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The ground beetles (Carabidae) of Priory Water NR, Leicestershire

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Chlaenius nigricornis

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Introduction

Ground beetles (Carabidae) have been widely used for ecological studies and are the subject of numerous publications. The family forms a well-defined taxonomic group that can be easily recognized on the basis of a combination of anatomical features that include a characteristic body shape, eleven-segmented filiform (thread-like) antennae and five-segmented tarsi on all pairs of legs. Ground beetles are often uniformly dark in colour, although some species, especially those that are day-active, are more brightly coloured and variously patterned. Identification keys to British species of Carabidae have been available for many years (for example; Joy; 1932; Lindroth, 1974) and the taxonomy has been extensively revised in a recently published key by Luff (2007). Additional aids to identification can be found on-line (e.g. http://markgtelfer.co.uk/beetles).

Ground beetles are very active, fast running beetles and many species are predators of smaller invertebrates. Their study has benefitted from the use of pitfall traps (see below in methods) although the technique has to be used with an awareness of the bias that may be present in the data obtained (Greenslade, 1964). Research into the carabid communities of different habitats (e.g. Pollard, 1968), the population ecology of particular species (e.g. Penney, 1969), their role in the biological control of pests in agricultural situations (e.g. Collins *et al,* 2002), as indicators of conservation potential (e.g. Butterfield *et al,* 1995) and many other studies have all been carried out with the aid of pitfall traps. There are 350 species of Carabidae in Britain and Ireland (Luff, 2007), a number sufficient to exhibit a wide range of ecological strategies but not so numerous as to be taxonomically overwhelming. It is, perhaps, for this reason as well as those mentioned above (ease of trapping, available keys etc) that these beetles have been so well researched.

Our knowledge of the ground beetles of Leicestershire and Rutland (VC55) has been greatly enhanced by the publication of '*A Provisional Atlas of the Carabidae of Leicestershire and Rutland*' (Lott *et al,* 2011). The Atlas brings together records collected over many years from naturalists working in the 19th century, such as Frederick Bates and his older brother Henry Walter Bates, to those of more recent recorders, especially Derek Lott. The Atlas describes the distribution of 175 species – exactly half of the Britain and Ireland total. As well as maps showing the distribution of individual species, the Atlas also provides lists of species for different sites (Gazetteer), the length of which must be a function of both habitat quality and the intensity of recording. The lower section of the River Soar has been thoroughly sampled by Derek Lott and others with a list of 95 species (Lott, 2009) while Bradgate Park, one of the best-worked sites in the county, has a species list of 93. Saddington Reservoir has been designated a Site of Special Scientific Interest (SSSI) primarily because of the presence of rare ground beetles (among a species list of 43) and rove beetles (Staphylinidae). Other VC55 sites with extensive lists of ground beetles include Buddon Wood (72 species), Lockington Marshes SSSI (63 species), Loughborough Big Meadow (77 species) and Rutland Water Nature Reserve (71 species). The Atlas has only three species recorded for Priory Water, the subject of this paper.

Priory Water NR consists of a complex of lakes of various sizes in abandoned gravel pits, separated by woodland and grassland habitats, in the flood plain of the River Wreake near Kirby Bellars (Melton Mowbray district of Leicestershire, SK7118). The pits were acquired by the Leicestershire Wildfowlers' Association in 1987 and managed by them as a reserve, principally to conserve wildfowl. The reserve covers an area of 81 hectares of which 32 are open water. For further information see the Priory Water Wildfowl Project handbook (Shelton, 2007). The aims of the present study were to record the ground beetles present in the different habitats at Priory Water, compare different sampling methods, investigate the effects of grazing on species richness and compare seasonal activity patterns in relation to habitat. We also examine the possibility of predicting the number of additional species that would be recorded by further sampling and suggest a simple method of selecting sites that would repay further sampling following an initial survey.

Materials and Methods

Site descriptions
The sites sampled by pitfall trapping, described below, were chosen to cover the range of terrestrial habitats present at Priory Water. Dates refer to sampling period.

(a) **Water's Edge, East Finger Lake (WE-EFL)** (SK717187) (26/03/2010–29/03/2012).
At this site the lake margin shelved gradually to the lake. The vegetation comprised Common Reed (*Phragmites australis*), Tufted Hair Grass (*Deschampsia cespitosa*), Crested Dog's-tail (*Cynosurus cristatus*), Yorkshire Fog (*Holcus lanatus*), Cocksfoot (*Dactylis glomerata*), Hard-rush (*Juncus inflexus*), Ribwort Plantain *(Plantago lanceolata*), Selfheal *(Prunella vulgaris*), Bird's-foot Trefoil (*Lotus corniculatus*), Sallow (*Salix caprea*), Osier (*Salix viminalis*) and Alder (*Alnus glutinosa*).

(b) **Water's Edge, Main Lake (A) (WE-MLA)** (SK716186) (26/03/2010–29/03/2012).
Here the bank margin was narrow and shelved into the lake more steeply than the other water edge sites. The vegetation comprised Sweet Reed-grass (*Glyceria maxima*) which was dominant, *P. australis*, Purple Loostrife (*Lythrum salicaria*), Water Figwort (*Scrophularia auriculata*), Nettle (*Urtica dioica*), *S. viminalis*, *S. caprea*, *A. glutinosa* and Hawthorn (*Crataegus monogyna*).

(c) **Water's Edge, Main Lake (B) (WE-MLB)** (SK717187) (05/04/2012–04/05/2013).
At this site the margin shelved gradually to the lake. The vegetation comprised *P. australis* (dominant), *D. cespitosa*, Bulrush (*Typha latifolia*), *J. inflexus*, Meadowsweet (*Filipendula ulmaria*), Marsh Woundwort (*Stachys palustris*), Teasel (*Dipsacus fullonum*), Ragwort (*Senecio jacobaea*), Great Willow-herb (*Epilobium hirsutum*) and Purple Loostrife (*Lythrum salicaria*).

(d) **Isthmus** (SK716186) (29/06/2012–04/04/2013).
A shingle and mud bar exposed by a fall in the Main Lake level during the summer of 2011. The bar was approximately 3m and ran from near the Water's Edge ML (B) site, across a corner of the lake, to the south bank.

(e) **River Wreake** (SK718188) (-May 2013).
A strip of bank close to the water level of a slow flowing section of the river. Abundant plants were *Glyceria maxima, Phalaris arundinacea* (Reed Canary-grass), *U. dioica* and Indian Balsam (*Impatiens glandulifera*).

(f) **Meadow** (SK717187) (26/03/2010–29/03/2012).
A grassland planted in March 2002 between the Main Lake and East Finger Lake. The vegetation included *D. glomerata*, False Oat-grass (*Arrhenatherum elatius*), Field Scabious (*Knautia arvensis*), Creeping Thistle (*Cirsium arvense*), Dock (*Rumex crispus*), Cow parsley (*Anthriscus sylvestris*), Ground Ivy (*Glechoma hederacea*), *L. corniculatus*, Creeping Buttercup (*Ranunculus repens*), Cowslip (*Primula veris*) and Yarrow (*Achillea millefolium*).

(g) **East Wood** (SK716187) (26/03/2010–29/03/2012).
An area of woodland that, like the other woods described below, was planted in the early 1990s. The field layer was dominated by Meadow Grass (*Poa* spp,) *A. sylvestris*, and *U. dioca*, with occasional *R. crispus*, Common Male Fern (*Dryopteris felix-mas*) and Cleavers (*Galium aparine*). There was a limited shrub layer of *C. monogyna* and Elder (*Sambucus nigra*) beneath a mixed canopy layer of *A. gutinosa*, Ash (*Fraxinus excelsior*), Cherry (*Prunus avium*), Field maple (*Acer campestre*), Oak (*Quercus robur*) and Sycamore (*Acer pseudoplatanus*).

(h) **West Wood** (SK712186) (05/04/2012–04/05/2013).
A woodland of mainly broad-leaf trees, including Silver Birch (*Betula pendula*), *A. glutinosa*, *F. excelsior*, *A. pseudoplatanus*, *Q. robur* and, Horse Chestnut (*Aesculus hippocastanum*). The field layer included Wood Avens (*Geum urbanum*), *A. sylvesris*, Hog Weed (*Heracleum sphondylium*), Wild Garlic (*Allium ursinum*), *U. dioica*, Garlic Mustard (*Alliaria petiolata*).

(i) **Rotary Triangle** (SK709185) (30/08/2012–04/05/2013).
A small area of woodland, at the western edge of the reserve with a mixture of young trees including *F. excelsior*, *A. glutinosa*, *P. avium* and *A. psuedoplatanus* with a scattered shrub layer of Dogwood (*Cornus sanguinea*) and Snowberry (*Symphoricarpos albus*) and a sparse field layer of *H. spondylium*, Ivy (*Hedera helix*) and Dock (*Rumex* spp).

(j) **Car Park** (SK712183) (29/09/2011–29/03/2012).
The car park was a small area of compacted granite chippings with a low, patchy, growth of various plants including Yarrow (*Achillea millefolium*), Ribwort Plantain (*Plantago lanceolata*) and grasses. It was bordered on one side by buildings and on the others by mown grassland and scrub vegetation including Wild Privet (*Ligustrum vulgare*) and Dog-rose (*Rosa canina*).

