experiment area 1 but there was no significant difference on experiment areas 4 and 5.

Bare ground

Whilst a comprehensive cover of nectar and pollen-rich forage was a target for habitat creation, bare ground is an important habitat feature for species associated with Thames Terrace Grasslands and Open Mosaic Habitats in the Thames Corridor (Harvey 2000). It can act as a nesting resource for ground nesting aculeate Hymenoptera and also as basking areas for other thermophilic insects, particularly those at the northern edge of their range. As such the ratio of cover to bare ground was viewed as another key indicator for habitat quality in terms of habitat creation at Hadleigh Park.

To assess the difference in vegetation cover, average counts of the number of quadrat sub-units containing no open bare ground were compared. Despite nine, six and five years having passed respectively since the three experimental areas were created, all of the green hayed plots had a higher average vegetation cover than their corresponding natural recolonisation plots (Figure 25). However, the differences in percentage cover were relatively small. Mann-Whitney U 2-tailed exact tests indicated that the difference in percentage cover was significant for experimental area 1 ($p = 0.004$), but was not significant for experimental areas 4 and 5 ($p = 0.011$ and 0.492 respectively).

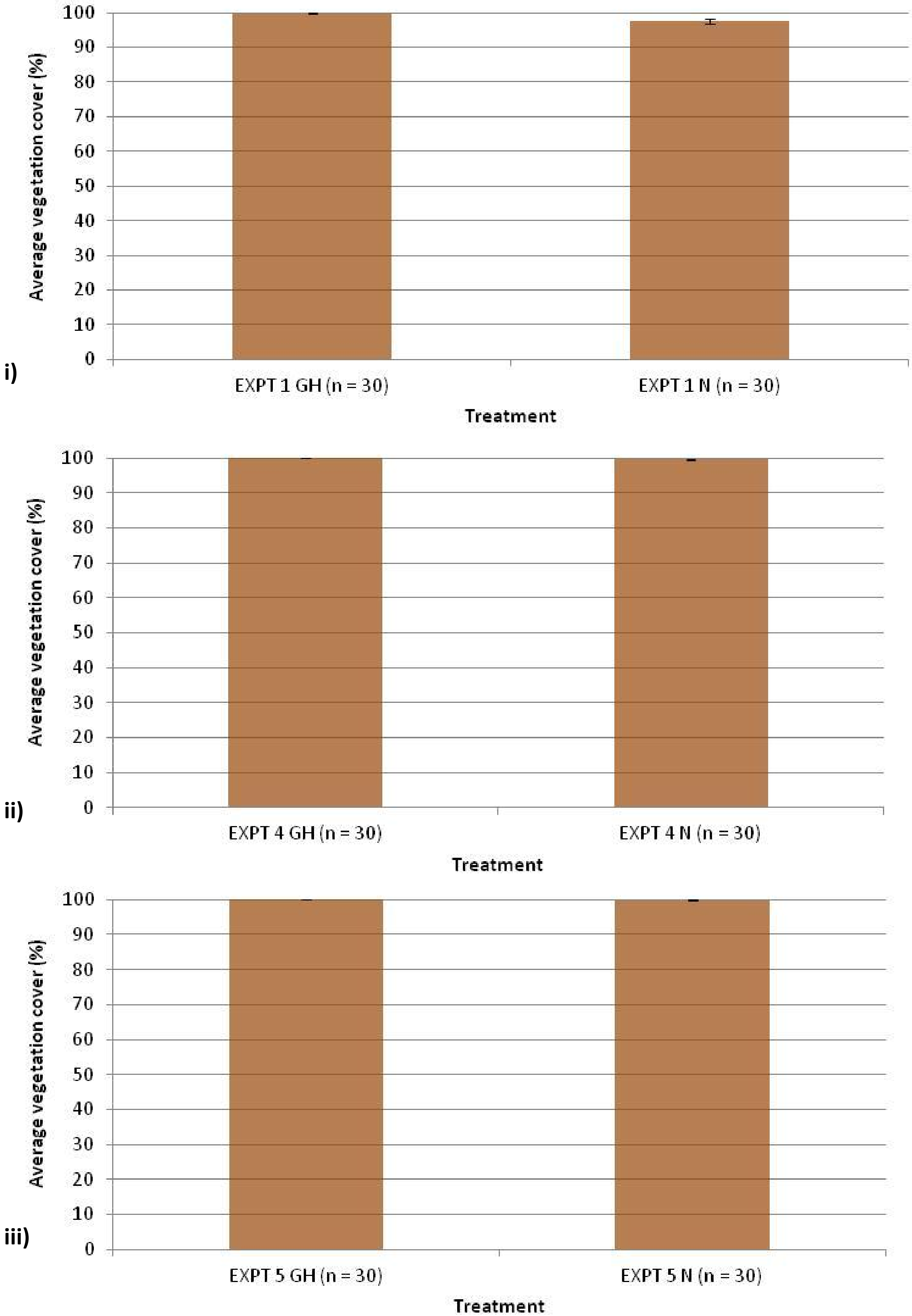

Figure 25. Average percentage cover of vegetation in floral survey quadrats. Data from the 1 x 1 m quadrat surveys on the trial plots of: i) experiment area 1; ii) experiment area 4; and iii) experiment area 5 at Hadleigh Park, August 2015. [Error bars denote standard error of the mean]

3.4 Discussion

Despite several years having passed since the green haying experimental trial plots were set up (nine, six and five years respectively for experiment areas 1, 4 and 5), substantial difference still persisted between the flora of the green hay areas and the corresponding natural recolonisation areas. This was apparent visually even prior to the quadrat surveys with divides in vegetation visible where the original green haying ended and the natural recolonisation areas began (Figures 26 to 28). Quadrat surveys supported this visual evidence with significant differences between the vegetation on the green hay plots and corresponding natural recolonisation plots.

Forage plants

Perhaps the starkest changes in the plots was the shift in overall total number of flower heads and *Odontites verna* abundance between the green hay plots and the natural recolonisation plots. Results of surveys carried out on the treatment plots of all three experimental areas a year after establishment identified significantly greater total flower heads and *O. verna* flower heads on the green hay plots compared to the natural recolonisation plots (Connop 2007, 2010, 2011).

Figure 26. Visible line in vegetation differentiating the green hay plot from the natural recolonisation plot in experiment area 1, August 2015.

Figure 27. Visible line in vegetation differentiating the green hay plot from the natural recolonisation plot in experiment area 4, August 2015.

Figure 28. Visible line in vegetation differentiating the green hay plot from the natural recolonisation plot in experiment area 5, August 2015.

At the time of this latest round of surveys, this was no longer the case for experiment areas 1 and 4 with significantly greater numbers of total flower heads and *O. verna* flower heads now recorded on the natural recolonisation plots. For experiment area 5, significantly more flower heads were recorded on the green hay plot but significantly more *O. verna* flowers were recorded on the natural recolonisation plot.

Odontites verna flowers are considered to be of particular importance to *Bombus sylvarum* with the majority of visits of these bees on south Essex sites being made to these flowers (Connop et al. 2010). The shift in abundance of *Odontites verna* and other flowerheads between the green hay plots and natural recolonisation plots appeared to be related to successional processes. Green haying appears to be an excellent method for creating suitable forage areas for bumblebees over short time periods by accelerating recolonisation rates. This was demonstrated by green hay areas having significantly greater vegetation cover than natural recolonisation areas in the first 1 to 3 years after clearance and green haying. At the time of this round of surveys, green hay areas had complete vegetation cover with almost no bare areas, whereas natural recolonisation areas recorded greater areas of bare ground (still significantly so for experiment area 1). *Odontites verna* appears to be an opportunistic species at Hadleigh Park appearing on areas that are regularly cut or more heavily grazed, particularly along the edge of pathways and other short sward areas at the park. Evidence from these surveys indicated that the abundance of these plants (in terms of both number of flower heads and cover) reduces with the time following the original clearance and the maturing of the wildflower areas.

This pattern of development of flora over time is also apparent from the results for *Lotus* species. Initially following green haying, very few *Lotus* species flowers were recorded on the green hay plots. However, significantly greater cover of *Lotus* species was recorded on the green hay plots of experiment areas 1 and 4 during this latest survey. This was also the case for *Centaurea nigra* with significantly greater cover and numbers of flower heads of this species recorded on all green hay plots compared to natural recolonisation plots.

The evidence from these surveys indicates that there appears to be a successional trend over time following the green haying. Initially the plots are dominated by *Odontites verna* and gradually this shifts to *Lotus species, Centaurea nigra* and also *Trifolium pratense*. Whilst this may be of benefit to the majority of bumblebee species (including *Bombus humilis*), this may not be ideal for *B. sylvarum*. Some consideration needs to be given therefore to ensuring a continuity of *Odontites verna* at the park. This could possibly be achieved by an ongoing programme of clearing areas and green haying some areas and leaving others to recolonise naturally, thus creating a mosaic of successional stages. Alternatively areas within those already cleared could be more intensively cut or scraped to create a mosaic of habitats and successional stages.

Scrub

Another apparent difference between the two habitat management methodologies was the reoccurrence of scrub following the clearance and experimental treatments. Three scrub species, *Crataegus monogyna*, *Rosa canina* and *Rubus fruticosus* were recorded with any regularity. Of these *C. monogyna* cover was recorded as significantly greater on all three of the natural recolonisation plots, *R. canina* was recorded as significantly greater on the natural recolonisation plot of experiment area 4 but non-significantly different on the other two experiment areas, and *R. fruticosus* cover was significantly more on the natural recolonisation plots of experiment areas 1 and 5 but there was significantly more cover on the green hay plot of experiment area 4. This evidence indicated that the green haying had some effect in terms of reducing the recolonisation of sites by scrub following clearance. This may be related to the reduction in bare ground following green haying, or even a mulching effect created by the hay which also seemed to reduce colonisation by ruderals such as thistles on the green hay plots initially following treatment (Connop 2007; 2008b; 2009; 2010; 2011).

Grasses

The other substantial difference between the trial plots identified by the vegetation quadrat surveys was in relation to the colonisation of the trial plots by grasses. Comparison of the average number of squares that grass or standing dead grass was recorded in was not significantly different for experiment area 4 or 5 but was for experiment area 1 with greater numbers recorded for the green hay area. However, due to the almost ubiquitous recording of at least a small amount of grass in all quadrat sub-units across all plots, these results could be slightly misleading in terms of understanding grass cover. To reduce this effect, additional analysis was carried out on the number of quadrat sub-units for which grass was the dominant vegetation type. By carrying out this assessment it was possible to compare the proportion of grass dominance of each treatment plot. Results indicated that significantly greater dominance of grasses was found on all natural recolonisation plots compared to green hayed plots. This provided additional evidence of the impact that green haying can have on the subsequent development of suitable foraging habitat for bumblebees.

