The effects of blanket bog management on ground beetles (Carabidae) with particular reference to the threatened *Carabus clatratus* L.

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The effects of blanket bog management on ground beetles (Carabidae) with particular reference to the threatened *Carabus clatratus* L.

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EXECUTIVE SUMMARY

Blanket bog, a priority (Annex 1) habitat in the EU's Habitats Directive, is being exploited in Ireland in a number of ways, most notably through afforestation, sheep farming and turf cutting. Although much data have been gleaned with respect to vascular plants and habitat conditions for birds, very little research has been conducted on the invertebrate communities that rely on this habitat.

The aim of the present study was two-fold: firstly to establish, through an intensive community study, the major differences in ground beetle species between different habitats under different management regimes and to identify indicator species for particular management conditions. Secondly, the study aimed to conduct the first national survey of invertebrates conducted by NPWS staff. The national survey was for *Carabus clatratus*, a species thought to be a blanket bog specialist and recognised as Nationally Scarce in the British Red Data Book.

Results indicated that afforestation was a far greater driver of change in community composition of ground beetles than was overgrazing / erosion or hand turf cutting. It also suggested that turf cut sites are more similar to pristine / recovered sites than to overgrazed / eroded sites. *C. clatratus*, although a significant indicator of peatland as opposed to conifer forests, showed no preference for any particular management in the peatland data-set. Continuous monitoring of ground temperature showed *C. clatratus* abundance to be positively related to ground temperature, but not significantly negatively related to vegetation structure, which adds weight to the hypothesis that this species thrives in disturbed habitats due to the effect of bare peat increasing ground temperature. These results are consistent with the results of previous studies. The national survey indicated that *C. clatratus* is really quite rare, occurring in only ten out of the 129 of the localities surveyed. The species, however, showed no preference for intact blanket bog and cut-over and raised bog habitats were equally as important. Also, the species tended to occur in habitats judged of "bad" ecological / environmental condition by the individual collectors.

Other *Carabus* species distributions are also considered. Notably, *Carabus problematicus* and *Carabus glabratus*, although not listed in the British Red Data Book, were found to be more restricted than *C. clatratus* in the surveyed localities in Ireland. General recommendations for the inclusion of invertebrates in site assessment and management plans are made based on the results of this study.

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We also thank all of the conservation rangers and other regional staff that helped to make the national survey such a success. In no particular order, we thank: Gerry Higgins, Elaine Keegan, Cathryn Hannon, Helen Carty, Becky Teesdale, Lee McDaid, James Kilroy, Nicola Carroll, Eoin McGreal, John Higgins, Rob Holloway, David Lyons, Maurice McDonnell, Emma Glanville, Penny Bartlett, Sinead Biggane, Liam Lenihan, Bart Venneman, Raymond Stephens, Aine Lynch, Kathryn Freeman, Eva Sweeney, Clare Heardman, Michael O’Sullivan, Patrick Graham, Danny O'Keeffe, Barry O'Donoghue, Sean Breen, Cyril Saich, Declan O'Donnell, Stefan Jones, Brian Duffy, Ger O'Donnell, Jason Monaghan, Roy Thompson, Ciara Flynn, Annette Lynch, Noel Bugler, Jacinta Murphy, Ciaran Foley, Lorcan Scott, Dominic Berridge, Maurice Eakin, John Brophy, Colm Malone, John Carroll, Andrea Webb, William Cormacan, Cameron Clotworthy, Padraig O'Donnell, Fiona Farrell, Ann Fitzpatrick, Ger O'Donnell, Louise McAlavey, Eimear Byrne, Andrew Speer, Miriam Crowley, Judit Kelemen, Robert Lundy, John Matthews, Sue Moles, Carl Byrne, Emer Magee, Emmett Johnston, Anthony Prins, Tim Roderick, Denis O'Higgins, David McDonagh and Sara Garcia.

1. GENERAL INTRODUCTION AND BACKGROUND TO THE PROJECT

The geographic and climatic characteristics of Ireland have allowed a significant proportion of the world's peatland resources, particularly blanket bog, to develop here (Foss & O'Connell 1996; Cross 2006). Both lowland and upland blanket bog are wetlands of international importance (Gosselink & Maltby 1990) under increasing threat from habitat degradation and land-use change. Furthermore, these habitats are protected under the EU Habitats Directive (1992) and, as such, there is an onus on the Irish government to oversee their protection and sustainable use.

As part of a pan-European project investigating "Landscape Development, Biodiversity and Co-operative Livestock System" (EVK2 – CT 2002-00150, referred to from here on in as LACOPE), the habitats of Connemara formed one of the main case study sites. The other sites were in Fennoscandia (Scandinavia), Tatra and Subtatra Region (Poland), the Bavarian Alps and Prealps (Germany), Entlebuch (Switzerland), La Mancha (Spain) and Alentejo (Portugal) (see http://144.41.253.33/lacope/index.html). The project Co-ordinator, Prof. Dr. Giselher Kaule of The Institute of Landscape Planning and Ecology, University of Stuttgart, was the leading participant in a number of the project work packages including:

- Functional relationships between large scale grazing and biodiversity.
- Development of common GIS tools; management of a common database.
- Regional targeting to implement specific schemes.

Additional work packages included a "scenario approach". Work in Connemara has resulted in a publication (currently in preparation, but kindly made available to the present author), which integrates detailed GIS habitat maps of Connemara with ground beetle (Carabidae) collections and a unique scenario-based approach to management options and their likely effects on habitat succession. A key finding is that the rare / threatened *Carabus clatratus* L. – currently listed as Nationally Scarce (A) in the UK[1] – may be under threat from land abandonment and the resulting ecological succession that would likely occur. It is here that the unique "scenario approach", although speculative, was most helpful. Furthermore, it was suggested that *C. clatratus* is a good indicator of habitats consisting of

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[1] Nationally Scarce (A) = occurrence in 30 or fewer 10 km squares of the National Grid or, for less well recorded groups, within seven or fewer vice-counties. However, translation of the UK status to the Irish fauna may not be appropriate due to the peculiarities in the Irish fauna (Anderson, 1996). The species was rated "C" i.e. found in 6-20 sites (maximum 100+, in the scheme of A - F) in Northern Ireland by Anderson (1996).

low-competitive plants e.g. *Drosera* spp. and *Sphagnum* mosses. Its known preference for adult feeding in bog pools (Thiele 1977) also make it indicative of particular microtopography. One of the unavoidable conclusions of succession is that the whole community of Carabidae is likely to change. With pitfall trapping, it is however difficult to disentangle a species' selection of particular habitats and microhabitats with the effects of vegetation resistance to the species movements (Greenslade 1964; Spence & Niemelä 1994). Nevertheless, alternatives to pitfall trapping are few and McAdam and Montgomery (in Anderson *et al.* 2000) note that "The most important advantage of pitfall traps, however, is that they collect large samples of invertebrates and produce more species than any other method. They also collect animals throughout the time they are in place, and so are less labour intensive for the number of species trapped".

The main impetus for the current research was to test some of the predictions of Kaule *et al.* (in prep) by conducting an intensive community study on western blanket bog. Although peatland management was the main focus in the original proposal, it was also decided to incorporate forestry effects since large areas of western blanket bog have been afforested and plantation forestry constitutes a major land use and potential factor influencing ground beetle communities. Also, the relative impacts of vegetation structure of blanket bogs on ground beetles may be compared with major land use change (i.e. afforestation). A number of detailed environmental variables, including ground temperature and relative humidity, using continuous recorders were also taken. Since basking has been hypothesised to be a major factor influencing *C. clatratus* habitat / microhabitat selection, the relative influence of ground temperature and vegetation structure metrics (vegetation length, height and density measure – falling plate meter)[2] is central to the investigation. Other aims of this study were to i) identify indicator species for blanket bog; ii) investigate the influence of trap-size effects to inform a subsequent national survey – see below.