Sampling methods

Pitfall traps
Pitfall trapping is a widespread method used for trapping surface-active arthropods especially Carabidae and Araneae. Pitfall traps can be traced back to Barber (1931) who used the method for trapping cavernicolous (cave-living) insects. They are still sometimes referred to as "Barber traps".

In this study, pitfall trapping took place over a seven day period in each month (except for December 2011), usually in the third week, from March 2010 to May 2013. Five traps were set approximately 1m apart in a line in each habitat. The traps used in this study consisted of 2 parts; a piece of plastic piping, internal diameter 65mm and length 100mm, that lined the hole dug for the trap and the pitfall trap itself, a plastic pot with a rim 65 mm in diameter, base 55mm and length 70mm, that rested inside the piping with the rim level with the ground surface. The pitfall trap was removed at the end of each trapping week and a lid was placed over the pipe to prevent captures during intervening periods. The outer pipe prevented soil collapsing into the hole and so removed the need to excavate new holes at the start of each trapping period.

The pitfall traps were filled with approximately 30mL of a mixture of 25% ethanediol (antifreeze) with water and a few drops of detergent. This solution kills and preserves invertebrates falling in to the trap while the detergent ensures they sink rather than crawl out. A wire mesh cover, with a grid of 2cm, was pinned over the traps to prevent the capture of small mammals and aluminium covers or ceramic tiles supported on pegs formed a roof to prevent the traps filling with rainwater. The contents of each trap from a site were emptied into one container and then sorted over a white tray for carabids at a later date.

Hand searching tussocks
Grass tussocks were searched for carabids in both grazed and ungrazed grassland within the reserve. Two areas were sampled, one near East Finger Lake (SK 716188) and the second to the west of West Wood (SK 711186). In each area, samples were taken on either side of a fence, which separated the grazed flood plain of the River Wreake from what can be referred to as the 'natural' reserve. The vegetation at the first site on the 'natural' side of the fence included *D. cespitosa*, *D. glomerata*, Creeping Cinquefoil (*Potentilla reptans*), *D. fallonum* and *R. crispus*. On the other side a small cluster of *D. cespitosa* tussocks grew in

heavily grazed grassland. In the second site the vegetation on the 'natural' side of the fence (named Tussock Grassland – see below) included *D. cespitosa, D.glomerata*, *A. elatius*, *C. arvense* and Hemlock (*Conium maculatum*) while on the other side a more extensive area of tussocks than at the East Finger Lake site grew in heavily grazed grassland. An equal number of *D. cespitosa* tussocks, were examined for carabids on either side of the fence in the two sites by cutting a 10cm x 10cm core out of the centre of the tussock with a hand saw. The samples were torn apart over a white tray and all carabids were collected in a pooter or by hand and preserved in specimen tubes with 75% industrial methylated spirits. Each of the grassland sites was sampled on two occasions; East Finger Lake in January and March 2011 and the West Wood site in January and February 2013.

Pitfall traps were set in Tussock Grassland for a brief period of continuous trapping (28/04/2013–30/05/2013) and emptied every week in an attempt to determine which of the species recorded in tussocks were susceptible to capture in pitfall traps.

Band Shelters (28/04/2011–04/05/2011)
Band shelters, comprising a 37cm wide strip of corrugated cardboard, were wrapped around the trunks of trees and tied in place with string, so as to form a continuous band approximately 1.5m above ground level. The cardboard acted as a shelter for arboreal species of carabid as well as other invertebrates. The shelters were left in place for seven days and at the end of this period the cardboard was pinned at one end with drawing pins, the string was cut and the band carefully unwound. Carabids that fell during this process were collected in a plastic cup held beneath the roll of cardboard as it was wound away from the trunk. Those that stayed in place were collected with a pooter or specimen tube. Sampling was confined to East Wood, where shelters were attached to *F. excelsior*, *A. campestre* and *A. glutinosa*.

Data analysis and identification
Cluster analysis was performed in Minitab and predictions of additional species that would be found by repeating sampling were calculated using SPADE (Species Prediction and Diversity Estimation (Chao & Shen, 2010; download at (http://chao.stat.nthu.edu.tw). Correlation and regression analyses were carried out using online software (http://www.wessa.net/slr.wasp). All carabids collected were identified to species, with the aid of a dissecting microscope, using the keys by Luff (2007) and Lindroth (1974). Voucher specimens of all species recorded were carded and kept for reference in a store box. Plant identification and nomenclature followed Stace (2001).

Results

First two years pitfall trapping
During the first two years of pitfall trap sampling (26/03/2010-29/03/2012) 46 species were recorded from four sites (Meadow, East Wood, WE-EFL and WE-MLA). A summary of the results is given in Table 1 and species abundance graphs for each site are given in Figure 1.

The species richness was highest in the WE-MLA and WE-EFL sites with 23 and 24 species respectively. The dominant species were different at these two sites with *Agonum emarginatum* dominating WE-EFL and *Pterostichus nigrita* WE-MLA. Both sites had these two species in common as well as less abundant species associated with damp ground such as *Oxypsephalus obscurus* and *Agonum fuliginosum*. Three local species in VC55, *Chlaenius nigricornis, C. vestitus* and *Bembidion fumigatum* were recorded from WE-MLA. *C. nigricornis* and *B. fumigatum* are designated Nationally Notable B (Hyman & Parsons, 1992).

The East Wood and Meadow sites were less species rich, with 16 and 18 species respectively, but distinctly different to the marsh sites as well as to each other. *Nebria brevicollis* dominated East Wood with *Pterostichus madidus* and *Pterostichus melanarius* also abundant. *Pterostichus strenuus* dominated the Meadow with *Badister bullatus* and *Stomis pumicatus*

relatively abundant. *Pterostichus macer*, a local and generally scarce species that lives partly below ground in soil crevices (Luff, 2007) was recorded in low numbers in Meadow and once in East Wood.

Table 1: Species found in the first two years of pitfall trapping at four sites

Species	East Wood	WE-MLA	Meadow	WE-EFL
Acupalpus dubius		2		
Agonum emarginatum		5		29
Agonum fuliginosum		9		1
Agonum thoreyi		2		1
Agonum viduum				1
Amara communis		2		1
Badister bullatus			7	
Bembidion aeneum			1	1
Bembidion assimile		2		
Bembidion biguttatum		2	1	1
Bembidion fumigatum		1		
Bembidion guttula	2	10	5	11
Bembidion lampros			1	3
Bembidion lunulatum			1	4
Bembidion mannerheimii				5
Bembidion obtusum			2	
Calathus rotundicollis	1			
Carabus nemoralis	2			
Chlaenius nigricornis		1		
Chlaenius vestitus		2		
Clivina fossor	1		5	3
Curtonotus aulicus			1	
Elaphrus cupreus		7		
Leistus ferrugineus		1		1
Leistus fulvibarbis	2			
Loricera pilicornis	5	6	1	
Nebria brevicollis	187	4		
Notiophilus biguttatus	7			
Ocys harpaloides				1
Oxypsephalus obscurus		14	1	14
Paranchus albipes			1	
Patrobus atrorufus				1
Poecilus cupreus		1	1	
Pterostichus diligens				2
Pterostichus macer	1		4	
Pterostichus madidus	71	12		
Pterostichus melanarius	53		3	3
Pterostichus minor		7		1
Pterostichus niger	1			5
Pterostichus nigrita		50		8
Pterostichus strenuus		14	19	11
Stenolophus mixtus		1	7	1
Stomis pumicatus	2		6	
Trechus obtusus	7	1		
Trechus secalis	1			
Trichocellus placidus				1

Species accumulation curves are given for each site in Figure 2. The graphs all show a roughly similar pattern of an initial rapid increase in the number of species found in the first spring/summer followed by a decline in autumn/winter. This was followed by a smaller increase in the second spring/summer with flattening off into a second plateau later in the second year. Although the pattern of species accumulation suggests that very few new species would have been found if sampling had continued into a third spring and summer, it is likely that new species would have been recorded.