Also of interest in relation to colonisation by grasses was the stark difference in terms of grass dominance between both plots of experiment area 5 and the other two experiment areas. Figure 29 shows the average number of quadrat sub-units dominated by grass for all six of the experimental plots. Dominance of grasses was much higher in experiment area 5 than the other plots, particularly for the green hayed area. Whilst this study provides no evidence for why this might be, it could be related to how the green hay was spread, the quality of the green hay the year it was cut, or even related to the substrate/seed bank in the area cleared. It will be interesting to monitor how this develops over time and how other newly created green hay areas develop. Nevertheless, both *Bombus humilis* and *Bombus sylvarum* are considered to nest at the base of dense grass swards on south facing slopes, so

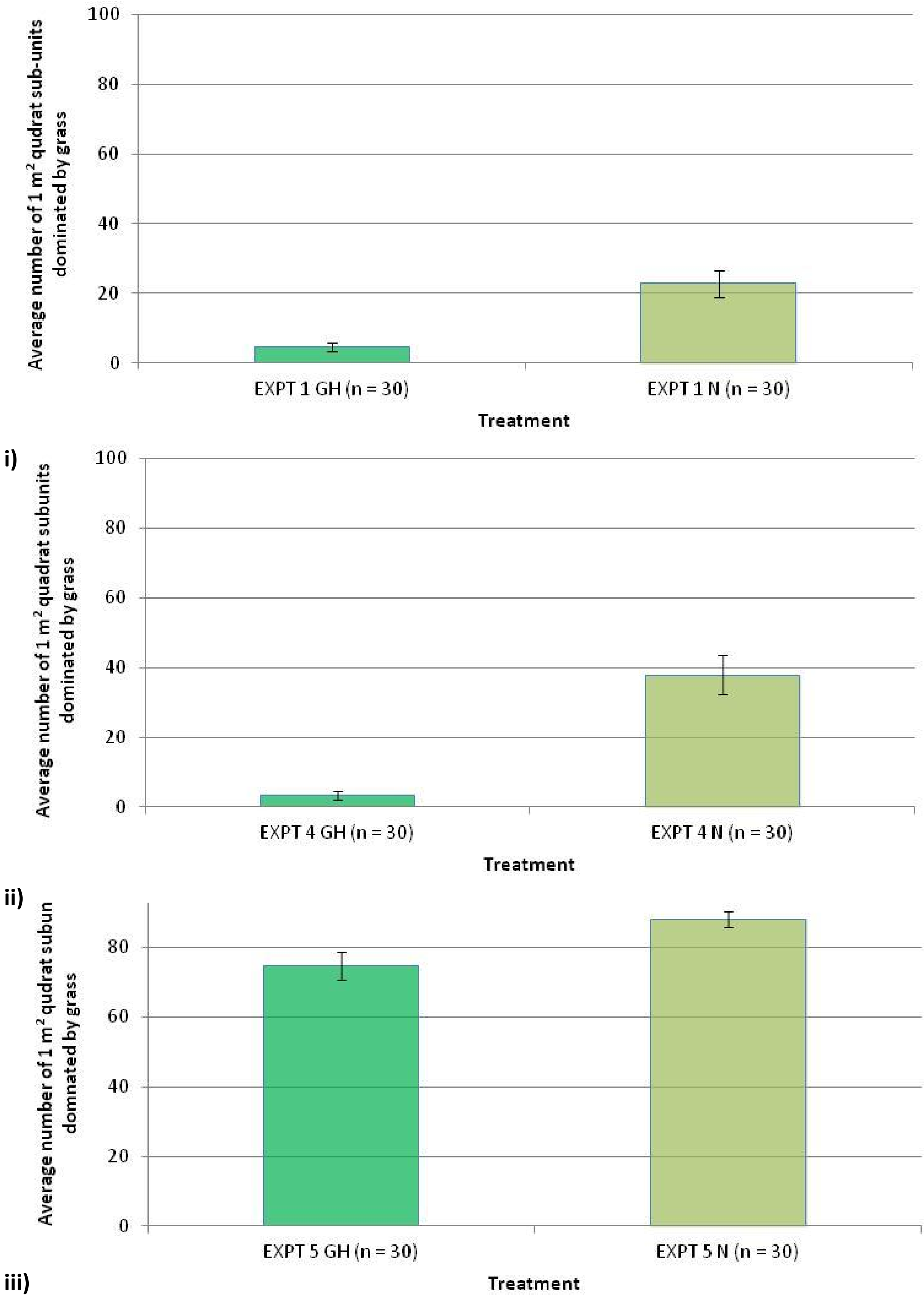

Figure 29. Average dominance of grass/standing dead grass within 1 m² quadrats at Hadleigh Park, August 2015. Dominance of grass on green hay trial plots and natural recolonisation trial plots at three experimental scrub clearance areas: i) experiment area 1; ii) experiment area 4; iii) experiment area 5. Dominance measured as the proportion of the 100 sub units of each quadrat for which grass was the dominant vegetation [Error bars denote standard error of the mean]

the grass dominated area created in experiment area 5 may well have additional value to the park in terms of creating suitable nesting habitat for the conservation priority bumblebees. Indeed another carder bee species considered to nest in dense grass swards, *Bombus lapidarius*, was observed nesting in experiment area 5 during the timed bumblebee counts (Figure 30). Several *B. humilis* individuals were also observed disappearing into the long grass in this area where no apparent suitable forage was available. Despite searches, however, no *B. humilis* nest were located.

Figure 30. *Bombus lapidarius* nest in experiment area 5, Hadleigh Park.

4. Bumblebee survey

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 is to provide long-term monitoring of population size so that an assessment can 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.

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 31). 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. 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 31. 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 the bumblebees 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 survey areas. 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.

4.3 Results

Results were analysed to assess the abundance and diversity of bumblebees on green hay plots compared to corresponding natural recolonisation areas on experiment areas 1, 4 and 5. Numbers and diversity on all of the originally established forage-rich areas and the cleared areas were also compared. Forage preferences on each area were also analysed.

Comparison between green hay and natural recolonisation areas

Timed bumblebee counts in experiment area 1 recorded greater average counts for target species *B. humilis* and for all *Bombus* species on the natural recolonisation plot (Figure 32).

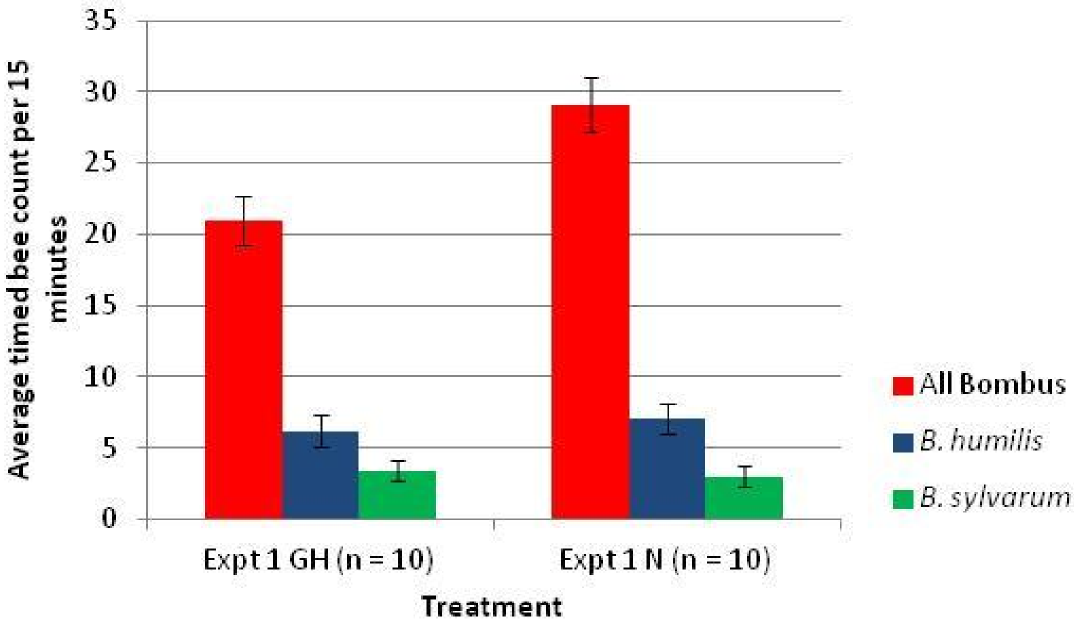

Figure 32. Average bumblebee counts on experiment area 1. Averages calculated based on number of individuals observed in the green hay (GH) and natural recolonisation plots (N) during a fifteen minute walked survey (*n* = 10). Averages given for all bumblebee species (All *Bombus*), and the habitat management target species *Bombus humilis* and *Bombus sylvarum*. [Error bars denote standard error of the mean]

Average counts for *B. sylvarum* were higher on the green hay plot. Average bumblebee species diversity was also higher on the natural recolonisation plot (Figure 33).

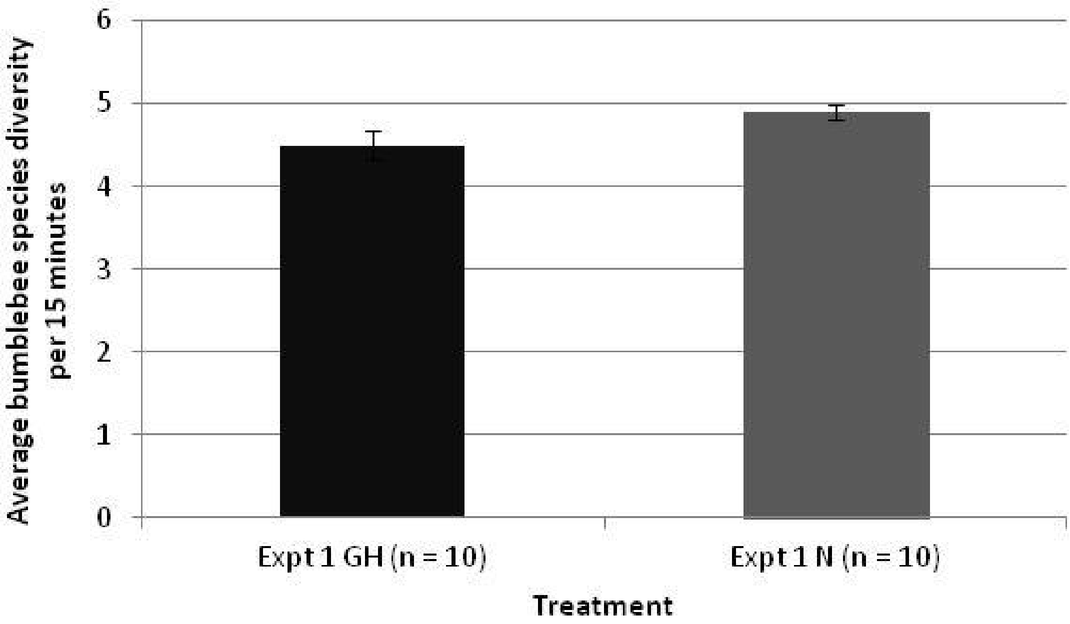

Figure 33. Average bumblebee species diversity on experiment area 1. Average diversity calculated based on number of species observed in the green hay (GH) and natural recolonisation plots (N) during a fifteen minute walked survey (n = 10). Averages given for all bumblebee species (All *Bombus*), and the habitat management target species *Bombus humilis* and *Bombus sylvarum*. [Error bars denote standard error of the mean]

Mann-Whitney U 2-tailed exact tests indicated that the difference in bumblebee counts between the green hay plot and natural recolonisation plot of experiment area 1 was significant for all *Bombus* species (p = 0.008), but was not significant for *B. humilis* (p = 0.59), *B. sylvarum* (p = 0.70), and species diversity (p = 0.14).

Timed bumblebee counts in experiment area 4 recorded greater average counts for target species *B. sylvarum* and for all *Bombus* species on the natural recolonisation plot (Figure 34). Average counts for *B. humilis* were higher on the green hay plot. Average bumblebee species diversity was also higher on the natural recolonisation plot (Figure 35).

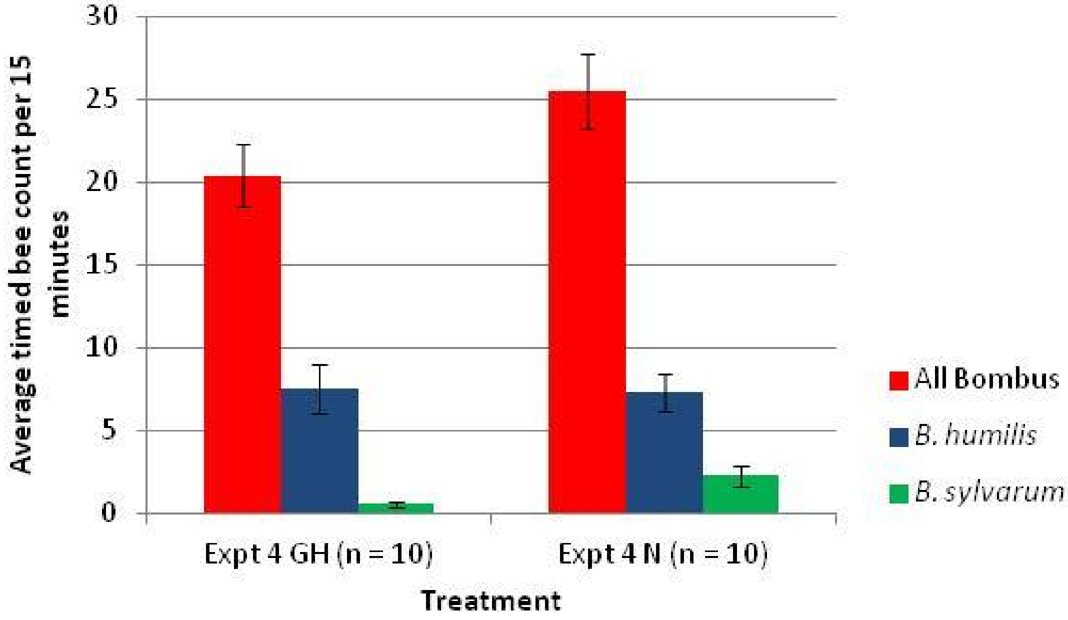

Figure 34. Average bumblebee counts on experiment area 4. Averages calculated based on number of individuals observed in the green hay (GH) and natural recolonisation plots (N) during a fifteen minute walked survey (n = 10). Averages given for all bumblebee species (All *Bombus*), and the habitat management target species *Bombus humilis* and *Bombus sylvarum*. [Error bars denote standard error of the mean]