Very little is known about the distribution of *C. clatratus*, particularly in the Republic of Ireland. The website "Ground beetles of Northern Ireland" notes the species as "Locally common in wet pasture and bog in Fermanagh but elsewhere its status is unknown though it should still be widespread in the west in areas of undisturbed Atlantic bog." (http://www.habitas.org.uk/groundbeetles/). However, much of the sampling effort in the Republic of Ireland has been sporadic and concentrated on the western peatlands, with many of the raised bog habitats not having been surveyed. The second part of the project aimed at redressing this. With the co-operation of NPWS staff, we sought to undertake a national survey, which made the best use of rangers' knowledge of local habitats and their

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[2] See relevant chapter below for the definition of these metrics

professional opinion on the status of the habitats in which the sampling was conducted. As the remaining species of the genus *Carabus* did not prove too difficult to determine, these species were also included, though most of the discussion remains focused on the focal species *C. clatratus*.

The following two chapters provide a concise description of the two studies along with suitable references and discussion. Additionally, a final year honours project was supervised in Connemara National Park under the NPWS student bursary scheme. Part of this study involved detailed GIS analyses of an area of cut-over bog. A mark-recapture study was initiated as part of this project. There was only modest success due to the effects of predation on marked individuals' survival. A copy of the thesis by Mr George Percival has been deposited with Dr Noel Kirby in Clifden (Percival 2009). Also, a project on the effects of fire on carabid beetle communities on raised bog (by Mr. Thomas Gorman) is currently being supervised and will be available on completion.

The remainder of the report is in the form of two papers for future publication and a general summary of the findings. The original data for the community analysis is presented in Appendix 1 and the handout and questionnaire for participating conservation rangers is presented in its entirety in Appendix 2. Two shorter publications were also produced – one an abstract for the British Ecological Society Annual meeting and one for the Ballycroy Newsletter.

2. EFFECTS OF LAND USE AND MANAGEMENT ON THE COMMUNITY ECOLOGY OF GROUND BEETLES ON WESTERN BLANKET BOG, WITH PARTICULAR REFERENCE TO *CARABUS CLATRATUS* L.

Abstract

An intensive community study of the ground beetle (Carabidae) fauna on western blanket bog was conducted from 4/6/2009 – 25/11/2009 in Ballycroy National Park and its environs (Co. Mayo). Nine locations were sampled in three habitat types (conifer forest plantation, impacted blanket bog and undamaged blanket bog) and a number of environmental variables also recorded. Trap size effects were also investigated.

There was no significant difference among trap sizes (6.5 – 9cm diameter) in carabid species richness and total abundance in either conifer or blanket bog habitats. Also, the abundance of the rare and threatened *Carabus clatratus* was not significantly different among trap sizes in the blanket bog areas. Furthermore, similarity in the whole data-set was not significantly explained by trap-size as a grouping variable. This suggests that, within this range of trap sizes, collections from different trap sizes are comparable.

The major difference in the carabid community was between conifer plantation and blanket bog habitat types. Whereas, common species e.g. *Abax parallelipipedus* tended to be indicative of coniferous sites, the rare and threatened *Carabus clatratus* was the strongest indicator of blanket bog. The major effect of afforestation on ground beetle communities was notable in comparison to other land uses and reflected in different environmental variables. Differences among the blanket bog sites were less obvious. However, overgrazed / eroded sites tended to cluster away from undamaged and cut-over sites indicating that overgrazing / erosion has a greater effect on ground beetle community composition compared to limited turf cutting.

Considering pooled data for the blanket bog locations showed that the abundance of *C. clatratus* was significantly positively related to average (mean) ground temperature taken every 15 minutes throughout the trapping period, but was not related to any of the metrics of vegetation structure or edaphic factors, giving strong evidence that higher collections of this individual in bare / eroded microhabitats is probably due to a preference for basking areas rather than lowered vegetation resistance.

Introduction

Blanket bog is a habitat of international importance (Gosselink & Maltby 1990) and is well represented in Ireland, which has approximately eight per cent of the world's blanket bog (Foss & O'Connell 1996). Although early anthropogenic deforestation is thought to have played a major role in the formation of many blanket bogs (Moore 1975), it is nevertheless seen as the natural potential vegetation for large parts of the west of Ireland (Cross 2006). It is the most extensive of Ireland's semi-natural habitats (Cross 2006) and its global conservation importance is recognised in its classification as a priority habitat (Annex 1) in the EU Habitats Directive.

The current major threats to blanket bogs include the negative effects of overgrazing and erosion, where high stocking densities of domestic livestock may lead to extensive, and sometimes irreparable, habitat destruction and degradation (Bleasdale & Sheehy Skeffington 1992; Bleasdale & Sheehy

Skeffington 1995; Bleasdale 1996; Sheehy Skeffington *et al.* 1996; Bleasdale 1998). Other threats include loss of habitat to afforestation (Farrell & Boyle 1990), drainage for agricultural improvement and the negative impacts of turf-cutting.

The commonage framework plans (CFPs) and current agri-environment schemes such as the Rural Environment Protection Scheme (REPS) and the National Parks and Wildlife Service Farm Plan scheme, aim to combat the negative effects of overgrazing and erosion by paying farmers for lowering the stocking density of pastoral land. Whereas changes in plant communities are well documented (Rawes 1983; Grant *et al.* 1985), less work has been conducted on changes in the invertebrate fauna of Irish peatlands, in response to changes in stocking density.

Ground beetles (Carabidae) have excellent potential as ecological and biodiversity indicators – *sensu* McGeoch (1998) – as noted by Rainio and Niemelä (2002), though they should be used with caution when interpreting general changes in insect diversity. Carabids have been successfully used in understanding how the habitat management of British heathlands (Gardener 1991) and moorlands (Gardener *et al*. 1997; Holmes *et al.* 1993) affect their composition and diversity. Vegetation structure, hydrology and nutrient status appear to be the major variables of importance. There have been fewer studies on Irish blanket bog. However, Day (1987) studied a number of habitats in nature reserves in Northern Ireland, including four blanket bogs; McFerran *et al.* (1994) studied grazing effects on carabids in heath and moorlands in Antrim and Mc Donnell *et al.* (2002) studied carabids in a succession of Atlantic heathland sites. Woodcock *et al.* (2004) investigated management (grazing and turf cutting) effects on Carabidae in oceanic blanket bog on the Beara Peninsula, West Cork. They found that whereas there was no negative effect on the threatened *Carabus clatratus* L., distinct communities were collected on managed as compared to control "pristine" sites.

Forestry is a major land use in Ireland with eight per cent of the land devoted to non-native conifer plantations (Cross 2006). Afforestation is one of the major threats to blanket bog conservation as national targets are set to double to 17 per cent of total land use by 2030 (Mullen *et al.* 2008). Non-native forestry plantations and clear-felled sites have been shown to have a distinct carabid beetle community compared to native forestry (Day *et al.* 1993; Fahy & Gormally 1998). Afforestation also shows distinct faunas as compared to neighbouring open habitats (Coll & Bolger 2007), although the species composition of Irish plantation sites is itself quite different from that of continental Europe (Coll *et al.* 1995). The forest cycle has also been shown to have a major influence on carabid diversity and composition (Mullen *et al.* 2008).

A recent study (Kaule *et al.* in prep) aimed at integrating landscape-level changes in management – abandonment versus balanced grazing scenarios – with habitat suitability analysis for the ground beetle *Carabus clatratus* L. Results suggest that ecological succession will lead to a significant reduction in suitable habitat for this beetle mainly as a result of the loss of suitable microhabitats important for basking.