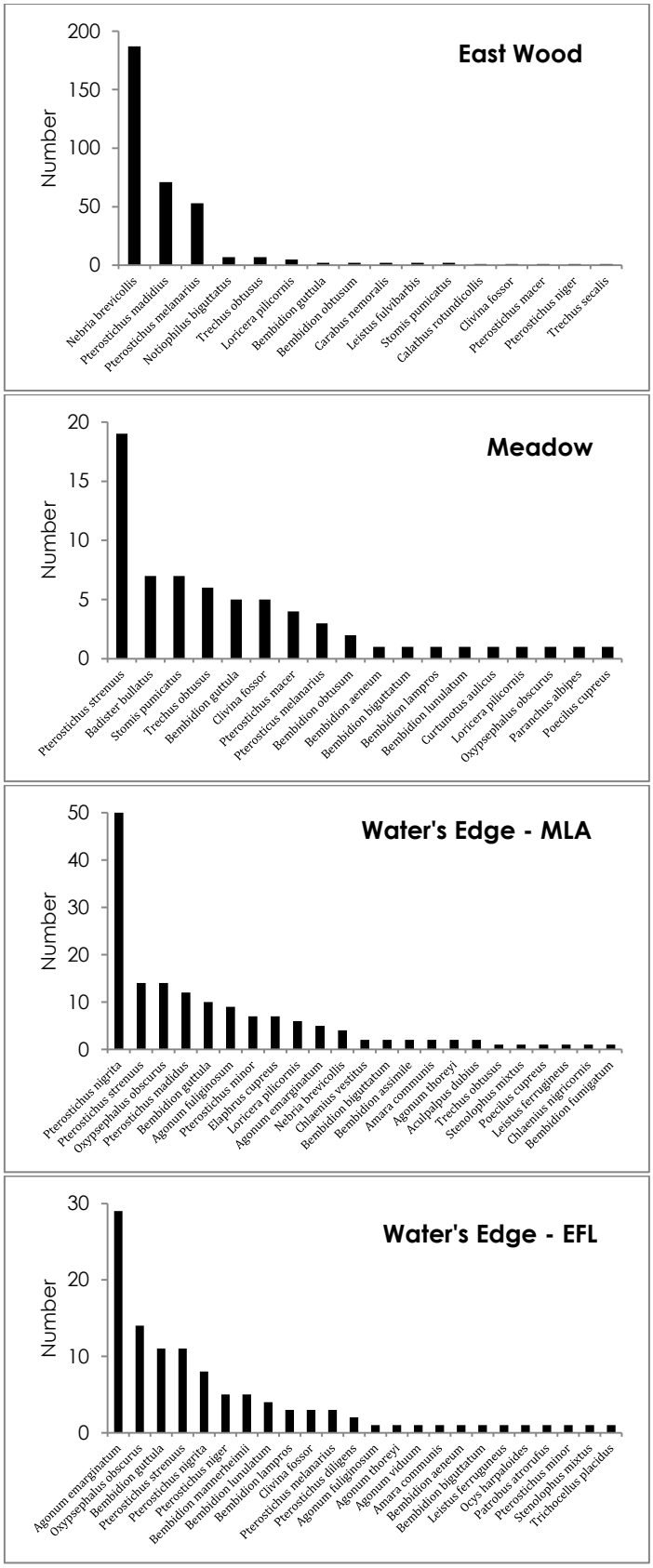

Figure 1: Species relative abundance from pitfall trap sampling over a two-year period (26/03/10-29/03/2012)

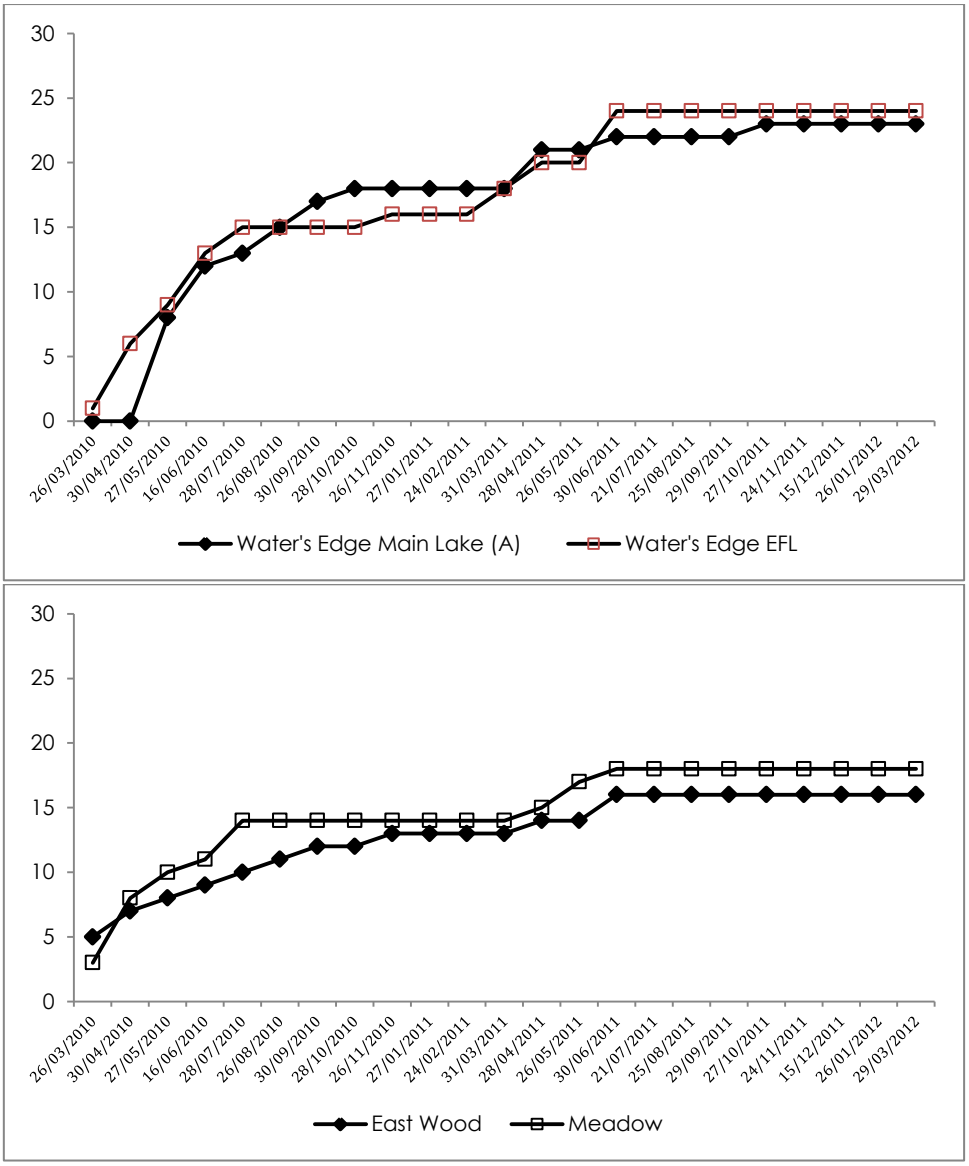

Figure 2: Species accumulation curves for the four sites sampled over a two-year period

A more exact analysis of the problem of predicting how many species might be recorded by further sampling, based on what has already been found, was carried out using the program SPADE (Species Prediction and Diversity Estimation; Chao & Shen, 2010). The program provides a range of different analyses and the one chosen for this study uses the data on species frequency obtained for a site to estimate the number of species that would be found by repeating the sampling procedure; in this case, for another two years. Table 2 provides a summary of the results for each of the four sites sampled in the first two years and for the sites combined based on Chao & Shen (2004) who used a model based on the Poisson distribution for species prediction.

The SPADE predictions in Table 2 appear to be closely related to the number of species found only once (singletons in Table 2). This relationship is developed further in the next section where data for seven additional sites sampled are presented. For the four 2-year sites combined, the prediction is that seven new species would be found by repeating the sampling procedure.

Table 2: The predicted number of new species that would be found by repeating the two-year sampling procedure
(Chao & Shen, 2004, 2010)

Site	Number of species found	Predicted number of new species	95% confidence limits	Singletons
East Wood	16	3.2	0.0 - 6.6	5
Meadow	18	8.2	1.1 – 11.0	9
Water's Edge, East Finger lake	24	10.4	2.9 – 14.6	12
Water's Edge, Main lake (A)	23	3.8	0.1 – 7.1	6
All above sites combined	47	7	2.3 – 11.7	

Table 3: Results of pitfall trapping in the third year of sampling*

Species	WE- ML(B)	Isthmus	Rotary Triangle Wood	West Wood	Car Park	River Wreake	Tussock Grassland
Acupalpus dubius	8						
Agonum emarginatum	29	1				2	
Agonum fuliginosum	11	20					
Agonum marginatum						2	
Amara aenea							2
Amara lunicollis							3
Bembidion aeneum							1
Bembidion assimile		1					
Bembidion biguttatum	31	2		1		1	
Bembidion guttula	1					1	
Bembidion lunulatum						1	
Bembidion obtusum						1	
Bembidion tetracolum					1	1	
Calathus fuscipes							
Calathus rotundicollis			8				
Carabus nemoralis							1
Clivina fossor	5						
Elaphrus cupreus	5	1					
Elaphrus riparius		1					
Leistus ferrugineus				2			
Leistus fulvibarbis				1			
Leistus rufomarginatus			3				
Leistus spinibarbis			3	1	6		
Loricera pilicornis	5		1			5	
Nebria brevicollis	2		65	29	5		2
Nebria salina					2		
Notiophilus biguttatus			4				
Ophonus rufibarbis				5			
Oxypsephalus obscurus	1				1		
Paranchus albipes						11	
Patrobus atrorufus	1						
Poecilus cupreus	1					1	7
Pterostichus gracilis	1						
Pterostichus macer	1			4			1
Pterostichus madidus			14		2		
Pterostichus melanarius	1			42			1
Pterostichus minor	8	2					
Pterostichus niger							3
Pterostichus nigrita	20	7		1		34	
Pterostichus strenuus	15	1				1	2
Pterostichus vernalis	1						4
Trechus obtusus			1	8			
Trichocellus placidus	1						

*The listed habitats were sampled during the following periods: WE-MLB and East Wood, 05/04/2012–04/05/2013; Rotary Triangle, 30/08/2012-04/05/2013; Isthmus, 29/06/2012-04/04/2013; River Wreake, 14/04/2013–28/04/2013 (within which there were two one week sampling periods); Tussock Grassland,28/04/2013-30/05/2013; Car Park, 29/09/2011-29/03/12.