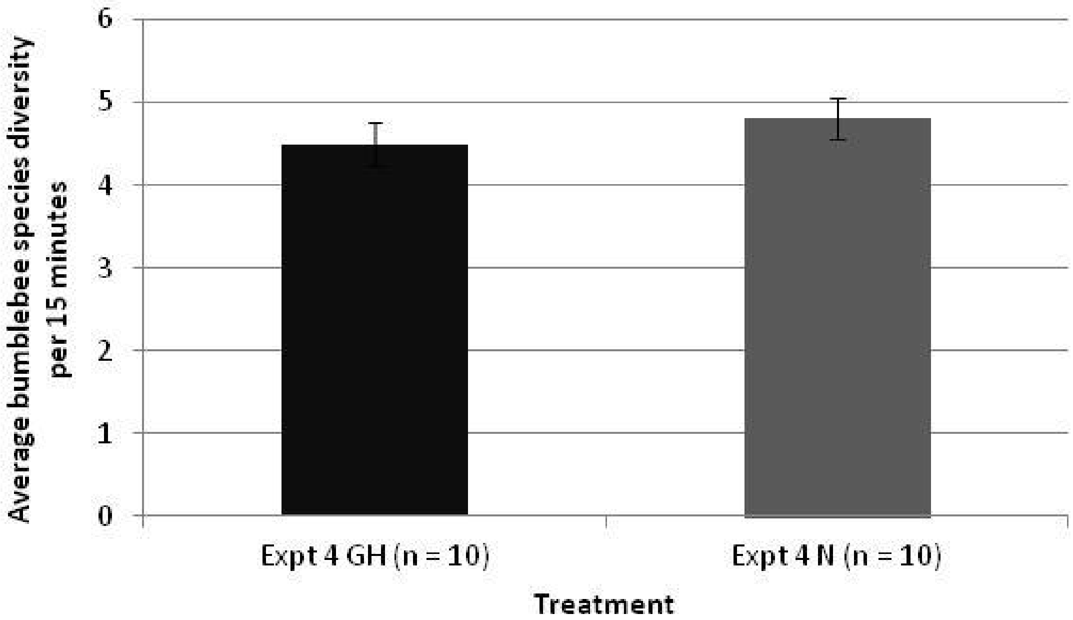

Figure 35. Average bumblebee species diversity on experiment area 4. Average diversity calculated based on number of species observed in the green hay (GH) and natural recolonisation plots (N) during a fifteen minute walked survey (n = 10). Averages given for all bumblebee species (All *Bombus*), and the habitat management target species *Bombus humilis* and *Bombus sylvarum*. [Error bars denote standard error of the mean]

Mann-Whitney U 2-tailed exact tests indicated that the difference in bumblebee counts between the green hay plot and natural recolonisation plot of experiment area 1 was significant for *B. sylvarum* (p = 0.02), but was not significant for *B. humilis* (p = 0.96), all *Bombus* species (p = 0.11), and species diversity (p = 0.36).

Timed bumblebee counts in experiment area 5 recorded greater average counts for target species *B. humilis* and for all *Bombus* species on the green hay plot (Figure 36). No *B. sylvarum* were recorded on the green hay plot or on the natural recolonisation plot. Average bumblebee species diversity was also slightly higher on the green hay plot (Figure 37).

Mann-Whitney U 2-tailed exact tests indicated that the difference in bumblebee counts between the green hay plot and natural recolonisation plot of experiment area 1 was significant for all *Bombus* species (p = 0.03), but was not significant for *B. humilis* (p = 0.13) and species diversity (p = 0.89).

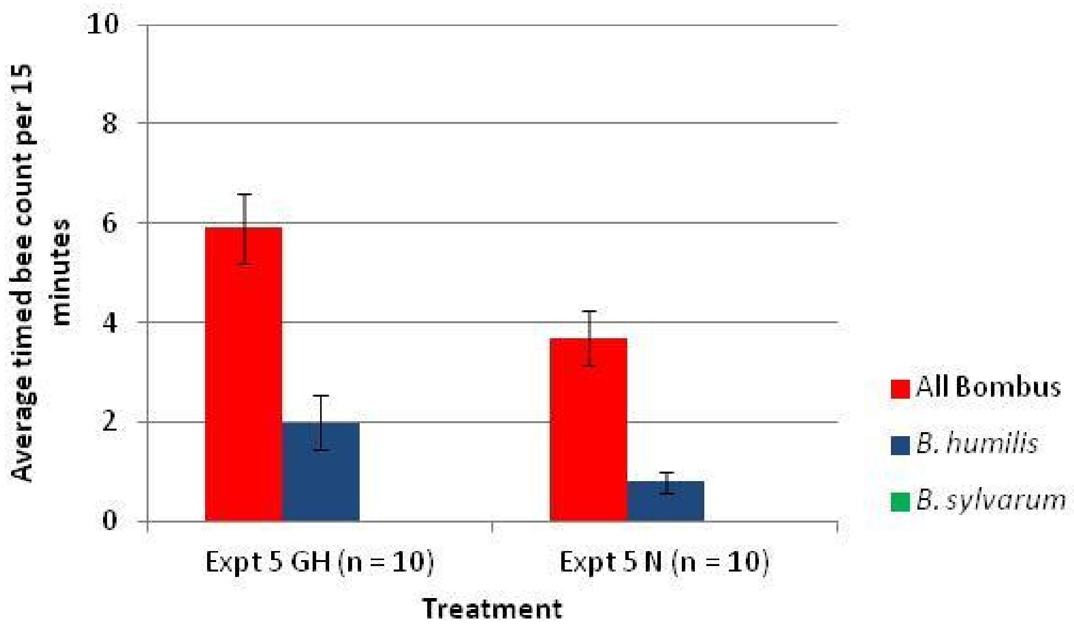

Figure 36. Average bumblebee counts on experiment area 5. Averages calculated based on number of individuals observed in the green hay (GH) and natural recolonisation plots (N) during a fifteen minute walked survey (n = 10). Averages given for all bumblebee species (All *Bombus*), and the habitat management target species *Bombus humilis* and *Bombus sylvarum*. [Error bars denote standard error of the mean]

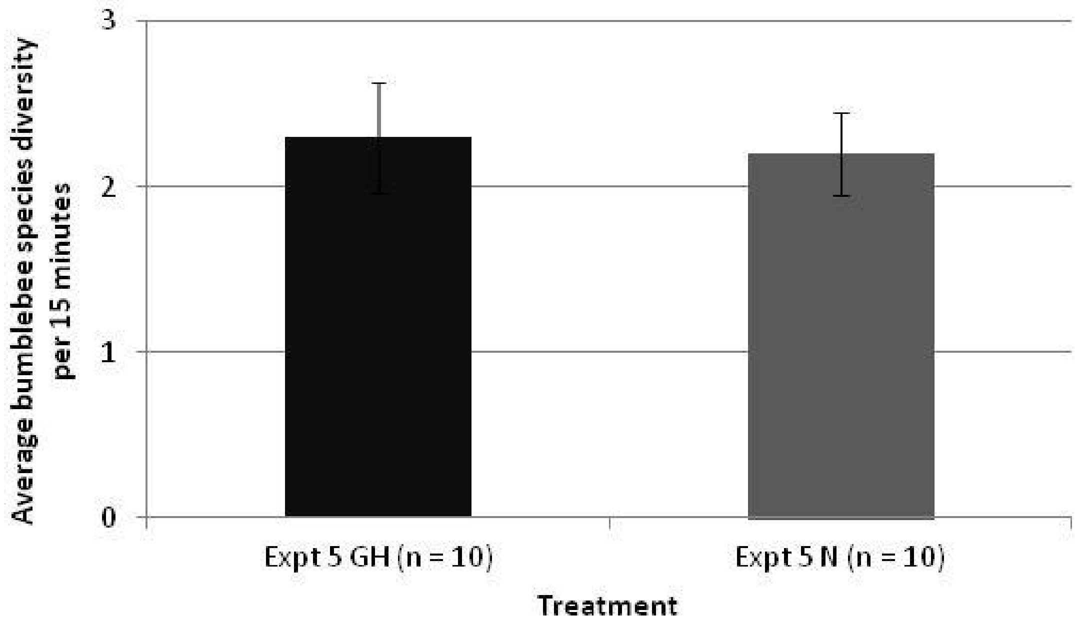

Figure 37. Average bumblebee species diversity on experiment area 5. Average diversity calculated based on number of species observed in the green hay (GH) and natural recolonisation plots (N) during a fifteen minute walked survey (n = 10). Averages given for all bumblebee species (All *Bombus*), and the habitat management target species *Bombus humilis* and *Bombus sylvarum*. [Error bars denote standard error of the mean]

Timed indices counts for all areas

Timed indices counts for experiment areas 1, 4 and 5 were compared to those recorded for the most forage-rich areas of Hadleigh Park when surveys were established in 2003. Results for *B. humilis* in 2015 are presented in Figure 38.

Highest average *B. humilis* counts were recorded on Benfleet Downs. However, numbers on the other historical key forage areas at the park were comparable with the newly created green hay plots of experiment areas 1 and 4 and the natural recolonisation plots of experiment areas 1 and 4. Average numbers on the green hay plot and natural recolonisation plot of experiment area 5 were the lowest recorded across the park.

Timed indices counts for *B. sylvarum* in 2015 are presented in Figure 39.

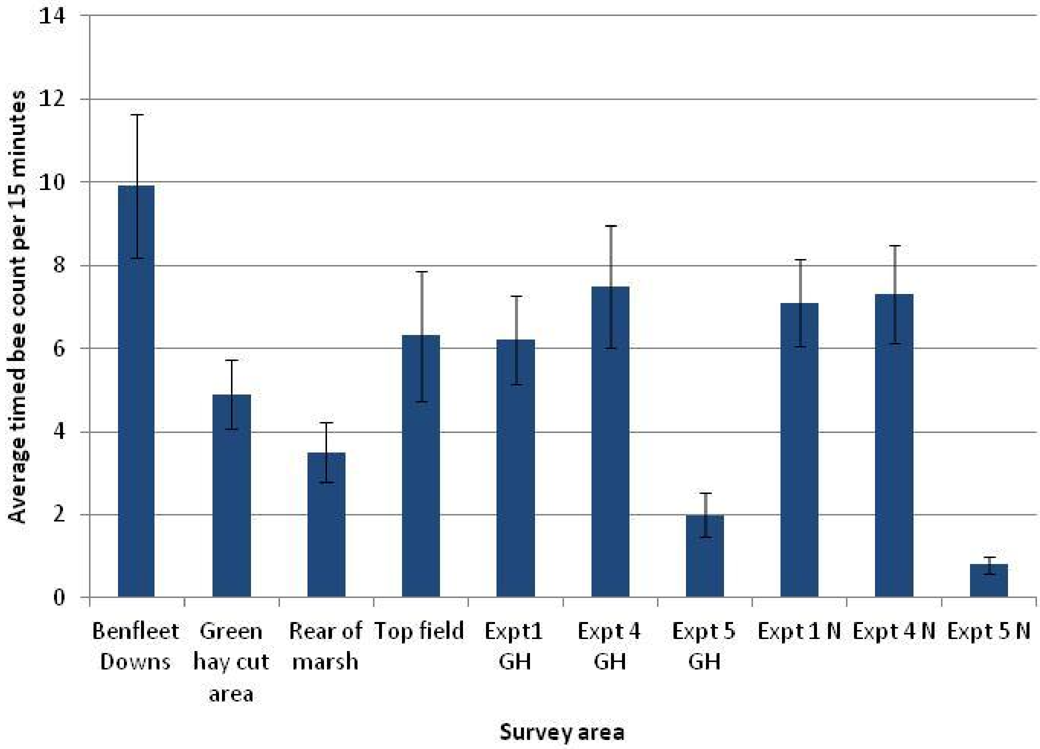

Figure 38. Average timed counts of *B. humilis* at Hadleigh Park, August 2015. Bee walk surveys carried out on experiment scrub clearance areas and other key forage areas. Timed counts of fifteen minutes in duration. All individuals recorded during walk. Ten walks carried out in each area. [Error bars denote standard error of the mean]