The aim of the present study was to investigate the relative impacts of land use and management on ground beetle diversity and composition at blanket bog and adjacent conifer plantations in the west of Ireland. The major environmental variables influencing both the community, in general, and specifically the rare *C. clatratus* were investigated. Also, the effects of different sized pitfall traps was considered to inform a national survey of *C. clatratus*.

Materials and Methods

Study sites

The study was conducted in the Ballycroy National Park and its environs in County Mayo in the west of the Republic of Ireland. The park was established in 1998 and is included within the Owenduff/Nephin Complex Special Area of Conservation (SAC) – site code 534 – and Special Protection Area (SPA) – 4098 – under the EU Habitats (Council Directive 92/43 EEC) and Birds Directives (Council Directive 79/409 EEC).

Three sites were chosen for the study and three habitats, nested within each site (Figure 2.1), were sampled. The grid reference and general features including management and condition of each location are indicated in Table 2.1. Management and conditions for each blanket bog location were generally based on guidelines produced by NPWS – then named Dúchas (Anon 1999); further details are given in Figure 2.3 and in the results section below.

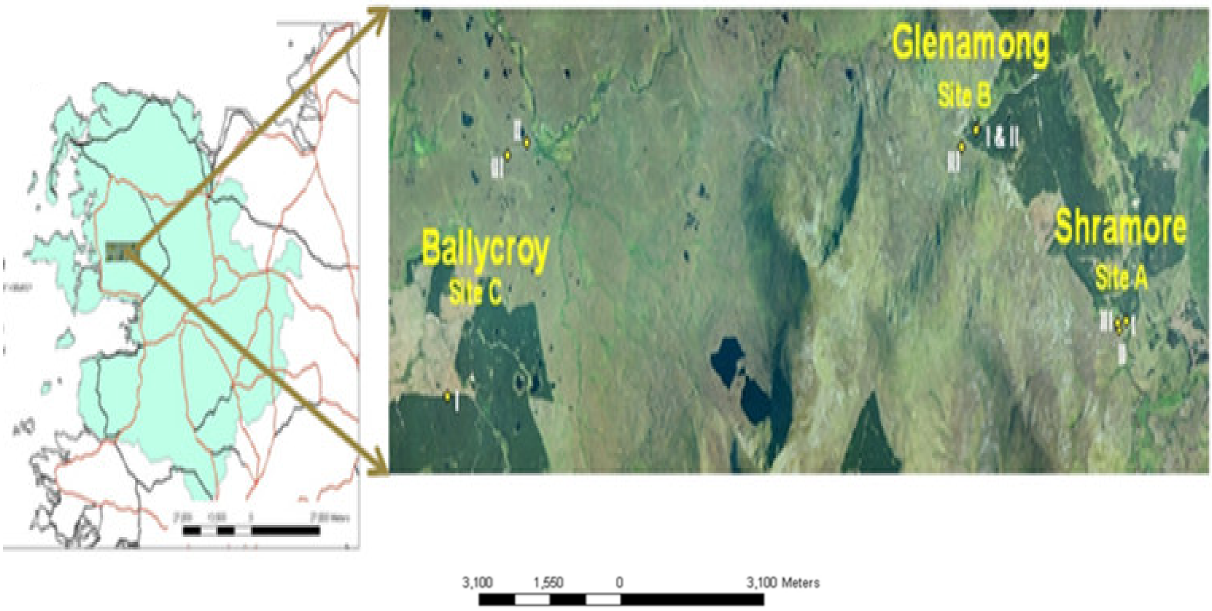


Figure 2.1: The nine locations sampled. Three habitats nested in each of three sites.

Table 2.1 General features of sampling locations.

Location	**Site**	**Grid Reference**	**Elevation (M above sea-level)**	**Habitat**	**Management / Condition**
1	Shramore (A)	F9658805482	42	Forestry (Pine & spruce)	Plantation
2	Shramore (A)	F9647905405	46	Blanket bog	Overgrazing / erosion
3	Shramore (A)	F9644805463	54	Blanket bog	Undamaged
4	Glenamong (B)	F9406007338	181	Forestry (Pine)	Plantation
5	Glenamong (B)	F9406607347	180	Blanket bog	Overgrazing / erosion
6	Glenamong (B)	F9381907158	175	Blanket bog	Undamaged
7	Ballycroy (C)	F8645207213	59	Forestry (Pine)	Plantation
8	Ballycroy (C)	F8611607083	48	Cut-over blanket bog	Turf cutting
9	Ballycroy (C)	F8509904750	52	Blanket bog	Undamaged

Pitfall trapping

Within each sampling location, a grid of nine (three x three) pitfall traps were arranged North – South. Three large (diameter 9cm), three medium (diameter 7cm) and three small (diameter 6.5cm) traps were arranged in a Latin-square to control for any systematic change in environmental parameters when testing for trap-size effects (Figure 2.2).

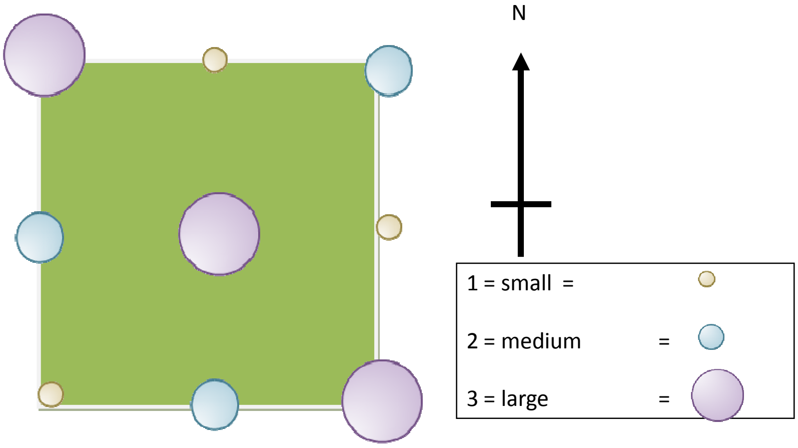


Figure 2.2: Trap layout at each sampling location

Pitfall traps consisted of two plastic cups buried below the ground surface, with a small slit to allow water to escape during flooding. They were filled to one third with ethylene glycol (20%) and a small amount of detergent to break the surface tension. A small square of green corriboard® (15cm x 15cm) supported by four six inch nails just above the ground were used as rain covers (Figure 2.3). Traps were collected every two weeks (4/6/2008 – 25/11/2008) and the contents sorted in the laboratory. Coleoptera were separated from other invertebrates and stored in 70% Industrial Methylated Spirit (IMS) for later determination. The Carabidae were determined to species level with Forsythe (2000) and Luff (2007).

Environmental variables

A number of environmental variables were also measured. Vegetation height (the height of the standing vegetation) and vegetation length (the length of the outstretched plant) were measured to the nearest half centimetre at eight positions around each trap (two at each of the four corners). Vegetation structure / microhabitat complexity was also assessed using a falling plate meter supplied by Jenquip®. Falling plate meters give readings that are dependent on both vegetation structure and vegetation density and readings are correlated with biomass for improved agricultural land. Falling plate meters, also known as drop disks, have been successfully used to gauge vegetation structure in previous studies of Carabidae (Woodcock *et al.* 2004 and Woodcock *et al.* 2005), but it should be noted that both this and the direct measurement method have advantages and disadvantages according to sward height (Stewart *et al.* 2001). Four falling plate meter readings were taken at each trap.

Luminosity was also measured above and below the ground flora at each trapping point with a Hanna® HI 97500 luxmeter. All of the above variables were measured twice during the trapping period, once near the start (12 – 13/6/2008) and once towards the end (25 – 29/6/2008). Means were used in the analyses.