Third year of pitfall trapping

A number of habitats within the reserve were sampled by pitfall trapping, for varying lengths of time, mainly during the third year of the study. Most of the new habitats were variations on the theme of the first two years sampling (woods, grassland and marsh), the only exception being the Car Park which was unlike any of those previously trapped. This site is included here, although sampled earlier than the others in this section.

The sampling of these additional sites added 12 new species to the list for the reserve (Table 3), the most notable being *Pterostichus gracilis*, a Nationally Notable B species and recorded in only seven other sites in VC55 (Lott *et al,* 2011). The sampling period for the majority of the sites was fairly brief and in some (Isthmus and River Wreake especially) sampling was cut short by flooding. SPADE predictions were calculated for all sites (Table 4) but only the data from the WE-MLB and West Wood sites, both of which were sampled for just over a year, are presented in full (Figures 3 & 4).

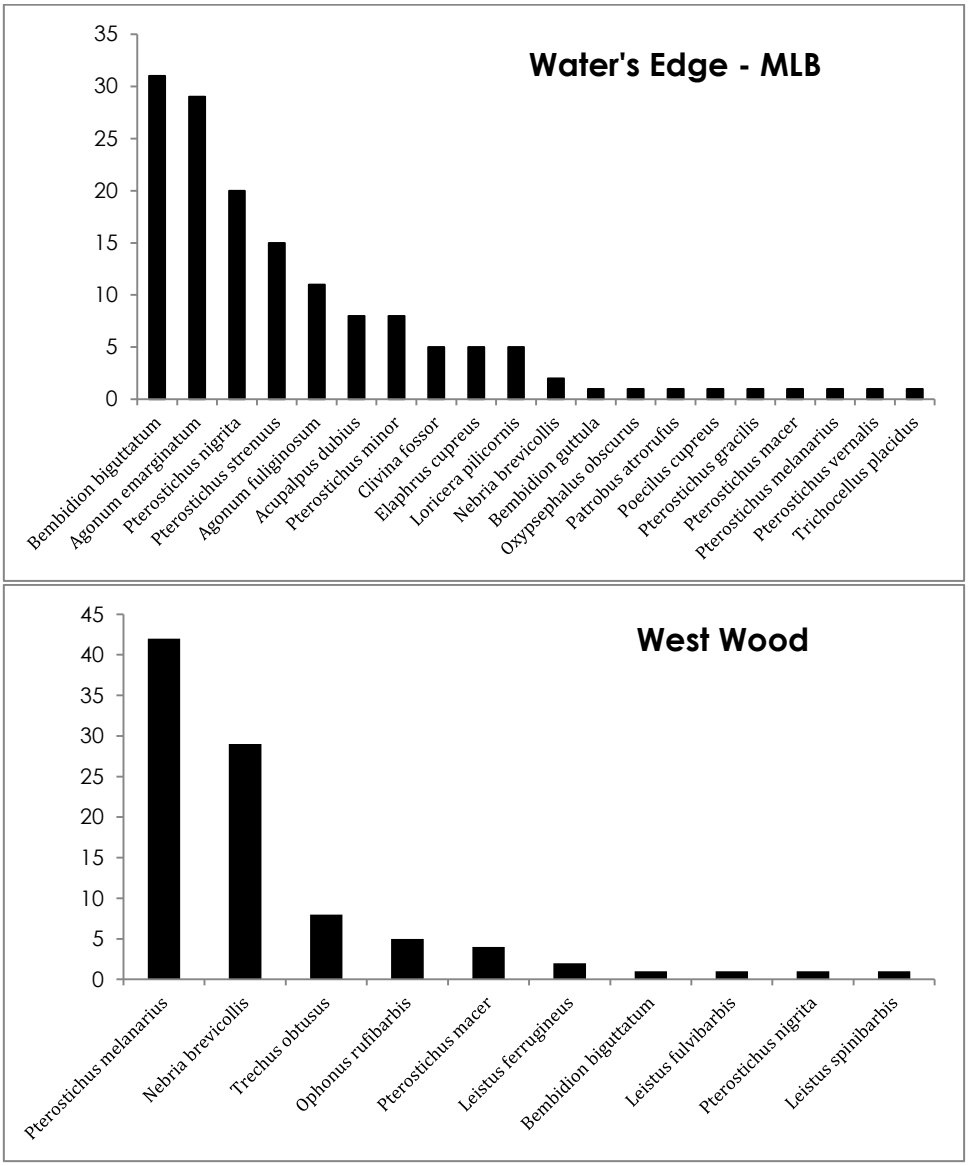

Figure 3: Species relative abundance in habitats sampled over a 13-month period

The WE-MLB and West Wood sites had a number of species in common with equivalent sites sampled in the first two years, as well as species previously unrecorded, including *P. gracilis* in the former and *Ophonus rufibarbis* in the latter. Overall, the three lake edge sites (WE-MLA,

WE-MLB and WE-EFL) shared two of their five most abundant species (*P. nigrita* and *P. strenuus*) and eight species in total. The two woodland sites (East Wood and West Wood) shared three of their five most common species (*N. brevicollis*, *P. melanarius* and *Trechus obtusus*) and five species in total. These similarities are reflected in the cluster analysis illustrated in the next section. Other sites sampled for shorter periods had their own unique characteristics as well as having species in common with similar habitats. The Rotary Triangle sample was dominated by *N. brevicollis* and *P. madidus* but also included a new woodland species, *Leistus rufimarginatus*. The River Wreake sample was dominated by *P. nigrita* but had relatively large numbers of *Paranchus albipes*, previously recorded only once in the Meadow. The sparsely vegetated Car Park was the only site for *Nebria salina*.

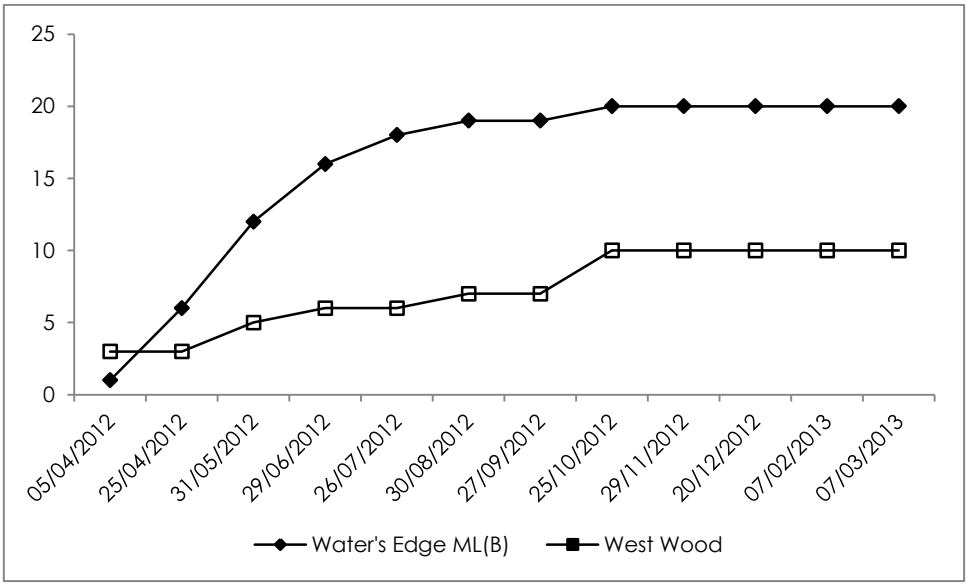

Figure 4: Species accumulation curves for two sites sampled over a 13-month period

The SPADE predictions for the third year sites are shown in Table 4. During the three-year sampling programme 58 species were recorded by pitfall trapping and the overall SPADE prediction for all 11 sites sampled (see Tables 2 & 4) is that 6-7 more species would be found by repeating all sampling procedures. There was a very significant correlation between SPADE predictions and singletons for the 11 sites ($r = 0.9842$, $P<0.001$), a relationship that is further demonstrated by the best-fit regression (Figure 5). There was also a weaker, but significant correlation ($r = 0.675$, $P<0.01$) between SPADE predictions and the number of species found. The value of these predictions for pitfall trap samples is assessed in the discussion.

Table 4: The predicted number of new species that would be found by repeating the sampling procedure for all the third year sites and for all sites sampled by pitfall trapping during the three year study (Chao & Shen, 2004, 2010).