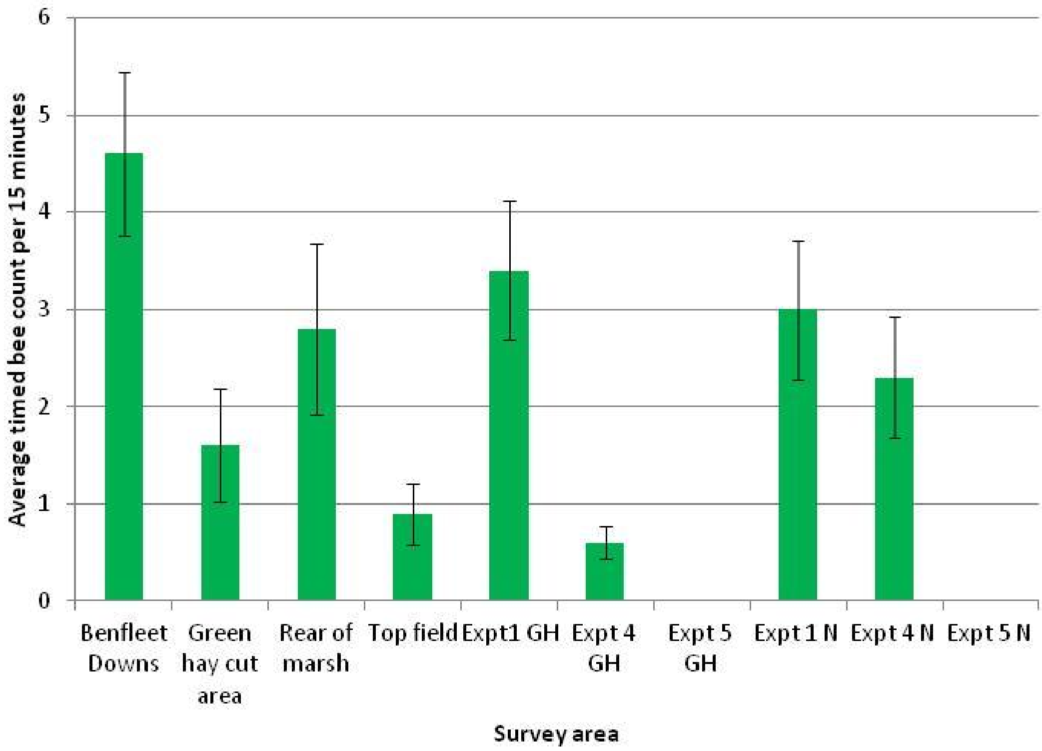

Figure 39. Average timed counts of *B. sylvarum* at Hadleigh Park, August 2015. Bee walk surveys carried out on experiment scrub clearance areas and other key forage areas. Timed counts of fifteen minutes in duration. All individuals recorded during walk. Ten walks carried out in each area. [Error bars denote standard error of the mean]

Similarly to *B. humilis* counts, highest average *B. sylvarum* counts were recorded on Benfleet Downs. Numbers on the other areas of the site varied substantially. Next highest numbers were recorded on the green hay and natural recolonisation plots of experiment area 1. Numbers here were higher than on the other forage-rich areas of the park. The natural recolonisation plot of experiment area 4 also recorded counts comparable to other forage-rich areas of the park. Experiment area 4 green hay plot recorded fewer individuals, however, numbers were still similar to the 'Top field' historically forage-rich area. Experiment area 5 recorded no *B. sylvarum* on the green hay or natural recolonisation areas.

Timed indices counts for all *Bombus* species in 2015 are presented in Figure 40.

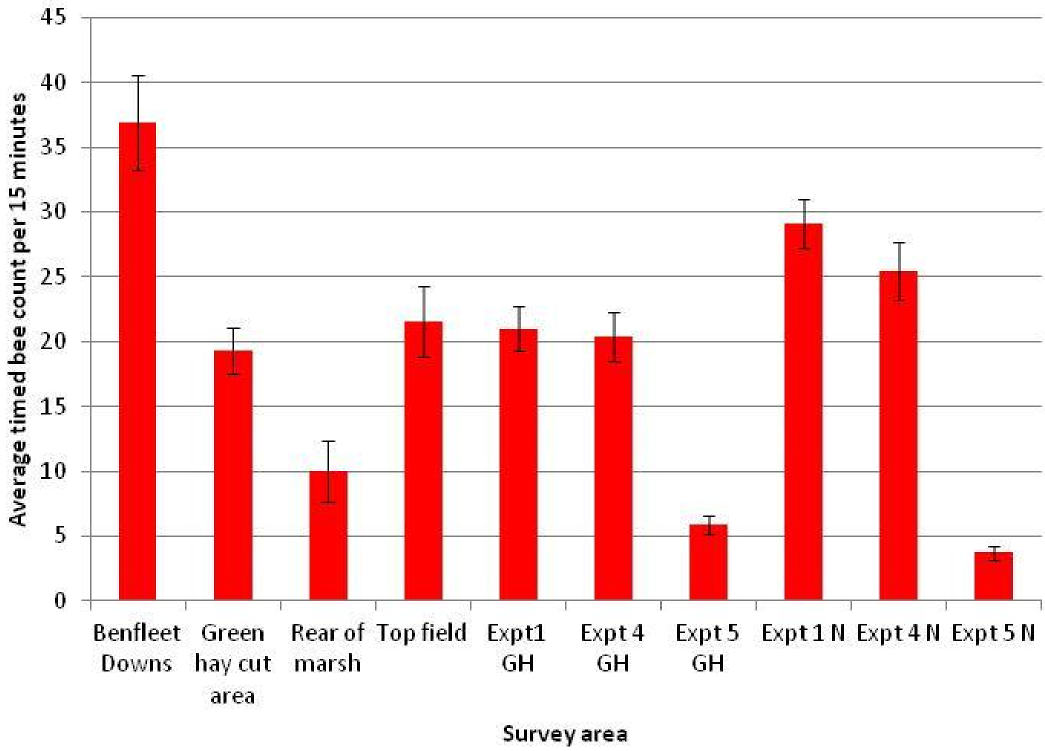

Figure 40. Average timed counts of all *Bombus* species individuals at Hadleigh Park, August 2015. Bee walk surveys carried out on experiment scrub clearance areas and other key forage areas. Timed counts of fifteen minutes in duration. All individuals recorded during walk. Ten walks carried out in each area. [Error bars denote standard error of the mean]

Counts for all bumblebees mirrored those for the two target species. Highest numbers were recorded on Benfleet Downs. Numbers on the green hay and natural recolonisation plots of experiment areas 1 and 4 were as high or higher than those on the other most forage-rich areas of Hadleigh Park. Numbers on both plots of experiment area 5 were the lowest recorded on any area.

Comparison of historical timed counts at Hadleigh Park with the 2015 timed counts for the key forage-rich areas of the site (Figure 41) and the green hay areas showed encouraging patterns. In terms of the green hay areas, *B. sylvarum* numbers had reduced compared to previous surveys on the same areas, but *B. humilis* numbers were as high as those recorded in 2011 and higher than those recorded in 2010. In terms of numbers at the most forage-rich areas across the park, numbers of *B. humilis* and *B. sylvarum* were encouraging. At the time of the last survey in 2011, both species of bumblebee had undergone trends of decline in average counts since peak numbers in 2007. Whilst it was never possible to demonstrate whether this was due to declines in population numbers at the park, or in the surrounding environment, or indeed merely an artefact created by a stable population able to forage over a larger forage resource (and hence being less densely distributed), continuation of the trend of decline would be a cause for some concern. Counts in the 2015 surveys indicated that numbers had recovered somewhat. Whilst still not as high as peak numbers in 2007, numbers of *B. humilis* were higher than those in 2008 and were, in fact, the third highest since recording began at the park. Numbers of *B. sylvarum* were also higher than those recorded in 2008 and were the fourth highest since recording began.

Forage preferences

In addition to counts of the total numbers and diversity of all bumblebees and the counts for *B. humilis* and *B. sylvarum*. A record of the flowers that bumblebees were visiting at the time of observation was taken. This enabled an analysis of forage preference of each bumblebee species at each survey area to be made. Figures 42 to 47 represent the forage preferences for the green hay and natural recolonisation plots of experiment areas 1, 4 and 5. As quadrat surveys of available flower heads were carried out in these areas, it was also possible to include an assessment of forage availability for each of these plots to compare it to the proportions of flowers visited by the bumblebees. These proportions were calculated by summing all of the flower heads in all thirty of the quadrats recorded in each treatment plot.

Results provided further evidence for the difference in forage preferences between *B. humilis* and *B. sylvarum* (Connop *et al*. 2010) with *B. sylvarum* recording a substantially greater proportion of visits to *Odontites verna* than *B. humilis* and all *Bombus* records for both plots of experiment areas 1 and 4 (the only experiment areas where *B. sylvarum* was recorded). Forage visits by *B. sylvarum* on these experiment areas were also higher than the proportion of *Odontites verna* flowers in these areas. *Bombus humilis* forage visits to treatment plots on all three experiment areas appeared to be more closely related to overall flower abundance with the exception of a stronger affinity to certain Fabaceae species (e.g. *Lotus* species and *Trifolium pratense*) than *B. sylvarum* and than floral availability proportions.

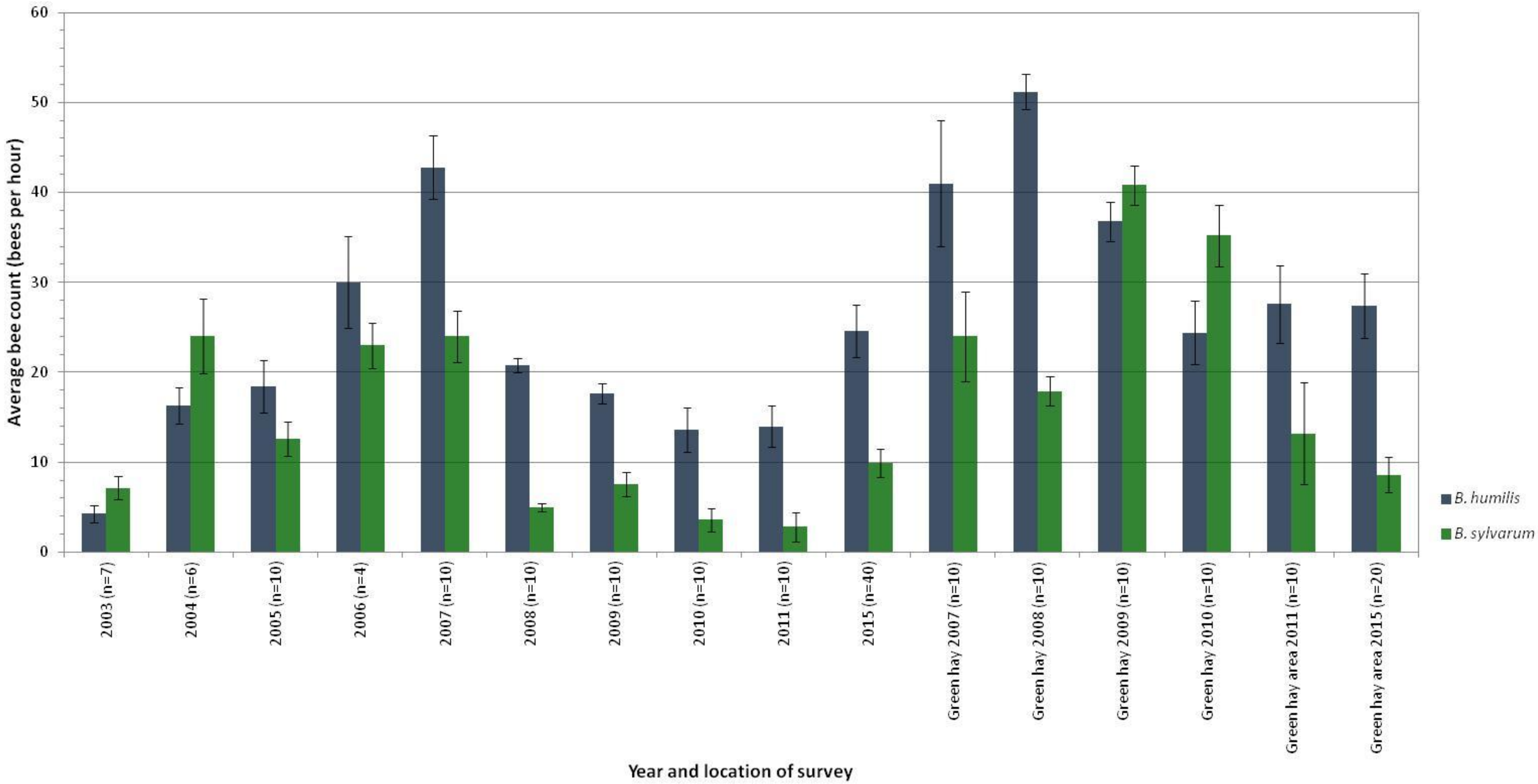

Figure 41. Average annual *Bombus humilis* and *Bombus sylvarum* counts at Hadleigh Park, 2003-2015. Counts were all conducted during August and September, the main foraging period for workers of the two species, over approximately equal areas. n= the number of timed surveys the average is based on. Averages are based on all surveys across the key forage patches at Hadleigh Park and those carried out on green hay plots. For 2015 counts, only green hay plot surveys on experiment areas 1 and 4 were included due to the very low numbers recorded on experiment area 5 [Error bars represent the standard error of the mean]