Relative humidity and temperature were recorded at the middle of each trapping grid every 15 minutes throughout the whole of the trapping period using Tinytag® plus 2 data loggers. Mean daily and daily minimum and maximum temperature and humidity were used in the analyses.

Soils were sampled from positions next to each trap on 11/12/2008 and moisture content, pH and loss-on-ignition (LOI) were determined according to British Standards (BSI 1990).

Statistical analyses

Species rank abundance curves were calculated using MS Excel, the trap-size effects and other univariate analyses were performed using SPSS version 17 and all multivariate analyses, including Multi-response permutation procedures (MRPP), Indicator species analysis (ISA) and Non-metric multi-dimensional scaling (NMS) were performed using PC Ord version 5.

a) Location 1 b) Location 2 c) Location 3 d) Location 4

e) Location 5 f) Location 6 g) Location 7 h) Location 8

i) Location 9

Figure 2.3: a) – i) Traps *in situ* from sampling locations 1-9. Photographs show trap placements and the general physiognomy of each location.

Results

Firstly, the different measured environmental conditions are considered. Initially, differentiation between coniferous plantation locations and peatland locations are made. Then, differences in environmental conditions are considered, in detail, among peatland sampling locations.

Trap-size effects on Carabidae in each of the major habitats are considered, followed by the major compositional differences in the species data-set. Results of the sub-set of samples from the peatland sites will be dealt with in more detail and, finally, the results with respect to the threatened *C. clatratus* are considered.

Environmental variables

Figure 2.4 shows quite clearly the different variables between coniferous forest and peatland sampling positions. Vegetation density is significantly greater in forestry sites, probably as a result of micro-topographic diversity as opposed to a dense ground flora (see Figure 2.3 a, d, and g). Other measures of vegetation structure, however, show a taller and longer ground flora at peatland positions. Unsurprisingly, peatlands are also more illuminated, have moister soil and greater organic content (LOI). Ground temperature and relative humidity are also significantly higher on the peatland sites as is the difference between daily minima and maxima (i.e. variation) of these variables.

The conifer sites are significantly more acidic than the peatland sites, probably as a direct result of needle fall. Augusto *et al.* (1998) showed that *Picea abies* had a significant effect on soil pH compared to other tree species although parent material was most important. In the present study, however, parent material is the same between all sites and we compare forested with open peatland sites. In general we can conclude that conifer sites are very different from peatland sites although they may be more moderate in terms of relative humidity and temperature.

Differences between individual sampling locations are shown in Table 2.2. There was much variation in vegetation density, with undamaged locations being denser than the cut-over location and the cut-over location being denser than the eroded locations. Only two pairs of locations were not significantly different from each other; one a pair of damaged sites and the other a pair of undamaged locations.

Rather interestingly, even though undamaged sites have taller mean vegetation (greater vegetation height) than eroded sites (with cut-over sites intermediate), the specific sequence of sites are different compared to vegetation density:

9(u)>6(u)>3(u)>8(c)>2(e)>5(e) for vegetation density versus:

3(u)>6(u)>9(u)>8(c)>5(e)>2(e) for vegetation height; where u = undamaged, c = cut-over and e = eroded.

It should be noted that for vegetation height, there are six comparisons that are not significant, two of these are cut-over versus eroded and cut-over versus undamaged, further highlighting the intermediate nature of vegetation structure under the cut-over management regime.

For vegetation length (length of outstretched plant), the same pattern of significance is shown as for vegetation height except that location 8 versus location 3 are significantly different. Thus, vegetation length and height detect similar levels of difference in vegetation structure, whereas the falling plate meter detected more differences among locations.

Table 2.2 also shows that the mass loss-on-ignition (LOI) for each location is fairly high, which is unsurprising for peatland habitats, though it should be noted that location 5 (damaged, at Glenamong) is somewhat lower in terms of LOI. Although there are significant differences among locations in terms of pH, these are not easily related to the damage status and probably reflect differences in the rhizosphere (i.e. in the acrotelm). The soil moisture level does appear to be influenced by damage status, with undamaged areas generally being more moist than eroded or cut-over sites.

Although light levels clearly separate forest and peatland sites (Figure 2.4), within the peatland locations, there were only a few significant differences in light levels between locations and there was no consistent grouping effect of damage status on the recorded light levels, though it should be noted that light intensity varies greatly from minute to minute and is probably not as good at detecting smaller differences. As only one Tinytag® plus 2 data logger was placed in each location, no statistical tests could be conducted on these metrics between zones, but they may be used in the pooled species data-sets and as overlays in multivariate analyses.

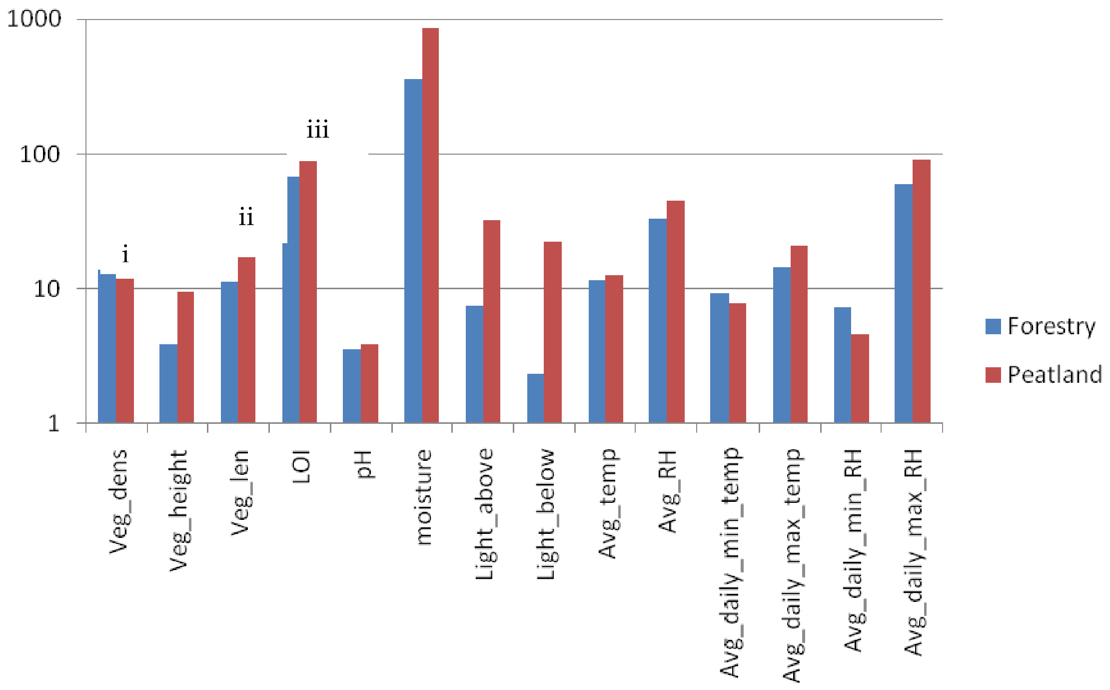


Figure 2.4: Mean scores for the environmnetal variables in coniferous forestry (blue) and peatland sites (red). Differences between all variables as tested by T-tests were significant at *P*<0.001 except the following: i) vegetation density and ii) length are not significantly different (*P*>0.05) and (iii) soil loss on ignition is less so (*P*=0.002). The ordinate axis is logarithmic (for clarity) and, therefore, has no error bars. The units are as follows: veg density (arbitrary, but relative), veg height and length (cm), LOI and moisture (% dry soil mass), pH, light above and below the vegetation (Lux) and temperature and humidity values ^{o}C and %, respectively.