Site	Number of species found	Predicted number of new species	95% confidence limits	Singletons
Water's Edge ML (B)	20	8.2	1.5 – 11.9	9
West Wood	10	3.3	0.0 – 6.0	4
Isthmus	9	3.8	0.1 – 7.5	5
Rotary Triangle Wood	8	0	0.0 – 0.0	2
Car Park	6	1.3	0.0 – 3.2	2
River Wreake	13	6.6	1.6 – 11.5	8
Tussock Grassland	11	3.8	0.2 – 7.4	5
All sites sampled by pitfall tapping during the study	58	6.5	1.8 - 11.1	

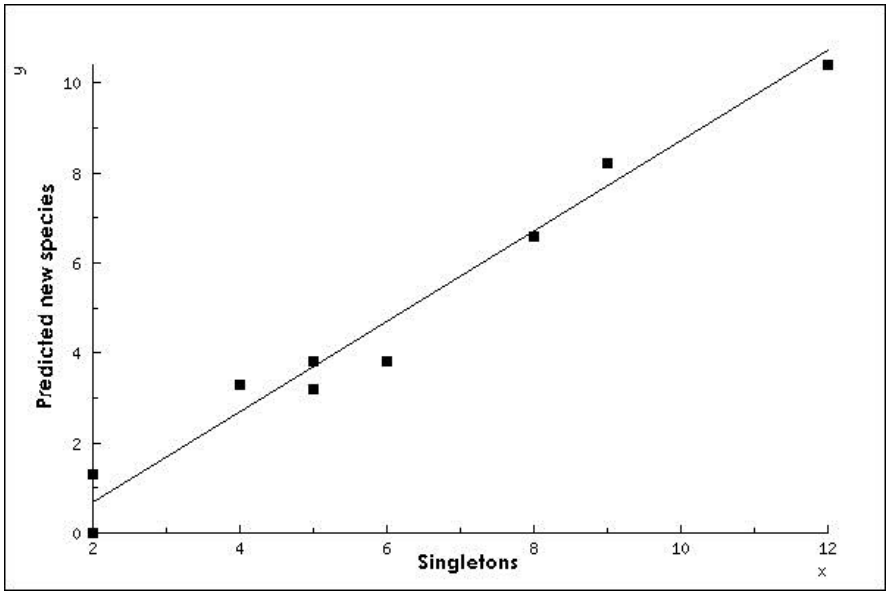

Figure 5: Relationship between predicted new species from repeat sampling (SPADE) and singletons for 11 sites
(Y = -1.341 + 1.005X; SE = 0.058; t = 17.47; P<0.001)

Cluster analysis

A cluster analysis was carried out on the four sites sampled for two years and the two sites sampled for 13 months. Other sites were not included because of the likely bias of shorter sampling periods. The analysis shows a reasonable separation of habitats based on the carabid species recorded by pitfall trapping. The lake edges and the woods form two fairly distinct groups while the grassland is an outlier tending towards the lake edge group (Figure 6).

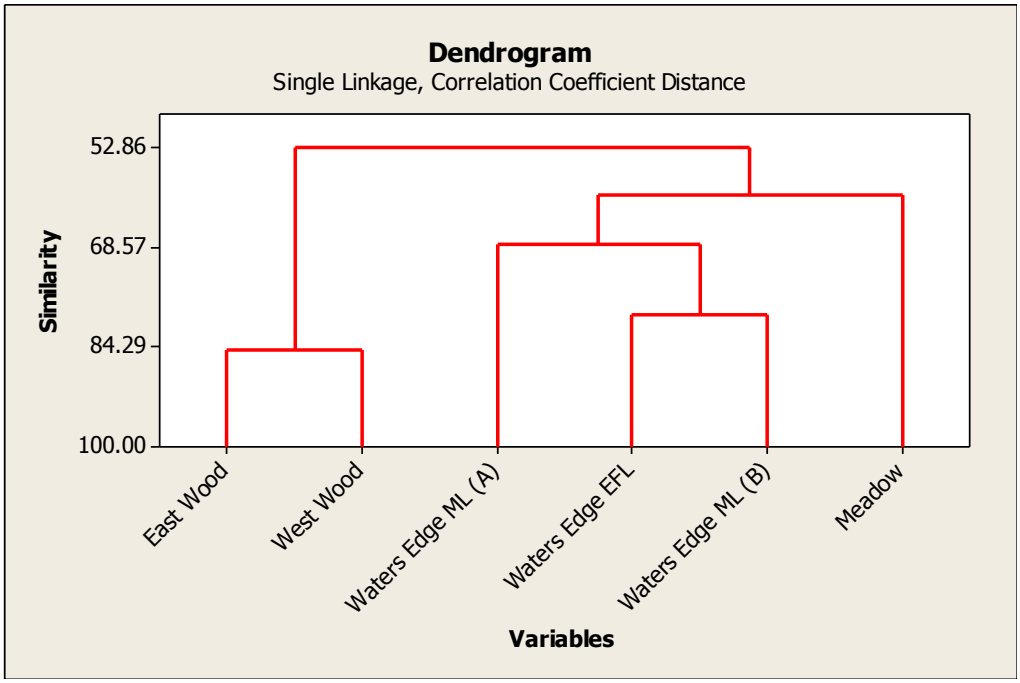

Figure 6: Cluster analysis of the four sites sampled for two years and the two sites sampled for 13 months

Tussock sampling

The results of tussock sampling in the East Finger Lake and West Wood grasslands are shown in Tables 5 & 6. The carabid fauna of *D. cespitosa* tussocks consisted of species also recorded by pitfall trapping, especially in the grassland and water's edge sites, as well as species found only in tussocks. With the exception of *Poecilus cupreus*, larger species of ground beetle were noticeably absent.

Table 5: Tussock sampling in East Finger Lake grasslands in 2011*

Species	January		March	
	Ungrazed	Grazed	Ungrazed	Grazed
Agonum emarginatum	3		2	
Agonum fuliginosum	3		2	
Amara communis			6	
Amara familiaris	1			
Amara lunicollis	1		3	
Amara similata			1	
Bembidion guttula	8			
Bembidion obtusum			1	
Bradycellus verbasci			1	
Calathus melanocephalus			2	
Clivina fossor	2		1	
Demetrias atricapillus	3			
Oxypselaphus obscurus	1		3	
Paradromus linearis	1		2	
Philorhizus melanocephalus	1		1	
Poecilus cupreus				2
Pterostichus strenuus	8		6	
Pterostichus vernalis	4		3	
Trechus obtusus	1		1	
Trichocellus placidus	8		12	

*Five *Deschampsia cespitosa* tussocks were sampled in each of the grasslands in both months.

Table 6: Tussock sampling in West Wood grasslands in 2013*

Species	January		February	
	Ungrazed	Grazed	Ungrazed	Grazed
Acupalpus dubius	1			
Agonum fuliginosum	3		4	1
Agonum marginatum		1		
Amara communis	1			1
Amara lunicollis	1	1		
Anisodctylis binotatus			1	
Badister bullatus	1			
Bembidion guttula	14			
Bembidion lunulatum			1	
Bembidion quadrimaculatum	2	1		1
Bradycellus verbasci	1			
Demetrias atricapillus	4		1	
Loricera pilicornis			1	
Oxypselaphus obscurus	10		11	
Poecilus cupreus		2	1	2
Pterostichus minor		2		2
Pterostichus strenuus	3	4	13	4
Pterostichus vernalis		7	14	7
Trichocellus placidus	1		1	

*Five *Deschampsia cespitosa* tussocks were sampled in each of the grasslands in both months. The ungrazed grassland is Tussock Grassland (Table 3)

It is apparent that heavy grazing has a negative impact on the carabid fauna of *D. cespitosa* tussocks. In the East Finger Lake grasslands only one species, *Poecilus cupreus,* was found in the grazed site where there was a small cluster of tussocks whereas 19 species were recorded from the ungrazed site. The West Wood grasslands also showed a large difference between grazed and ungrazed with seven and 17 species respectively. The greater number

of species from the grazed site at West Wood probably reflected the larger area of tussocks present.

A comparison of tussock sampling and pitfall trapping in Tussock Grassland (West Wood ungrazed grassland) showed that over a short period more species of carabid were found by the former than by the latter method and the species recorded fell into two distinct groups (Table 7). A total of 24 species were found of which seven were found only in traps, 12 only in tussocks and four in both. Overall, 28 species were recorded from *D. cespitosa* tussocks nine of which were not caught in pitfall traps. The relative abundance of carabids in all tussocks sampled is shown in Figure 7.