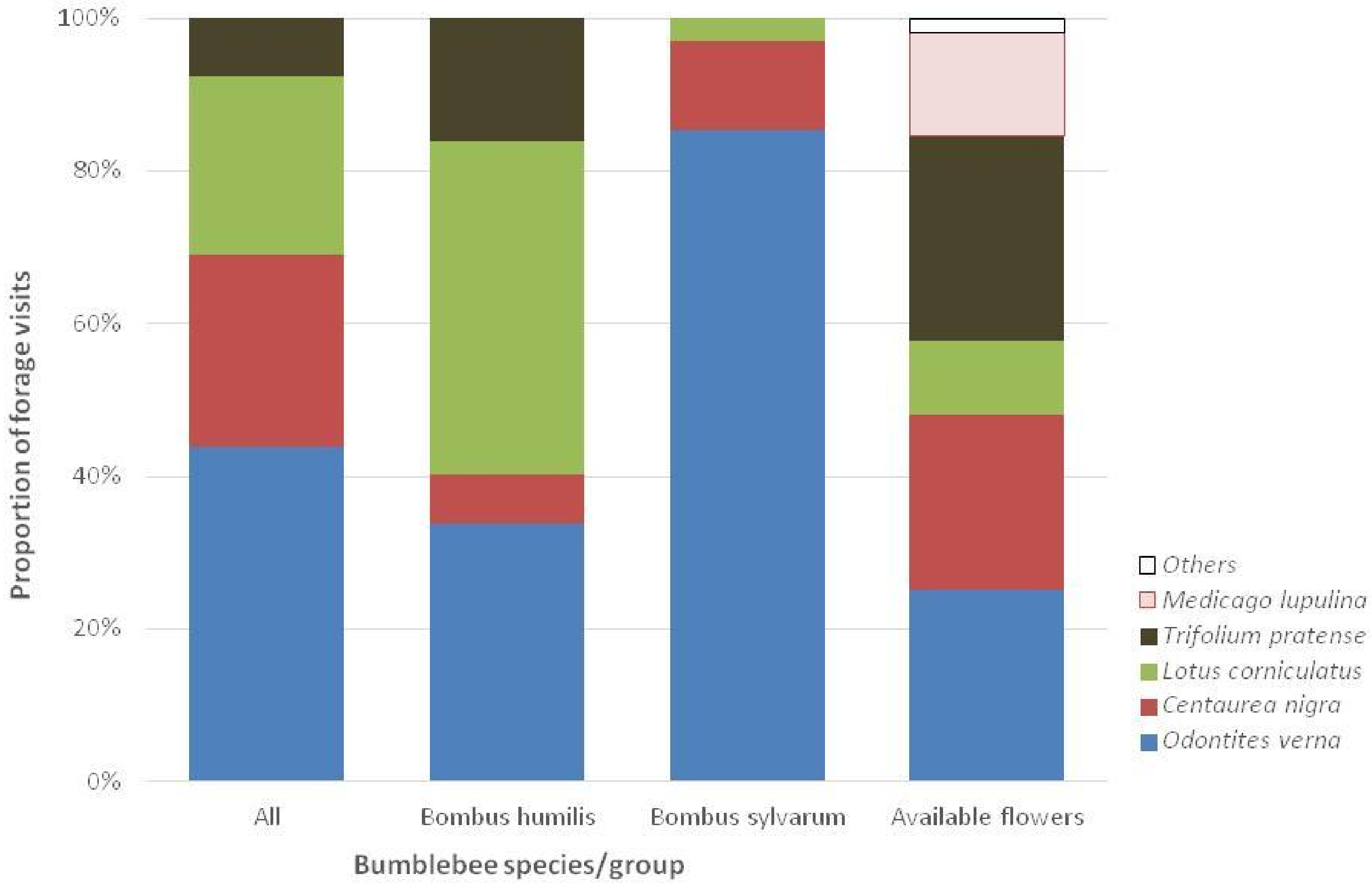

Figure 42. Forage preferences of bumblebees foraging on the green hay plot of experiment area 1 Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals. Total proportion of available flowers from quadrat survey also presented (*n* = 30).

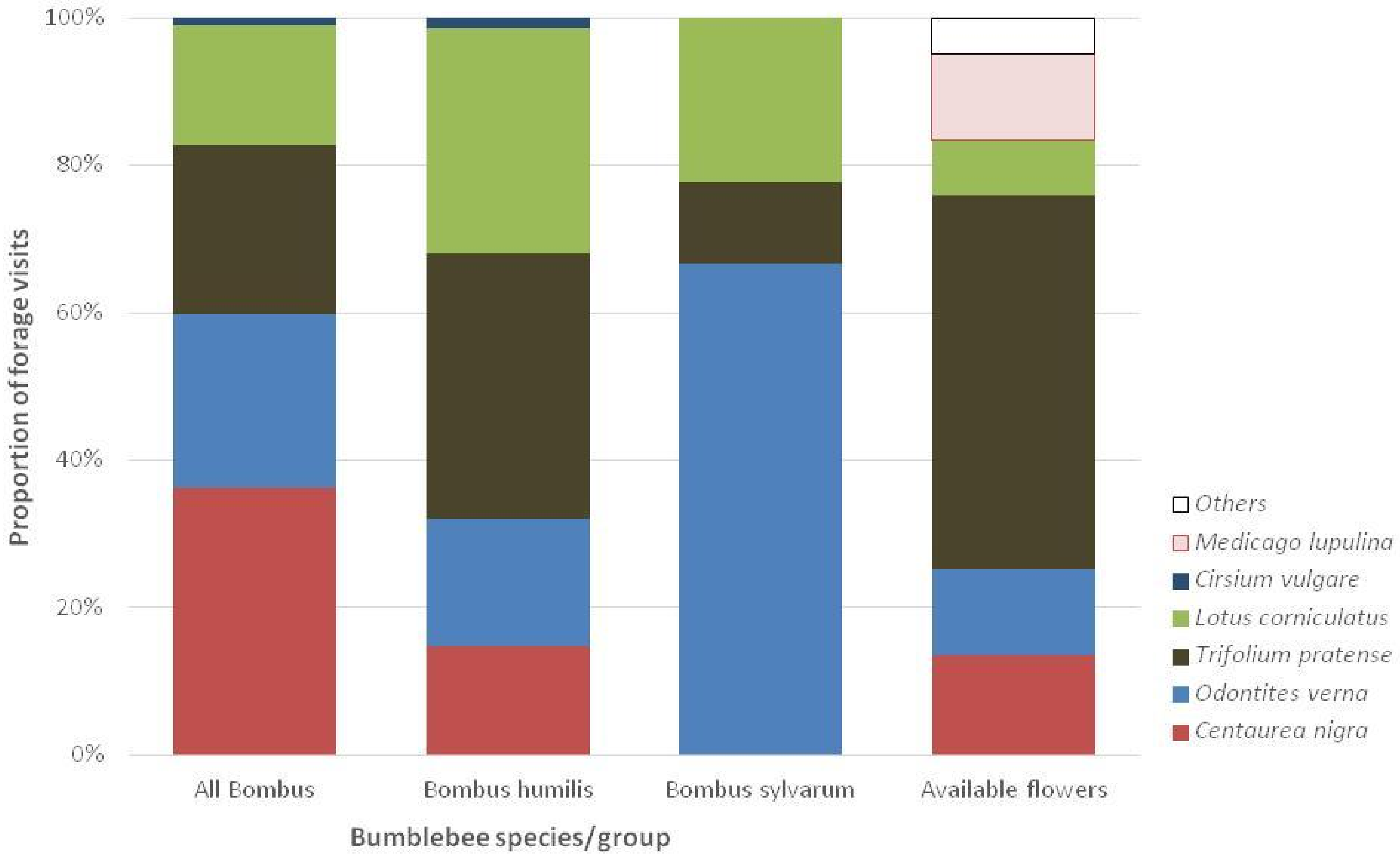

Figure 43. Forage preferences of bumblebees foraging on the green hay plot of experiment area 4 Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals. Total proportion of available flowers from quadrat survey also presented (*n* = 30).

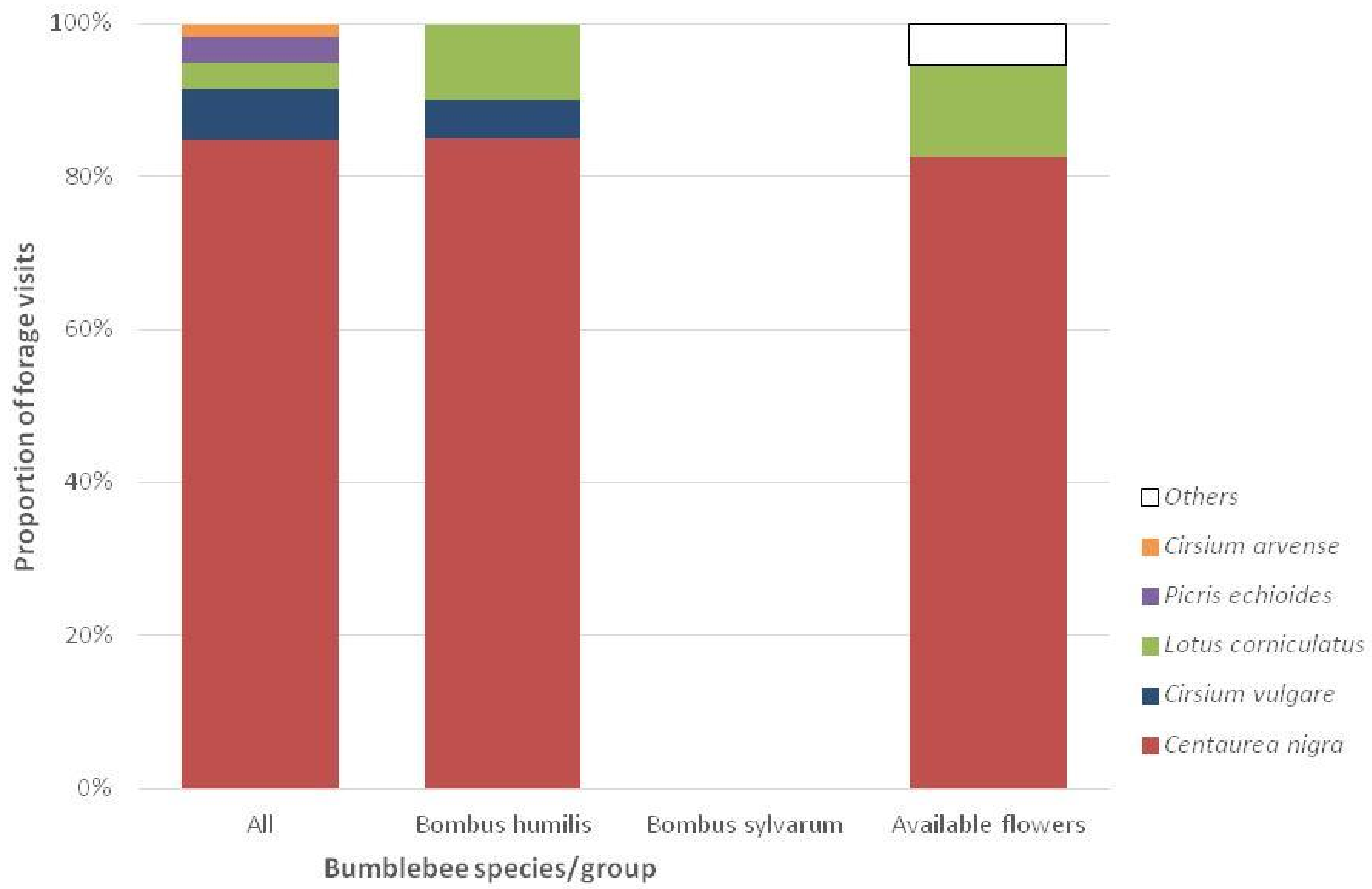

Figure 44. Forage preferences of bumblebees foraging on the green hay plot of experiment area 5 Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals. Total proportion of available flowers from quadrat survey also presented (*n* = 30).