Table 2.2: Pairwise comparison (Least Significant Difference) between environmental variables for the peatland habitats sampled. Locations refer to Table 1. NS = not significant, * = P <0.05, ** = P <0.01 and *** = P<0.001.

Location	**2 (n=9**	**3 (n=9)**	**5 (n=9)**	**6 (n=9)**	**8 (n=9)**	**9 (n=9)**
Mean vegetation density (drop disk)	4.69555	14.3633	7.17	14.44556	10.23889	20.0577
2 (damaged / eroded)	X					
3 (undamaged)	-9.67***	X				
5 (damaged / eroded)	NS	7.19***	X			
6 (undamaged)	-9.75***	NS	-7.28***	X		
8 (damaged / cut-over)	-5.54***	4.12**	-3.07*	4.21**	X	
9 (undamaged)	-15.36***	-5.69**	-12.89***	-5.61***	-9.82***	X
Mean vegetation height (cm)	2.92333	15.8577	3.9	14.46333	5.595556	13.83778
2	X					
3	-12.93	X				
5	NS	11.96***	X			
6	-11.54***	NS	-10.56***	X		
8	-2.67***	NS	NS	8.87***	X	
9	-10.91***	NS	-9.94***	NS	-8.42***	X
Mean vegetation length (cm)	7.9	26.257778	8.2077778	26.53	12.29333	22.815556
2	X					
3	-18.36***	X				
5	NS	18.05***	X			
6	-18.63***	NS	128.32***	X		
8	-4.39*	13.96***	NS	14.24***	X	
9	-14.92***	NS	-14.61***	NS	-10.52***	X
Mean soil loss-on-ignition (% dry mass)	92.66667	94.66667	75.22222	91.33333	94.11111	96.7777
2	X					
3	NS	X				
5	17.44***	19.44***	X			
6	NS	3.33*	-16.11***	X		
8	NS	NS	-21.56***	NS	X	
9	-4.11*	NS	-14.61***	-5.44**	NS	X
Mean soil pH	4.047778	3.958889	3.625556	3.838889	3.99777	4.01222
2	X					
3	NS	X				
5	0.422***	0.333***	X			
6	0.209***	0.12*	0.213**	X		
8	NS	NS	-0.372***	-1.159**	X	
9	NS	NS	-0.387*	-0.17**	NS	X
Mean soil moisture (% dry mass)	720.3278	876.6589	472.3567	1174.611	683.1244	1267.334
2	X					
3	NS	X				
5	24.97*	404.30***	X			
6	-454.28***	-297.95**	-702.25***	X		
8	NS	-193.53*	-210.76*	491.49***	X	
9	-547.01	-390.68***	-794.98***	NS	-584.21***	X
Mean light above vegetation (Lux)	22.22333	28.84333	31.15778	27.08	41.19779	42.08889
2	X					
3	NS	X				
5	NS	NS	X			
6	NS	NS	NS	X		
8	-19.866**	NS	NS	-15.01*	X	
9	-18.974**	NS	NS	-14.12*	NS	X
Light below vegetation(Lux)	17.88889	24.44778	25.60778	13.09222	25.51222	26.66778
2	X					
3	NS	X				
5	NS	NS	X			
6	NS	11.36*	12.51*	X		
8	NS	NS	NS	-13.58**	X	
9	NS	NS	NS	-12.42*	NS	X

Trap size effects

The total abundance and species richness of Carabidae showed no significant difference among different trap sizes for either the coniferous forest (Figure 2.5) or the blanket bog sites (Figure 2.6). Furthermore, the abundance of *C. clatratus* was not significantly different among trap sizes in the blanket bog sites (Figure 2.6). As only one *C. clatratus* was collected from a single conifer trap, its abundance could not be tested among trap sizes in this data-set.

The lack of trap-size effects was also noticeable in the Multi-response permutation procedure (MRPP) (Table 2.3). MRPP is a non-parametric test in which the explanatory power of a grouping variable may be tested on multivariate data. The technique is based on permutation of data in a similarity matrix, which provides a *P*-value and a chance-corrected within-group agreement (*A*), which is a measure of within-group homogeneity (Mielke & Berry 2001). For both the full data-set (including coniferous forest plots) and the blanket bog sub-set of the data, there was no significant effect of trap size, though various other grouping variables were significant (see below).

Given the above results, we may reasonably conclude that in terms of carabid abundance, species richness, the abundance of the focal species of interest (*C. clatratus*) and community similarity (in both the full and blanket bog sub-sets), trap size is not significant and may be treated as negligible in the subsequent analyses.

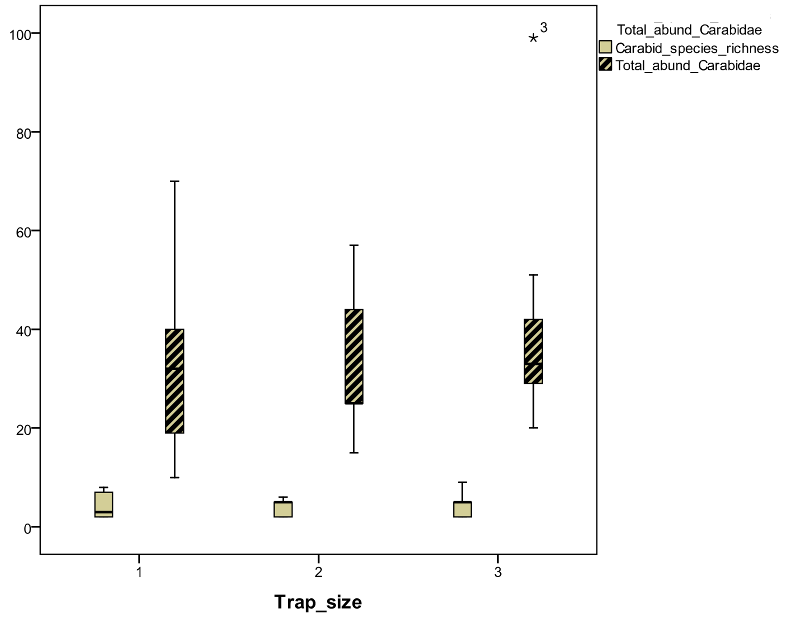


Figure 2.5: Box-plot of total abundance and species richness of Carabidae over the sampling period caught in small, medium and large traps in the coniferous forest locations – Differences were not significant among trap sizes ($P > 0.05$) Kruskal-Wallis non-parametric analysis of variance. 1 = small, 2 = medium and 3 = large; Asterisk = extreme outlier.

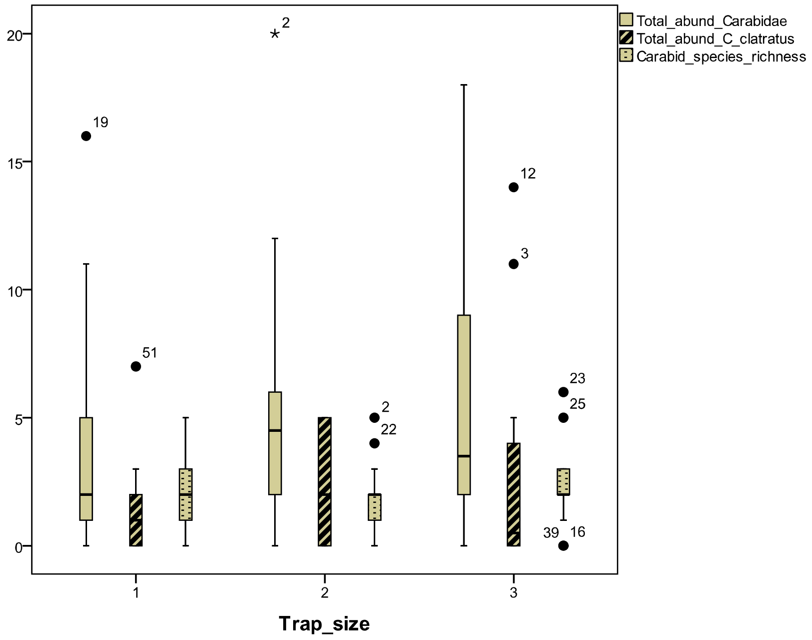


Figure 2.6: Total abundance and species richness of Carabidae and total abundance of *Carabus clatratus* over the sampling period caught in small, medium and large traps in the peatland locations – Differences were not significant among trap sizes for any of the variables ($P > 0.05$) Kruskal-Wallis non-parametric analysis of variance. Circle = outliers and asterisk = extreme outlier.