Table 7: Species found in Tussock Grassland by pitfall trapping (as in Table 3) and tussock sampling (totals from Table 6)

Species	Pitfall trapping	Tussock sampling	Species	Pitfall trapping	Tussock sampling
Acupalpus dubius		1	*Carabus nemoralis*	1	
Agonum fuliginosum		7	*Demetrias atricapillus*		4
Amara aenea	2		*Loricera pilicornis*		1
Amara communis		1	*Bebria brevicollis*	2	
Amara lunicollis	3	1	*Oxypsephalus obscurus*		21
Anisodactylis binotatus		1	*Poecilus cupreus*	7	1
Badister bullatus		1	*Pterostichus macer*	1	
Bembidion aeneum	1		*Pterostichus niger*	3	
Bembidion guttula		1	*Pterostichus melanarius*	1	
Bembidion lunulatum		1	*Pterostichus strenuus*	2	16
Bembdion quadrimaculatum		2	*Pterostichus vernalis*	4	14
Bradycellus verbasci		1	*Trichocellus placidus*		2

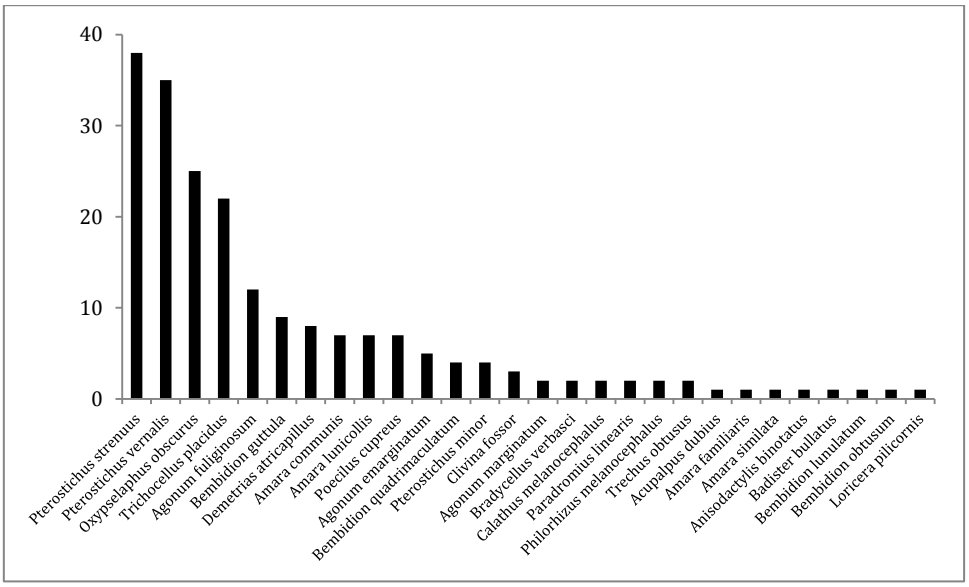

Figure 7: Relative abundance of carabids in all tussocks sampled

Band Shelters

The only species found under band shelters were *Dromius quadrimaculatus* and *Ocys harpaloides*. The former, being a new record for the reserve, was fairly abundant, especially on Field Maple, bringing the total list of species to 68. The latter was found only once under band shelters and had already been recorded in pitfall traps.

A full list of Carabidae found during the survey by different sampling methods is given in Appendix 1.

Seasonal activity

The seasonal activities for more abundant species caught in pitfall traps during the first two years are illustrated in Figures 8a,b. Numbers were taken from the site in which they were most abundant (rather than combining numbers from different sites) except for *P. strenuus*, which is shown for two marsh sites combined and for grassland.

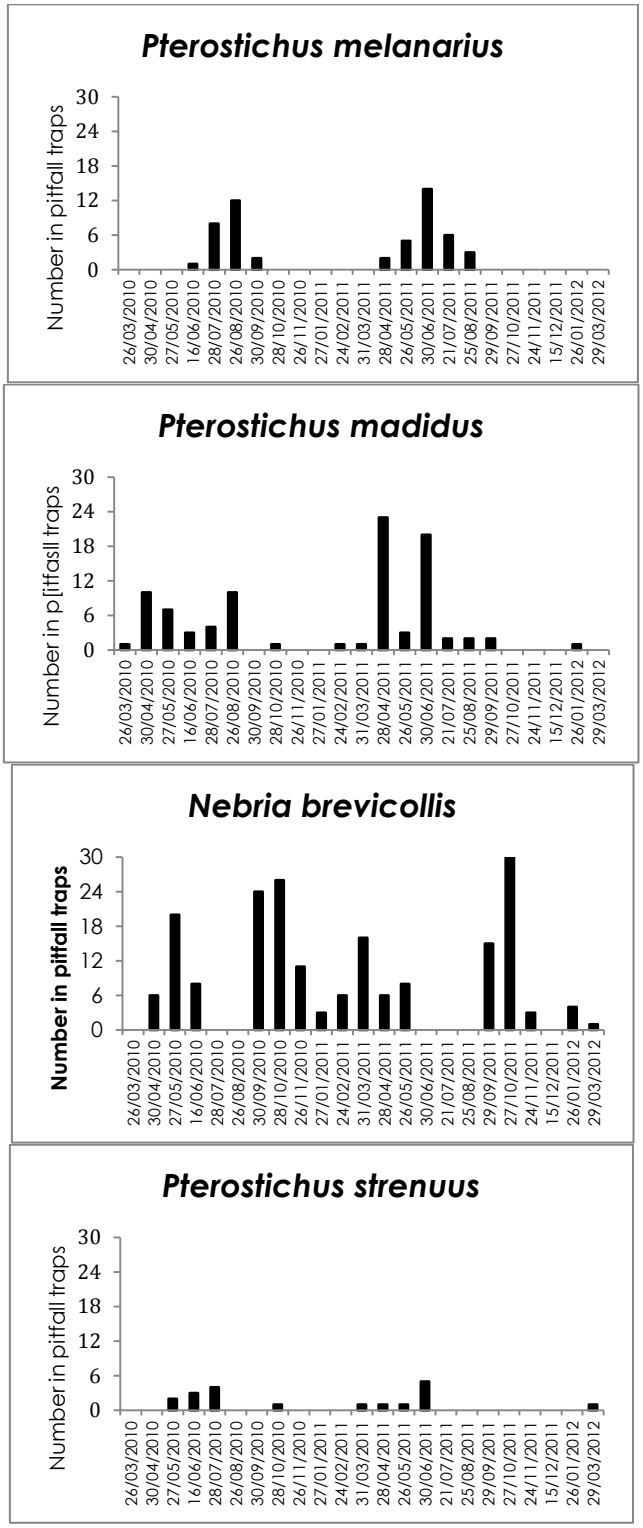

Figure 8a: Activity patterns of three woodland species (data from East Wood 26/03/2010-29/03/2012) and one grassland species (*P. strenuus*, data from Meadow 26/03/2010-29/03/2012)

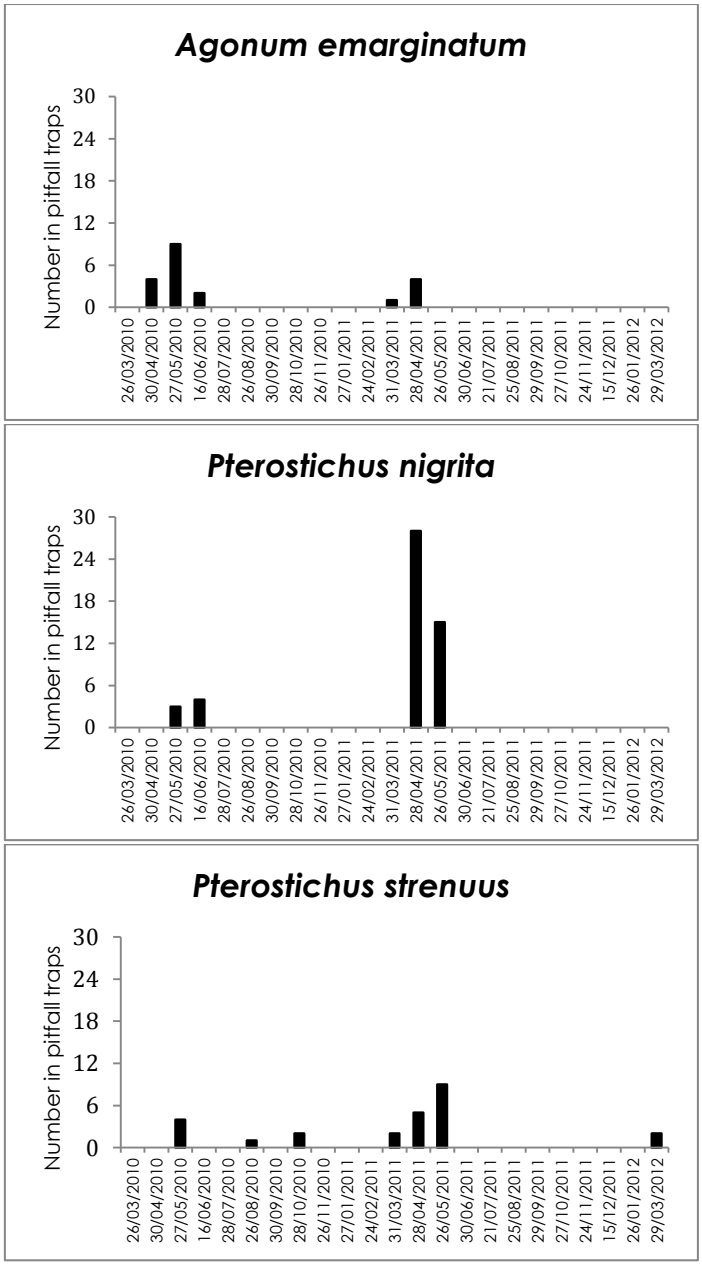

Figure 8b: Activity patterns of three Water's Edge species (*A. marginatum* data from WE-WEFL; *P. nigrita* data from WE-MLA); *P. strenuus* data from WE-EFL & WE-MLA)

Figure 9a,b show the seasonal activity for all species in habitats sampled for one or two years.