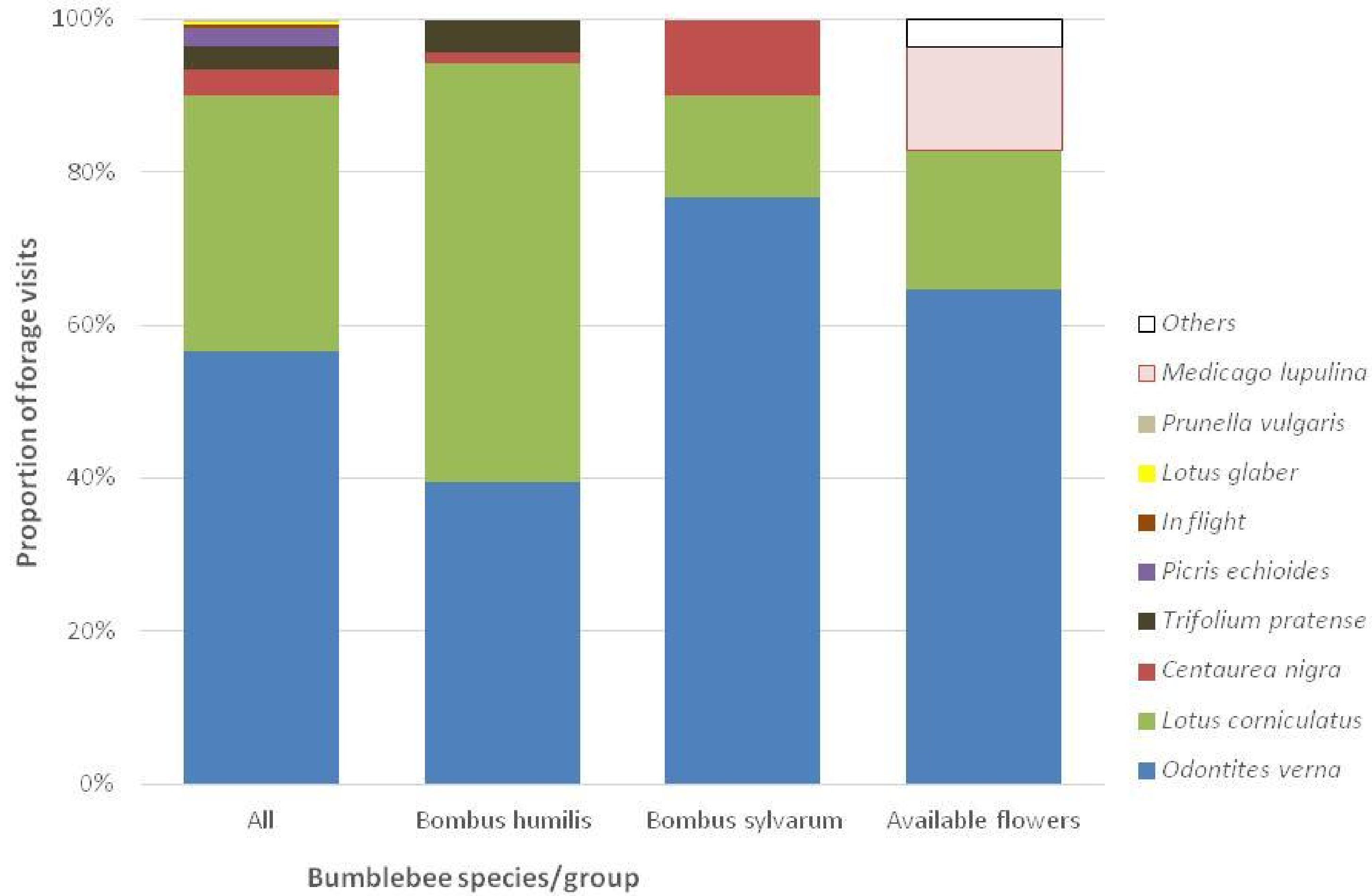

Figure 45. Forage preferences of bumblebees foraging on the natural recolonisation plot of experiment area 1 Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals. Total proportion of available flowers from quadrat survey also presented (n = 30).

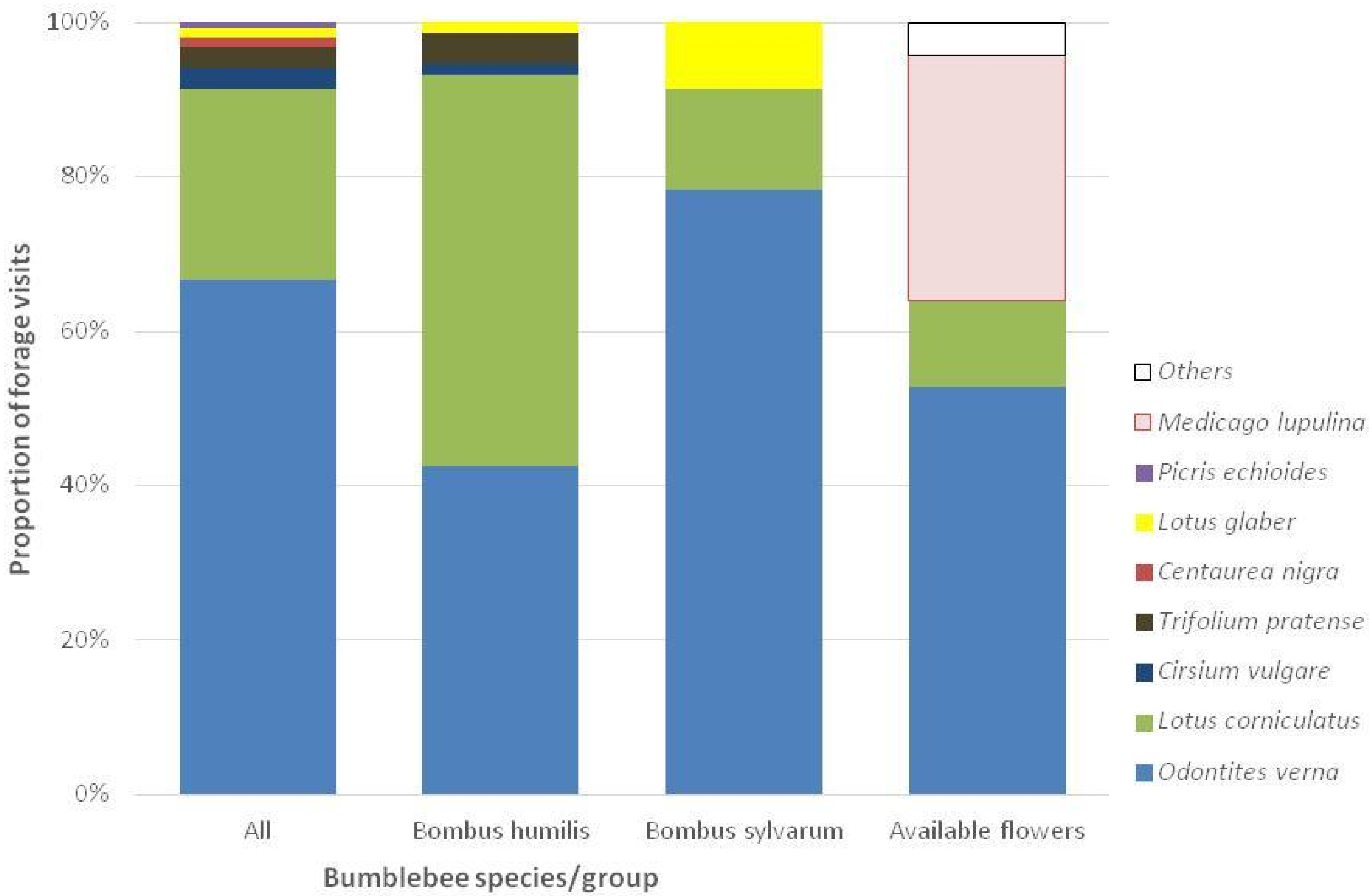

Figure 46. Forage preferences of bumblebees foraging on the natural recolonisation plot of experiment area 4 Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals. Total proportion of available flowers from quadrat survey also presented (*n* = 30).

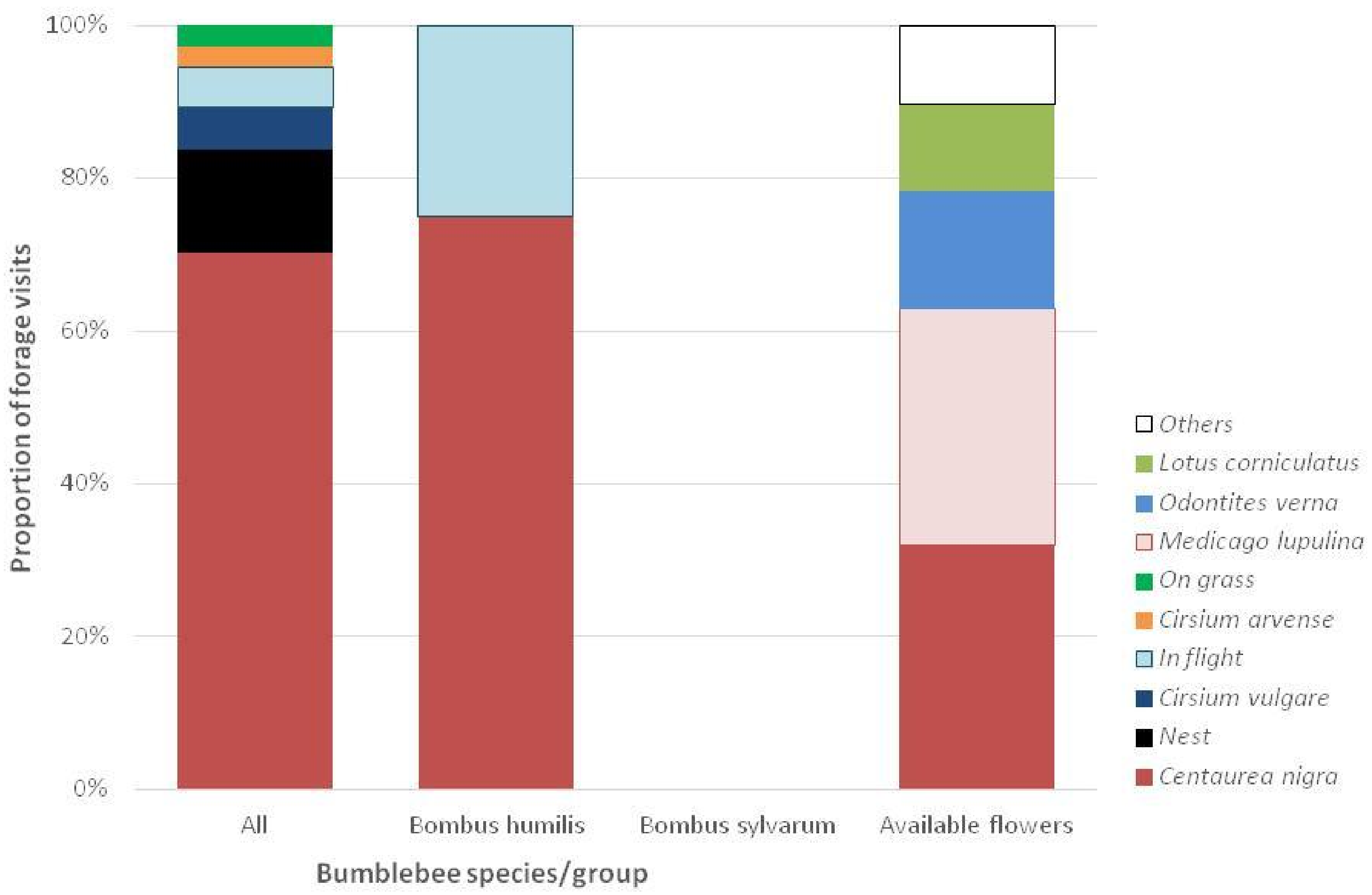

Figure 47. Forage preferences of bumblebees foraging on the natural recolonisation plot of experiment area 5 Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals. Total proportion of available flowers from quadrat survey also presented (*n* = 30).