Table 2.3: Multi-Response Permutation Procedure showing the effect-size of various grouping variables on the community similarity for the full data-set (including coniferous forest plots) and the blanket bog sub-set. Asterisks mark significant grouping variable (* = $P < 0.05$, ** = $P < 0.01$).

Grouping variable	No. groups	Chance-corrected within-group agreement (A)	P (Monte Carlo simulation)
Full data-set			
Location	9	0.500	$<10^{-8**}$
Habitat type	3	0.372	$<10^{-8**}$
Forest versus blanket bog	2	0.356	$<10^{-8**}$
Site	3	0.0383	0.0113^{*}
Trap size	3	-0.0144	0.995
Blanket bog sub-set			
Location	6	0.189	$3.7\text{x}10^{-6**}$
Habitat type	2	0.0718	$3.8\text{x}10^{-4**}$
Impact type	3	0.128	$1.3\text{x}10^{-5**}$
Site	3	0.086	$4.9\text{x}10^{-4**}$
Trap size	3	$5.81\text{x}10^{-4}$	0.4

Major distinctions in the community data-set.

Species rank abundance curves, or Whittaker plots as they are sometimes known (Whittaker 1965), show quite clearly a major difference in the dominant species of: (a) coniferous and (b) blanket bog sites (Figure 2.7). The species richness, evenness and dominance structure of Location 1 (Pine (*Pinus contorta*) and Spruce (*Picea abies*) – Table 2.1) contrasts with those of Locations 4 and 7 (both Pine – Table 2.1); the latter two locations, generally being less species-rich and possessing a lower evenness – i.e. a steeper curve (Figure 2.7 a).

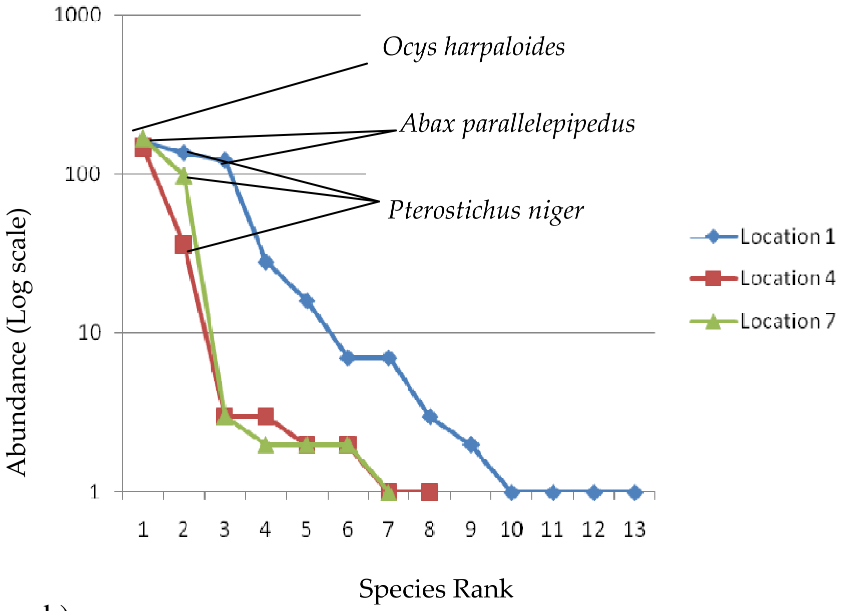
For the blanket bog sites (Figure 2.7 b), the sequence of rank abundance curves does not follow a consistent grouping in impact statuses i.e. with the exception of Location 5, which appears to be more diverse than the other locations, the rank abundance curves do not group together as impacted (eroded or cut-over) versus undamaged nor according to the site in which they were sampled. Location 5 was notable in the analysis of environmental variables in having a lower LOI, indicating a less peaty substrate. Even though this site is certainly more diverse than the others – diversity is only one criterion in a site's status as favourable.

Non-metric multi-dimensional scaling (NMS) is an ordination technique based on minimising stress between the ordination and the multi-dimensional similarity matrix (Kenkel & Orloci 1986). The technique is based on ranked distances and, as such, has many advantages over techniques based on eigenvalues, since the latter typically assume multivariate normality, which is often not the case for joint distributions of variables that arise in natural communities (McCune & Grace 2002). This indirect ordination technique allows for an objective determination of the appropriate number of dimensions to display the multivariate community data and can be used to assess which of the measured environmental variables are most highly correlated to these major dimensions.

The ordination of pitfall traps in species-space resulted in a 2-dimensional ordination (Table 2.4) with a final stress of 15.13318 and a final instability of 0.00240. Figure 2.8 a shows a clear separation between the traps collected in coniferous forest plantations and those collected on blanket bog sites. However, there appeared to be no consistent grouping of undamaged versus impacted blanket bog sites, with blanket bog traps apparently occupying a wide range of dissimilarity and overlapping in their compositions. Furthermore, a species vector plot shows two quite distinct species constellations (Figure 2.8 b); one a tightly knit group of coniferous forest species towards the top of the ordination and a second more dispersed blanket bog constellation of species. The overlay of environmental variables (Figure 2.8 a and b) and their correlations with ordination axes (Table 2.5) show quite clearly that the coniferous forest plots (having high axis 2 scores) tend to have lower average daily maximum and average temperatures, but a higher average daily minimum temperature (i.e. are less variable). The conifer sites also tend to have lower average relative humidity and lower average daily maximum relative humidity, but a higher average daily minimum relative humidity (again less variable). They also have lower soil loss-on-ignition, lower soil moisture and lower soil pH values. Unsurprisingly, the conifer plots also have lower light values.

These results are supported by the MRPP results (Table 2.3) on the full data-set, which indicate that, unsurprisingly, location (each of the three by three sampling grids) explains the most variation among samples, accounting for 50% of this variation (i.e. $A = 0.5$). Site, although significant, accounts for less than 4% of the variation among sample dissimilarities (i.e. $A < 0.04$), but habitat (conifer forest versus undamaged blanket bog versus impacted blanket bog) is both significant and explains a high proportion of the variation in sample dissimilarity ($A = 0.37$). However, most of this variation can be attributed to differences between coniferous forest plots versus blanket bog ($A = 0.36$) rather than between blanket bog sites of different damage status.

a)



b)