The woodland species *P. madidus*, *N. brevicollis* and, to a lesser extent, *P. melanarius* showed a more extended pattern of activity throughout the year than did the wetland species *Agonum emarginatum* and *Pterostichus nigrita* which had very discrete peaks of activity earlier in the year. *P. strenuus*, which was relatively common in both grassland and water's edge sites showed activity peaks that fit this trend, earlier in Water's Edge sites and slightly later in grassland, although numbers are small. The activity of all species combined (Figure 9a,b) also reflects the differences in the duration and peaks of activity between habitats, especially for woodland and water's edge sites, although for the four two-year sites these patterns will be heavily influenced by the common species already referred to.

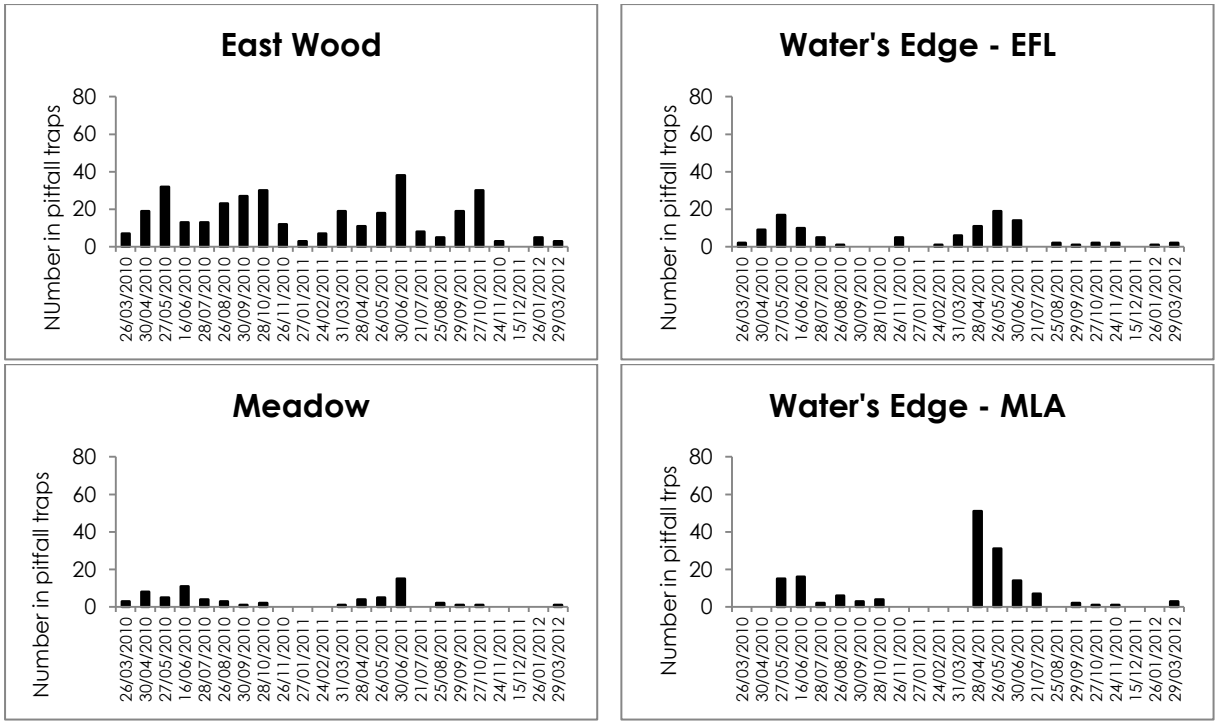

Figure 9a: Seasonal activity of all carabid species caught by pitfall traps in different habitats sampled for two years (26/03/10-29/03/12)

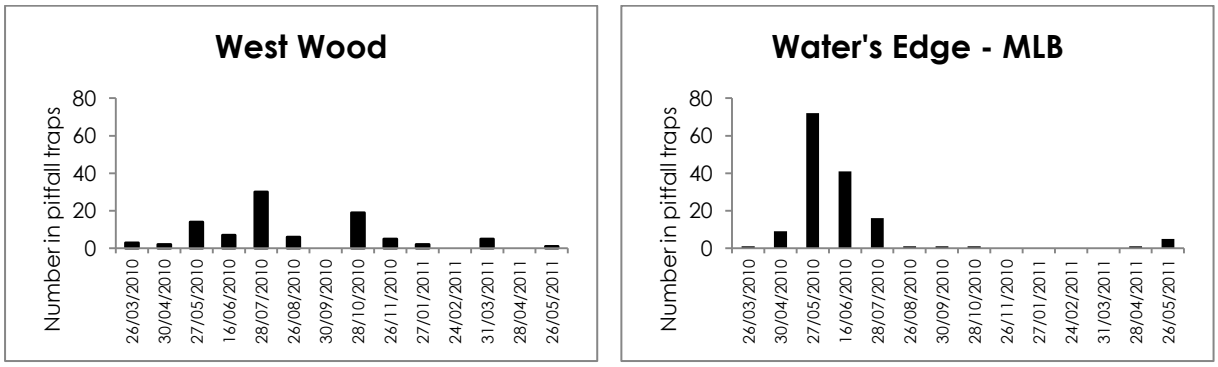

Figure 9b: Seasonal activity of all carabid species caught by pitfall traps in different habitats sampled for 13 months (05/04/2012-04/05/2013)

Discussion

Most of the 68 species of Carabidae recorded at Priory Water during this three-year study are fairly common both in VC55 and nationally. Three Nationally Notable B species were recorded: *Pterostichus gracilis* *Chlaenius nigricornis* and *Bembidion fumigatum* (Hyman & Parsons, 1992). *P. gracilis* is widespread, but local, in England, north to Cumbria, and Wales and is confined to damp habitats such as river banks and the margins of lakes and ponds (Luff, 2007). *C. nigricornis* has a very similar national distribution to *P. gracilis* and occurs in damp grasslands and lowland marshes (Luff *opp. cit.*). *B. fumigatum* has a more easterly distribution with few records from the south west of England or Wales and a northerly limit in Lancashire. It occurs in lowland fens on clay soils and in saltmarshes (Luff *opp. cit.*). In VC55 these species have been recorded from 7, 6 and 8 other sites respectively. Other species recorded that are local in VC55 were *Pterostichus macer* (14 other sites), *C. vestitus* (5 sites) and *Leistus rufomarginatus* (11 sites). *Leistus rufomarginatus* is a recent immigrant to Britain,

first recorded in the 1940s but now widespread throughout England and Wales, with a few records for Scotland and Ireland, occurring mainly in woodland.

Although most species were common, some of those recorded have been shown to be in decline throughout their range in the UK (Brooks *et al,* 2012). Species that have declined by over 50% during the 10 year period up to 2008 include the following recorded at Priory Water: *Demetrias atricapillus*, *Agonum emarginatum*, *Bembidion biguttatum*, *Trechus obtusus*, *Bembidion aeneum*, *Calathus melanocephalus*, *Bembidion lunulatum* and *Leistus fulvibarbis*. The reasons for these declines appear to be a mixture of climate change and / or extreme climatic events and local changes in habitat quality.

The habitats sampled at Priory Water are, with the exception of the River Wreake, relatively recent in origin, which may explain the low number of rare or local species recorded. Work on wetland invertebrates, including carabids (Lee *et al,* 2012), and on woodland carabids (Assmann, 1999) has shown that recently created habitats can be as species-rich, or richer, than long established sites, but may lack rare species of high conservation value which are more exacting in their requirements (stenotopic) and slow to colonise. A larger number of generalist species may be expected in younger sites, which are able to survive because of suitable abiotic conditions and the absence of competition from specialists. This idea was somewhat contradicted by a comparison of established fen and recently created wetland in the Norfolk Broads (Lee *et al, opp. cit*.) which showed no difference in either overall diversity of invertebrates or the presence of species of conservation interest. On the other hand, research into the carabids of created wetlands, varying in age from 1 year to 60 years, and undrained fenland in the Wicken Fen area of Cambridgeshire showed that, although the sites all had similar numbers of species, both notable and common wetland species were more abundant on undrained fen than on created wetland sites, except for the 60 year old site, which had a similar number of common wetland species (Martay *et al,* 2011). The authors suggest that drainage ditches, which form a system of interconnected riparian habitats running throughout the Wicken Fen sites, may provide a source of colonists for created wetlands. In the case of Priory Water, it is likely that the River Wreake and bordering grazed flood plain have been the source of at least some of the wetland species that now occupy the lake edge habitats.