The forage preferences for bumblebees surveys were also assessed on the other key forage-rich areas of Hadleigh Park. Results are presented in Figures 48 to 51. As no floral quadrat surveys were carried out in these areas, no assessment of the proportion of available flower heads could be included.

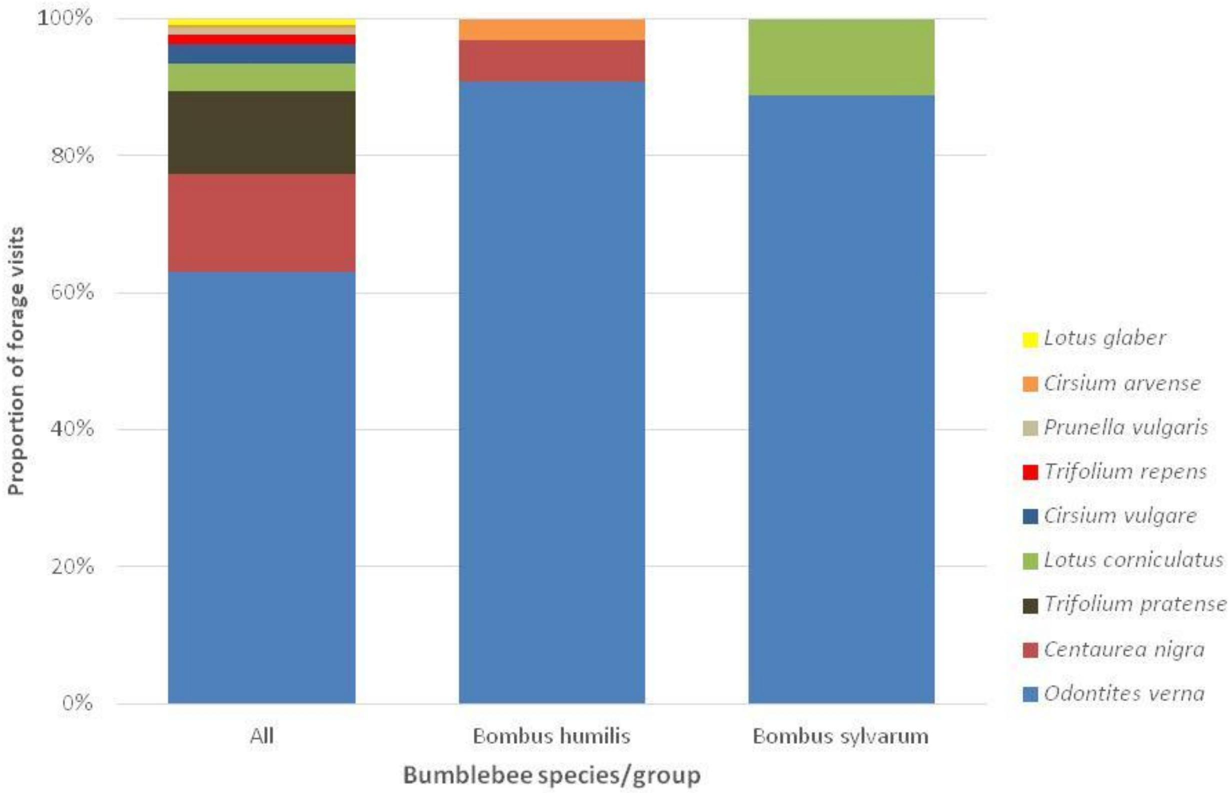

Figure 48. Forage preferences of bumblebees foraging on the key forage area - the Top Field, Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals.

For three of the key forage areas, rear of the marsh, hay cut area and Benfleet Downs, patterns of flower visitation were very similar to those recorded on the experiment areas. Proportions of flower visits by *B. sylvarum* were greater to *Odontites verna* flowers than those by *B. humilis* or visits by all *Bombus* species. The only area where this was not the case was the top field where the proportion of visits by *B. humilis* to *O. verna* flowers was greater than those for *B. sylvarum*. However, very few observations were made for *B. sylvarum* on this area (*n* = 8). Results for *B. humilis* across the forage-rich areas also replicated those recorded on the experiment areas with results similar to those for all *Bombus* species but with a greater proportion of visits to Fabaceae species and *Centaurea nigra*.

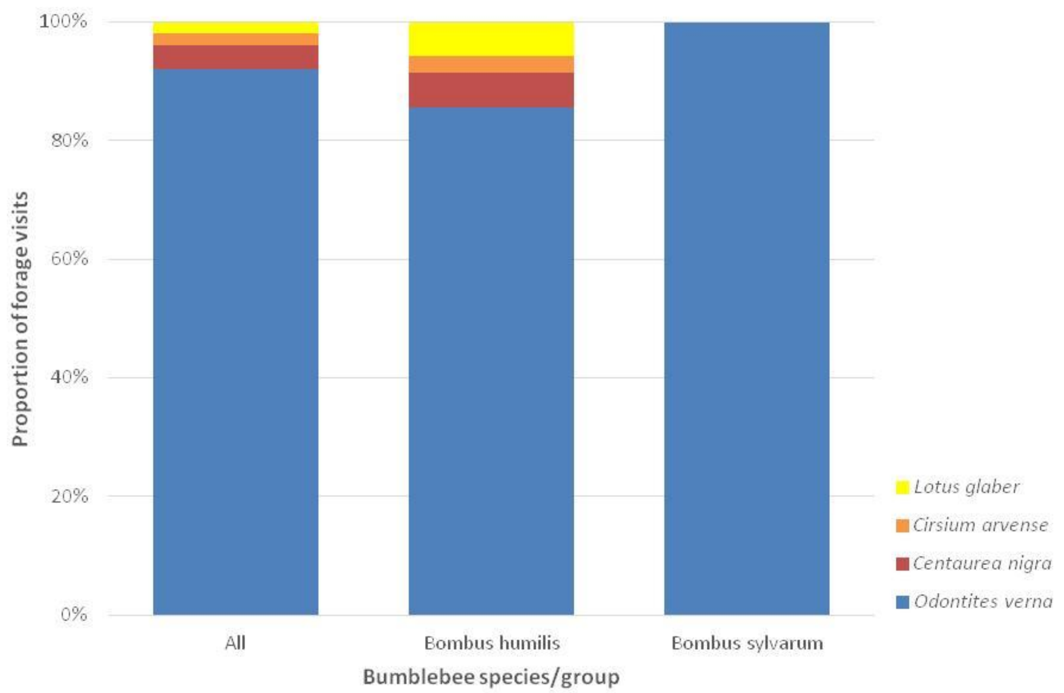

Figure 49. Forage preferences of bumblebees foraging on the key forage area - the Rear of the Marsh, Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals.

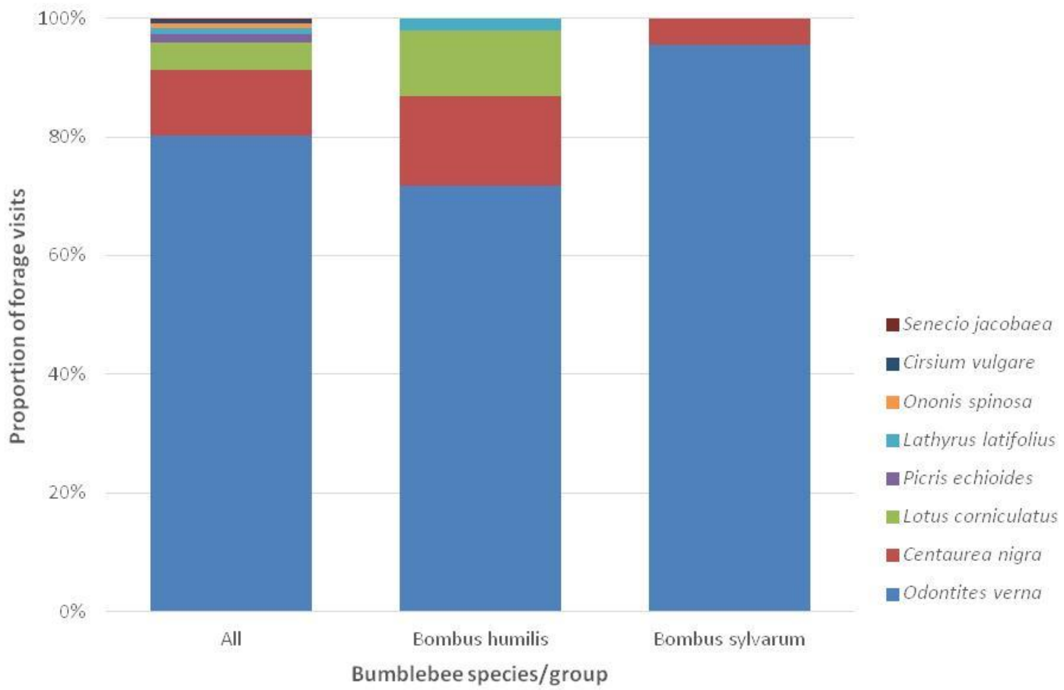

Figure 50. Forage preferences of bumblebees foraging on the key forage area - Benfleet Downs, Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals.

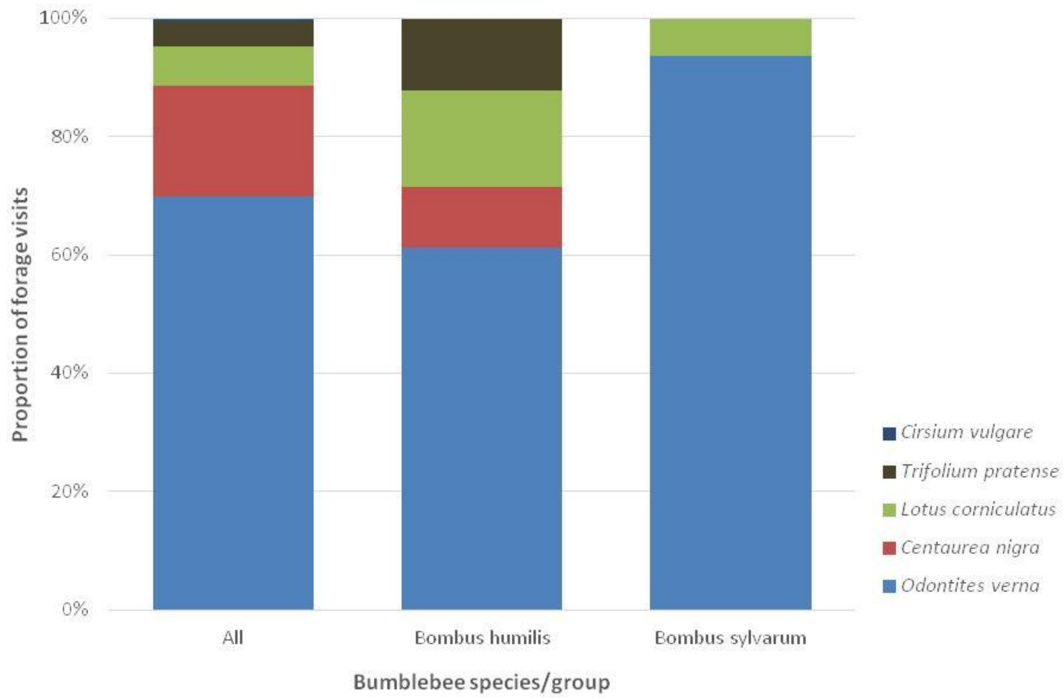

Figure 51. Forage preferences of bumblebees foraging on the key forage area - the Hay Cut area, Hadleigh Park, August 2015. Forage preferences recorded as the flower being visited at the time of observation and displayed as a proportion of total flower visits. Forage visits recorded during ten bee walks of 15 minutes duration each. Forage visits presented for all bumblebee individuals, *Bombus humilis* individuals and *Bombus sylvarum* individuals.

Also of interest from the timed surveys at key forage patches around Hadleigh Park were the results for the area at the rear of the marsh. When the timed surveys were initiated at the park, this area had abundant *Lotus glaber* forage available. *Lotus glaber* is considered to be a key forage species for both *B. sylvarum* and *B. humilis* in their south Essex metapopulation, particularly at the key site of Canvey Wick SSSI. In 2015, very few records of either *B. humilis* or *B. sylvarum* were made to this species and this appeared to be due to a lack of available *Lotus glaber* flowers in the area where they were previously abundant.