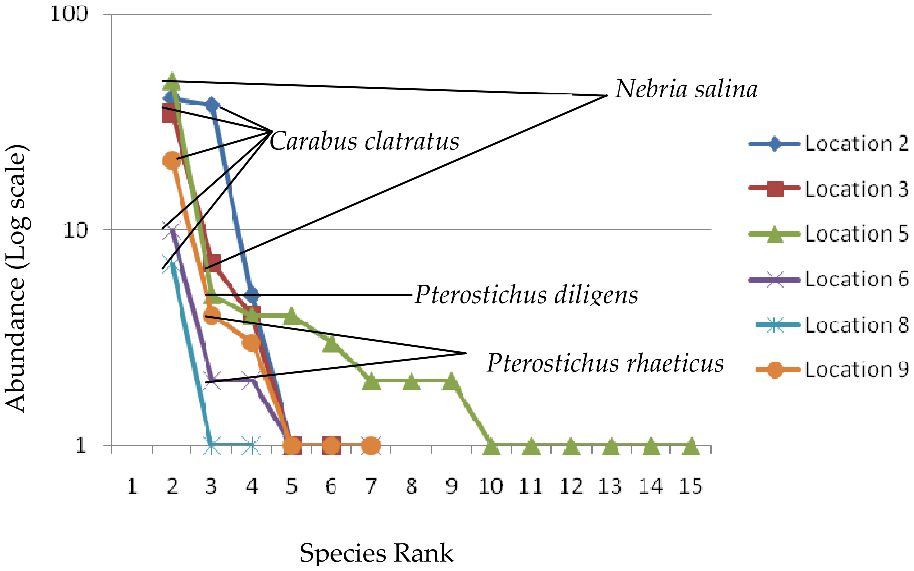


Figure 2.7: Species rank-abundance curves for a) the forestry sites and b) the blanket bog sites. Dominant species are labelled in each case.

Table 2.4: Axes significance tested by Monte Carlo permutation for the two ordinations (Full data-set and blanket bog sub-set).

	Stress in real data 250 runs			**Stress in randomized data, Monte Carlo test, 250 runs**			
Axes	**Minimum**	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**	***P***
Full data-set							
1	29.381	45.075	57.421	43.143	49.163	57.080	0.0040
2	15.133	16.768	21.697	25.635	29.246	58.803	0.0040
Blanket bog sub-set							
1	31.747	42.733	56.957	32.488	44.020	57.077	0.004
2	19.901	21.119	26.360	18.672	24.211	62.148	0.0239

Table 2.5: Correlation coefficients between environmental variables and ordination axes for the complete data-set NMS.

Axis	**1**		**2**	
	r	**r^2**	**r**	**r^2**
Vegetation density (falling plate meter)	-0.430	0.185	0.209	0.044
Vegetation height	-0.185	0.034	-0.355	0.126
Vegetation length	-0.166	0.028	-0.173	0.030
Soil loss on ignition (LOI)	-0.039	0.002	-0.465	0.216
Soil pH	-0.077	0.006	-0.701	0.492
Soil moisture	-0.191	0.037	-0.625	0.391
Light above ground vegetation	0.014	< 0.000	-0.725	0.526
Light below ground vegetation	0.160	0.026	-0.714	0.510
Average temperature	-0.081	0.007	-0.882	0.778
Average relative humidity	0.347	0.120	-0.529	0.280
Average daily minimum temperature	-0.089	0.008	0.881	0.776
Average daily maximum temperature	0.038	0.001	-0.926	0.857
Average daily minimum relative humidity	0.420	0.177	0.477	0.228
Average daily maximum relative humidity	0.143	0.020	-0.767	0.589

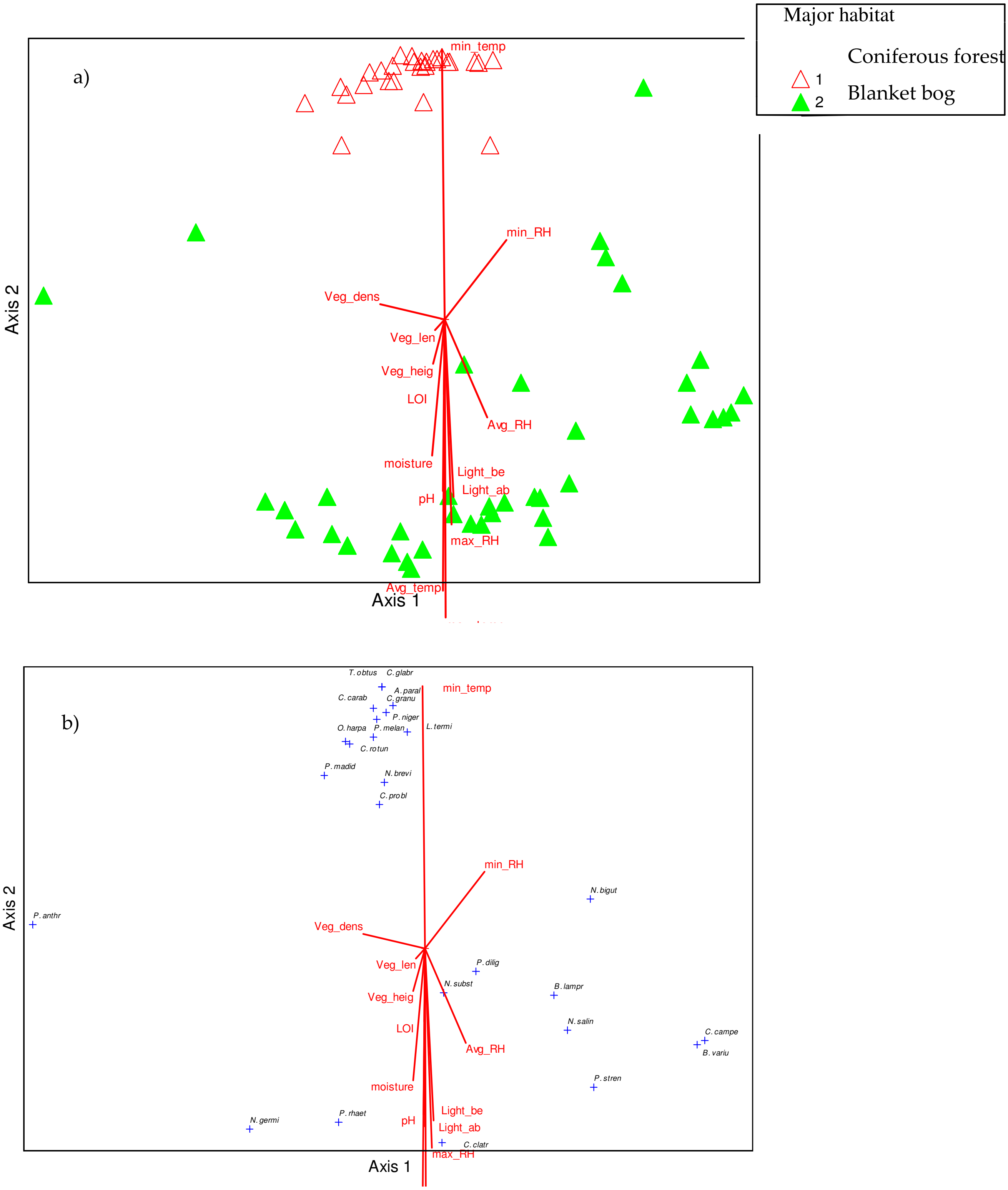


Figure 2.8: NMS plot of pitfall traps in species space (a) and species vectors (b). Environmental overlays are shown in red. Axis 1 explains 18% of the variation in dissimilarities among traps and axis 2 explains 62.3% of the variation – measured as coefficients of determination for the correlations between ordination distances and distances in the original 26 species space. Orthogonality between axes = 99.9%.

Indicator species analysis (ISA) assesses the preference of species for particular groups by considering both the relative frequency and relative abundance of the species in the various groups (Dufrene & Legendre 1997). Monte Carlo permutation tests give an estimated *P*-value for the percentage of perfect indication, or indicator value (IV). Significant indicators of the coniferous forest versus blanket bog major habitat division are given in Table 2.6. Species most indicative of coniferous plots are fairly common e.g. *Abax parallelipipedus* (Piller & Mitterpacher) whereas the strongest indicator of the blanket bog habitat (in general) is the threatened *C. clatratus*.