A total of 39 species were recorded from lake edge habitats at Priory Water, which is not far short of the number of species (46) found at Saddington Reservoir by a number of workers over a period spanning more than a century (Lott *et al,* 2011). However, while the Saddington list had 31 wetland species including seven Nationally Notable B (67%), Priory Water had 22 wetland species including three NNB (56%). This difference may be due as much to habitat as to the age of the sites. Martay *et al* (*opp. cit*.) found that open sites with high soil moisture were the most favourable for species of notable carabids that they recorded in pitfall traps. The Saddington Reservoir shoreline was sparsely vegetated (and subject to widely fluctuating water levels) while the sites at Priory Water were relatively well vegetated. It may be significant that all three notable species at Priory were found at Water's Edge Main Lake (A) (WE-MLA) which had a sparser ground flora and more open ground than the other sites due to the shade of overhanging bushes. With the proviso that these differences may, in part, be due to denser vegetation affecting the movement of ground beetles and hence their susceptibility to capture by traps (Greenslade, 1964), the evidence suggests that the maintenance of patches of open ground in wetland habitats, including the lake edges at Priory, might enhance the diversity of specialist carabids.

Twenty-four species were recorded from the woodland at Priory Water, a number exceeded by only a few other woods in VC55, the most species rich being Buddon Wood (Quorn), an ancient woodland and SSSI with a list of 72 species, which has been sampled over many years (Lott *et al, opp. cit*.). Research by Terrell-Nield (1990) in England demonstrated a significant relationship between the diversity of all carabids and woodland age and between specifically woodland carabids and woodland age. Work by Assmann (1999) in

north-west Germany showed no significant difference in species richness between recent and ancient woodland but a larger proportion of woodland species in older woods. The English study found no species that were indicators of ancient woodland but some that occurred only in woods that were more than 90 years old, while in Germany two species appeared to be confined to ancient woodlands (*Carabus glabratus* and *Abax parallelus*). The Priory woodlands contained species that are often at their most numerous in woodlands (*Nebria brevicollis* and *Pterostichus madidus*) but commonly occur in other habitats, as well as species considered to be more specifically associated with woodland (*Notiophilus biguttatus*, *Calathus rotundicollis* and *Leistus rufomarginatus*). Species characteristic of older woods like *Cychrus caraboidedes* and *Platynus assimilis* (Terrell-Nield, *opp.cit.)* are common in VC55 but were absent from Priory Water. These species may be slow to colonise (*C. caraboidedes* is wingless) or may require the abiotic and/or biotic conditions that develop as woods age.

The 18 species recorded in the main grassland of the study (Meadow) overlapped to some extent with those found in the Water's Edge sites, two of which were close by and were transition habitats, or ecotones, with a grassland element. The Tussock Grassland site was only a few metres from West Wood and pitfall samples here added another six species to the grassland total which had more of a woodland association. The species found by searching grass tussocks formed a mixed group, with dry grassland species such as *Paradromius linearis* occurring in the same site as damp grassland and wetland species such as *Agonum emarginatum*. The tussock sampling added 17 species to the grassland list obtained from pitfall trapping and demonstrates the value of using more than one sampling method when carrying out a survey. A total of 28 species were recorded from tussocks, nine of which were not recorded by trapping. Had other methods been employed in the wetland and woodland sites more species may have been found but the time available made this impossible. There are species of carabid that are rarely, if ever, caught by pitfall traps (Nyundo & Yarro, 2007) and will only be recorded if other sampling methods are employed. Conversely, there may be species caught by traps that are hard to find by other methods. Lott (Lott *et al, opp. cit*.) sampled a complex of sites along the River Wreake in the 1980s by hand searching flood refuse and the river bank and found 27 species. In the Priory Water study only 12 species were recorded by pitfall trapping along the Wreake although four of these, including the most abundant species (*Pterostichus nigrita*), were not recorded by Lott. These species may have been absent from the areas he sampled, but it is possible that some are harder to detect by searching.

The problem of predicting how many species would be found by further sampling and, by iteration, how many species may actually be present on a site, has been the subject of numerous papers (see Chao & Shen, 2004). The SPADE predictions are based on the numbers of less common species in a sample (Chao & Shen, *opp. cit*.) and so the strong relationship between singletons and SPADE predictions is, perhaps, to be expected. This relationship could be useful in biodiversity surveys by providing a convenient way of assessing, on the basis of initial surveys, which sites would most repay further sampling. The important question is whether or not the predictions give useful results in practice. The data collected during the first two years of pitfall trapping at Priory Water can be used as a very approximate assessment, by using the first year's results to predict the number of new species recorded in the second year. The singletons from the four sites at the end of the first year were; 6 (East Wood), 4 (WE-MLA), 7 (Meadow) and 7 (WE-EFL). The new species recorded by the end of the second year in these sites were 3, 2, 4 and 7 respectively. Although there are far too few samples to assess significance, the trend is in the right direction (but, of course, could be due to chance). This would be an interesting subject for further research. One difficulty in using this approach with pitfall trapping is that those species of carabid that avoid traps fall outside the prediction. Ideally, the method of sampling should be capable of including all the species in the target group as, for instance, is the case when plants are sampled with quadrats. Nevertheless, if pitfall trapping of carabids was to be continued at Priory Water on

a limited number of sites, the data in Tables 1 and 3 may give a useful guide to those most likely to yield new species.

Carabid beetles have traditionally been divided into spring and autumn breeders, the former overwintering as adults and reproducing in the spring or early summer with the latter overwintering as larvae and reproducing in late summer or autumn. Although a useful distinction, some species have more complex life cycles that do not fit this pattern (Thiele, 1977). It has been found, for instance, that in some species adults that breed in the autumn may overwinter with the larvae and reproduce again in the following year. Carabids are most active and hence more readily caught in pitfall traps when breeding. The relationship between seasonal activity and habitat has been described by Murdoch (1967), who found that 20 of the 21 wetland species he studied were spring/summer breeders and overwintered as adults while 9 of 12 non-wetland species were autumn breeders and overwintered as larvae. The activity patterns of the common species recorded at Priory Water agree with Murdoch's findings. The common wetland beetles were active in the spring and the woodland species showed a peak of activity in summer and autumn. The adaptive advantage of spring breeding in wetland habitats may be that adult beetles are more able to withstand flooding of overwintering sites than are the larvae (Murdoch, *opp. cit.*). There are, however, wetland species that overwinter as larvae and woodland species that overwinter as adults making generalisations difficult. Overwintering larvae must have better survival rates than adults in certain conditions as this is such a common strategy among carabids. One possible explanation is that overwintering adult carabids may lose more energy than larvae overwintering in the same conditions, as has been shown for the nut weevil *Curculio nucum* (Bel-Venner *et al,* 2008).

Some of the issues raised by this study of carabids at Priory Water suggest further work, especially the idea of creating more diverse wetland habitats for carabids by maintaining open areas, the possibility of predicting how many new species would be found by further sampling based on the number of singletons in initial samples and the use of other sampling methods to add to the species list.

Acknowledgements

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Appendix - Priory Water NR Carabidae

Species	Pitfall traps	Tussocks	Band shelters	Species	Pitfall traps	Tussocks	Band shelters
Aculpalpus dubius	x	x		*Dromius quadrimaculatus*			x
Agonum emarginatum	x	x		*Elaphrus cupreus*	x		
Agonum fulinogosum	x	x		*Elaphrus riparius*	x		
Agonum marginatum	x	x		*Leistus ferrugineus*	x		
Agonum thoreyi	x	x		*Leistus fulvibarbis*	x		
Agonum viduum	x			*Leistus rufomarginatus*	x		
Amara aenea	x			*Leistus spinibarbis*	x		
Amara communis	x	x		*Loricera pilicornis*	x	x	
Amara familiaris		x		*Nebria brevicollis*	x		
Amara lunicollis	x	x		*Nebria salina*	x		
Amara similata		x		*Notiophilus biguttatus*	x		
Anisodactylus binotatus		x		*Ocys harpaloides*	x		x
Badister bullatus	x	x		*Ophonus rufibarbis*	x		
Bembidion aeneum	x			*Oxypsephalus obscurus*	x	x	
Bembidion assimile	x	x		*Paradromius linearis*		x	
Bembidion biguttatum	x	x		*Paranchus albipes*	x		
Bembidion fumigatum	x			*Patrobus atrorufus*	x		
Bembidion guttula	x	x		*Philorhizus melanocephalus*		x	
Bembidion lampros	x			*Poecilus cupreus*	x	x	
Bembidion lunulatum	x	x		*Pterostichus diligens*	x		
Bembidion mannerheimii	x			*Pterostichus gracilis*	x		
Bembidion obtusum	x	x		*Pterostichus macer*	x		
Bembidion quadrimaculatum		x		*Pterostichus madidus*	x		
Bembidion tetracolum	x			*Pterostichus melanarius*	x		
Bradycellus verbasci		x		*Pterostichus minor*	x	x	
Calathus fuscipes	x			*Pterostichus niger*	x		
Calathus melanocephalus		x		*Pterostichus nigrita*	x		
Calathus rotundicollis	x			*Pterostichus strenuus*	x	x	
Carabus nemoralis	x			*Pterostichus vernalis*	x	x	
Chlaenius nigricornis	x			*Stenolophus mixtus*	x		
Chlaenius vestitus	x			*Stomis pumicatus*	x		
Clivinia fossor	x			*Trechus obtusus*	x	x	
Curtonotus aulicus	x	x		*Trechus secalis*	x		
Demetrias atricapillus		x		*Trichocellus placidus*	x	x	
68 species							

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