4.4 Discussion

Overall, timed bumblebee counts were encouraging. At the time of the last bumblebee counts at Hadleigh Park, numbers of both *B. humilis* and *B. sylvarum* were undergoing a prolonged decline. It was not possible to establish whether this was due the same number of individuals being dispersed over a larger area of available forage or whether the south Essex populations were undergoing declines mirroring both species nationally. Results from the 2015 survey indicated that patterns of decline had reversed for both species and, although not higher than peak historical surveys, numbers across large areas of the parks were encouraging that habitat management at the park was achieving its aims in relation to these target species.

Unlike in previous surveys, there was no substantial difference between the *B. humilis* and *B. sylvarum* counts in the green hay and corresponding natural recolonisation plots. The most likely reason for this was the development of suitable forage on the natural recolonisation plots in relation to the corresponding green hay areas on the intervening years since the original establishment of the trials (2006, 2009 and 2011 respectively). As the natural recolonisation plots were made directly next to the green hay plots, it is impossible to disentangle the effects of transfer of the green hay area seed bank from the green hay plot on the development of the neighbouring natural recolonisation plots. Nevertheless, results indicated that both methods can provide beneficial forage resources supporting substantial numbers of both *B. humilis* and *B. sylvarum*. The key difference appeared to be the timescales over which this can be achieved. Results indicated that green haying could achieve this over short timescales and that it took longer on natural recolonisation plots on neighbouring areas. This creates an ideal mosaic of suitable forage with different key bumblebee forage species dominant on each area. The challenge now is to ensure that this forage resource is maintained in the long-term. Whilst the programme of scrub clearance will achieve this in the short-term, it might be worth considering additional disturbance/scrapes on these plots in the long-term to maintain the mosaic of early-successional habitat that appears to be associated with greatest *O. verna* abundance.

There were some interesting differences between the performance of the different experiment areas. Most apparent of these was the low numbers of both *B. humilis* and *B. sylvarum* on the treatment plots of experiment area 5. This was presumably due to lack of suitable forage on these areas and the presence of grasses as the dominant vegetation as evidenced by the quadrat surveys. There is no obvious reason as to why this difference has occurred as the same green hay source was used and a nearby area of scrub was cleared, but it may have been due to how the green hay was spread, the quality of the green hay the year it was cut, or even related to the substrate/seed bank in the area cleared. Monitoring should be continued on this area over subsequent years to assess how it develops. This should also be expanded to include other areas that are cleared annually and green hayed to attempt to identify a pattern as to why such a stark variation in vegetation development occurred. Nevertheless, this more grass-dominated vegetation adds to the overall mosaic of habitats as evidenced by the observation of *Bombus lapidarius* nesting within this area.

5. Habitat management recommendations

Based on the results of the summer 2015 white-letter hairstreak, green hay vegetation monitoring, and timed-bumblebee count surveys, a series of conclusions can be drawn in relation to legacy habitat management plans:

White-letter hairstreaks:

- White-letter hairstreak individuals appeared to be broadly distributed throughout the park associated with elm stands and neighbouring bramble along rides.
- Continued monitoring of these populations is vital in order to understand how the Hadleigh Park population is faring compared to recently reported national declines (Guardian 2016);
- As initial results demonstrated a broad and variable distribution in the park dependent upon the location and the survey visit, it was not possible to established a hotspot for the species in the park nor a preferred habitat type in terms of maturity of elms and availability of bramble. Now that the monitoring protocol has been established, continuing the surveying in subsequent years may provide more evidence in relation to these aims.
- 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.

Conservation priority bumblebees:

- Green haying and the subsequent late cut management seems to be an effective method for creating suitable forage areas for conservation priority bumblebees at the park;
- The combination of green haying half of the cleared plots and allowing natural recolonisation of the other half was an effective method for creating a mosaic of habitat and successional stages providing suitable forage for *B. humilis* and *B. sylvarum* potentially over longer durations than solely green haying. As such consideration should be given to continuing this method of habitat creation following scrub clearance;
- Results from this monitoring round indicate that green haying and current management levels are effective for providing suitable Fabaceae dominated wildflower areas for generalist bumblebee species and the target conservation priority species *B. humilis* over several years. Current habitat management methods are, however, less effective at securing abundant *Odontites verna* over long periods which appears to be the most frequently visited forage species of *B. sylvarum*.

- Small trials of more intensive cutting/grazing regimes or small scrapes could be established to investigate good practice for providing early successional areas abundant in *Odontites verna* for foraging *B. sylvarum*;
- Early cuts could also be trialled on small patches of some green hayed areas to assess whether forage availability could be extended later in the season to ensure that suitable forage is available throughout the *B. humilis* and *B. sylvarum* life cycle (which can extend to mid/late October) ;
- Further monitoring is necessary to assess the effect on maintaining suitable forage of shifting from a single late cut management to the low-level grazing management that was being introduced in 2015. Of course, heavy grazing/trampling between the months of May and October should be avoided on key forage areas.
- The key forage area of *Lotus glaber* at the rear of the marsh had reduced significantly in terms of value to foraging bumblebees. The majority of *B. humilis* and *B. sylvarum* sightings in this area were on *Odontites verna* along the edges of the path. *Lotus glaber* 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 to assess whether it is possible to re-establish the comprehensive *Lotus glaber* forage that was found here previously.
- Green haying appeared to be a more effective method than natural recolonisation for reducing scrub and grass redevelopment following scrub clearance. Further monitoring is required to establish the effects of this long-term.
- Consideration could be given to introducing new aggregates onto the site to enhance the open mosaic nature of the habitats to provide resources to other invertebrate groups that could benefit from the substantial areas of forage created by the scrub clearance and green haying. UEL PhD student, James McGill, has already initiated this by introducing several 5 tonne sand mounds to rank grassland areas along the marsh. Continued roll out of this over larger areas could create added value to the green haying programme.

6. References

Banaszak, J. (1980) Studies on methods of censusing the number of bees (Hymenoptera, Apoidea). Polish Ecological Studies 6, 355-365.

Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J. and Kunin, W.E. (2006) Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands. Science 313, 351 – 354.

Bowers, M.A. (1985) bumblebee colonization, extinction, and reproduction in subalpine meadows in Northeastern Utah. Ecology 66(3), pp. 914-927.

Butterfly Conservation (2016) White-letter hairstreak fact sheet. Available at: https://butterfly-conservation.org/files/white-letter-hairstreak-psf.pd.

Carvell, C. (2002) Habitat use and conservation of bumblebees (*Bombus* spp.) under different grassland management regimes. Biological Conservation 103, 33-49.

Carvell, C., Meek, W.R., Pywell, R.F. and Nowakowski, M. (2004) The response of foraging bumblebees to successional change in newly created arable field margins. Biological Conservation 118, pp. 327-339.

Connop, S. (2006) Bumblebee forage patch creation experiment at Hadleigh Castle Country Park, September 2006. Report produced for Hadleigh Castle Country Park.

Connop, S. (2007) Hadleigh Castle Country Park bumblebee habitat improvement: Experimental forage plot surveys I. Report produced for Essex County Council.

Connop, S.P. (2008a) PhD Thesis. Submitted to the University of East London.

Connop, S.P. (2008b) Hadleigh Castle Country Park bumblebee habitat improvement: Experimental forage plot surveys II. Commissioned report for Essex County Council.

Connop, S. (2009) Hadleigh Castle Country Park bumblebee habitat improvement: Experimental forage plot surveys III. Report produced for Essex County Council.

Connop, S. (2010) Hadleigh Castle Country Park bumblebee habitat improvement: Experimental forage plot surveys IV. Report produced for Essex County Council.

Connop, S. (2011) Hadleigh Castle Country Park bumblebee habitat improvement: Experimental forage plot surveys V. Report produced for Essex County Council.

Connop, S., Hill, T., Steer, J. and Shaw, P. (2010) The role of dietary breadth in national bumblebee (*Bombus*) declines: simple correlation? Biological Conservation 143 (11), 2739-2746.

Dramstad, W. and Fry, G. (1995) Foraging activity of bumblebees (Bombus) in relation to flower resources on arable land. Agriculture, Ecosystems and Environment 53, pp. 123-135.

Edwards, M. (1998) Annual UK Biodiversity Action Plan Bumblebee Working Group Reports. Unpublished annual report for the UK BAP Bumblebee Working Group, Midhurst, UK.

Edwards, M. and Jenner, M. (2005) Field guide to the bumblebees of Great Britain & Ireland. Ocelli, Eastbourne, UK.

Goodyear, L. and Middleton, A. (2007) Survey Tips - how to find adult White-letter Hairstreaks. Available at http://www.hertsmiddx-butterflies.org.uk/w-album/w-album_tips-adult.php

Guardian (2016) Rare UK butterfly under threat as elms disappear. Article available at: http://www.theguardian.com/environment/2016/jan/11/butterfly-white-letter-hairstreak-elm-trees-disease

Harvey, P.R. (1999) A report on the status of the Shrill carder bee Bombus sylvarum in Essex. Essex Naturalist (New Series) 16, 79-82.

Harvey, P.R. (2000) The East Thames Corridor: a nationally important invertebrate fauna under threat. British Wildlife 12(2), 91-98.

Harvey, P.R. (2015) Hadleigh Park Invertebrate Assemblage Monitoring. Report produced for the University of East London Sustainability Research Institute.

JNCC (2010) Species pages for 2007 UK BAP Priority Species White-letter Hairstreak *Satyrium w-album* (Knoch, 1782). Available at: http://jncc.defra.gov.uk/_speciespages/2586.pdf

Kosior, A., Celary, W., Olejniczak, P., Fijal, J., Krol, W., Solarz, W. and Plonka, P. (2007) The decline of the bumble bees and cuckoo bees (Hymenoptera: Apidae: Bombini) of Western and Central Europe. Oryx 41, 79-88.

Kwak, M.M. (1987) Marking bees without anaesthesia. Bee World 68, 180-181.

Pollard, E., Yates, T.J., (1993) Monitoring butterflies for ecology and conservation. Chapman & Hall, London.

Prŷs-Jones, O.E. and Corbet, S.A. (1987) Bumblebees: Naturalists' Handbooks 6. The Richmond Publishing Co. Ltd, Slough.

Rasmont, P. (1995) How to restore the apoid diversity in Belgium and France? Wrong ways and right ways, or the end of a projection paradigm!. In: Banaszak, J. (ed) Changes in fauna of wild bees in Europe. Pedagogical University, Bydoszcz, pp 53-64.

Saville, N.M., Dramstad, W.E., Fry, G.L.A. and Corbet, S.A. (1997) Bumblebee movement in a fragmented landscape. Agriculture, Ecosystems and Environment 61, 145-154.

Stace, C. (2010) Field Flora of the British Isles. Cambridge University Press, Cambridge, UK.

Trueman, I. and Millet, P. (2003) Creating wildflower meadows by strewing green hay. British Wildlife 15(1) pp. 37-44.

Williams, P.H. (1982) The distribution and decline of British bumble bees (*Bombus* Latr.). Journal of Apicultural Research 21, 236-245.

Williams, P.H. and Osborne, J.L. (2009) Bumblebee vulnerability and conservation world-wide. Apidologie 40, 367-387.

Appendix 1 - Images of Hadleigh Park white-letter hairstreak observation points

Figure 52. White-letter hairstreak observation point 1, Hadleigh Park.

Figure 53. White-letter hairstreak observation point 2, Hadleigh Park.

Figure 54. White-letter hairstreak observation point 3, Hadleigh Park.

Figure 55. White-letter hairstreak observation point 4, Hadleigh Park.

Figure 56. White-letter hairstreak observation point 5, Hadleigh Park.

Figure 57. White-letter hairstreak observation point 6, Hadleigh Park.

Figure 58. White-letter hairstreak observation point 7, Hadleigh Park.

Figure 59. White-letter hairstreak observation point 8, Hadleigh Park.

Figure 60. White-letter hairstreak observation point 9, Hadleigh Park.

Figure 61. White-letter hairstreak observation point 10, Hadleigh Park.

Figure 62. White-letter hairstreak observation point 11, Hadleigh Park.

Figure 63. White-letter hairstreak observation point 12, Hadleigh Park.

Figure 64. White-letter hairstreak observation point 13, Hadleigh Park.

Figure 65. White-letter hairstreak observation point 14, Hadleigh Park.

Figure 66. White-letter hairstreak observation point 15, Hadleigh Park.

Figure 67. White-letter hairstreak observation point 16, Hadleigh Park.

Figure 68. White-letter hairstreak observation point 17, Hadleigh Park.