Table 2.6: Indicator species analysis – significant indicators of coniferous forest plots versus blanket bog sites.

Carabid species	**Major habitat**	**Indicator value (IV) %**	**Significance (Monte Carlo) *P***
Abax parallelipipedus	Coniferous forest	99.6	$2x10^{-4}$
Pterostichus niger	Coniferous forest	98.7	$2x10^{-4}$
Ocys harpaloides	Coniferous forest	44.3	$2x10^{-4}$
Carabus granulatus	Coniferous forest	37.0	$2x10^{-4}$
Pterostichus melanarius	Coniferous forest	29.0	$2x10^{-4}$
Nebria brevicollis	Coniferous forest	23.4	$5.4x10^{-3}$
Cychrus caraboides	Coniferous forest	22.2	$1.8x10^{-3}$
Leistus terminatus	Coniferous forest	17.1	$2x10^{-4}$
Carabus clatratus	Blanket bog	71.2	$2x10^{-4}$
Nebria salina	Blanket bog	52.3	$2x10^{-4}$
Pterostichus rhaeticus	Blanket bog	21.3	0.025

Distinctions within the blanket bog sub-set.

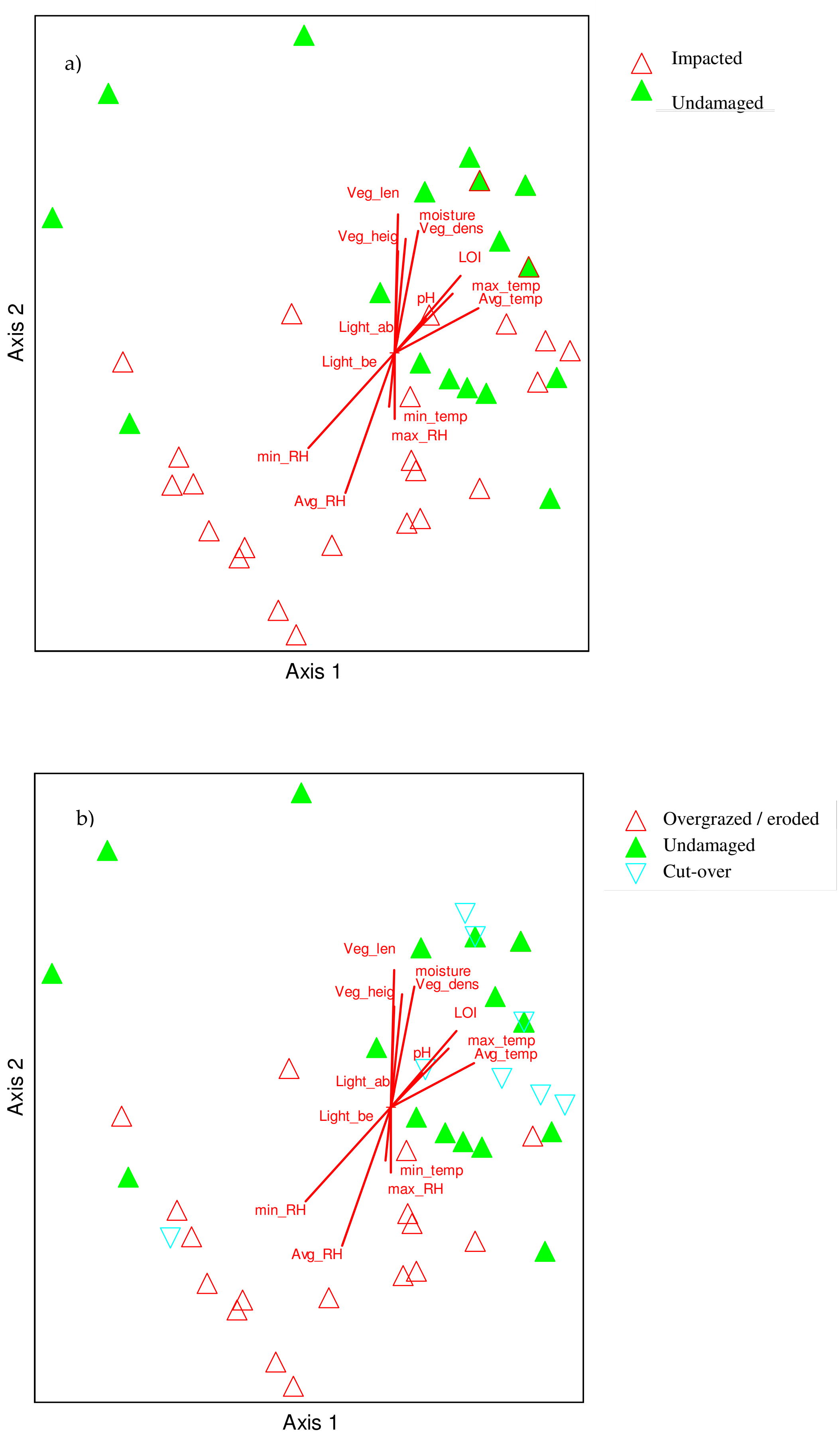
NMS ordination of the blanket bog sub-set of the data also resulted in a two-dimensional ordination (Table 2.3) with a final stress in the data of 20 and a final instability of $6.1x10^{-4}$. The ordination of traps in species-space shows quite a large overlap when habitat type (impacted versus undamaged) is considered (Figure 2.9 a), but less overlap when impact type (overgrazed / eroded versus cut-over versus undamaged – Figure 2.9 b) is considered. This is largely as a result of many of the cut-over traps overlapping with the undamaged rather than the overgrazed / eroded sites. These results are supported by the MRPP (Table 2.3), which shows that an additional 5.6% of the variation is explained when "impact type" is considered rather than "habitat type". This amounts to an increase of 78% in *A* (see Table 2.2).

In general, undamaged and cut-over traps tend to occur at higher axis 1 and 2 scores. Axis 1 scores are positively correlated with soil loss on ignition, soil pH, average temperature, average daily maximum temperature and negatively with average relative humidity and average daily minimum relative humidity. Axis 2 scores are positively correlated with the vegetation structure metrics and negatively with soil moisture and relative humidity values (Table 2.7).

The indicator species analysis for the blanket bog sub-set shows fewer significant indicators as compared to the conifer versus blanket bog major habitat division (Table 2.8 c.f. Table 2.5). The three significant indicators are all for impacted sites – one for cut-over (*Pterostichus rhaeticus* Heer) and two for overgrazed / eroded sites (*Nebria salina* Fairmaire et Laboulbene and *Bembidion lampros* (Herbst)). Two of these indicators (*P. rhaeticus* and *N. salina*) were also indicative of blanket bogs in general, though their higher IV's in Table 2.7 show them to be more specific in their affinities. These results are supported by the species vector plot (Figure 2.9 c), which shows most species centred around the grazed sites. Interestingly, *C. clatratus* does not have a preference for any particular impact type, and so, given its high IV in Table 2.5, it may be considered a general indicator for all blanket bog sites in the present study.

Table 2.7: Correlation coefficients between environmental variables and ordination axes for the complete data-set NMS.

Axis	**1**		**2**	
	r	**r^2**	**r**	**r^2**
Vegetation density (falling plate meter)	0.197	0.039	0.616	0.379
Vegetation height	0.111	0.012	0.583	0.340
Vegetation length	0.112	0.013	0.681	0.463
Soil loss on ignition (LOI)	0.470	0.221	0.507	0.257
Soil pH	0.325	0.105	0.339	0.115
Soil moisture	0.279	0.078	0.639	0.408
Light above ground vegetation	0.111	0.012	0.233	0.054
Light below ground vegetation	-0.006	< 0.000	-0.067	0.005
Average temperature	0.530	0.281	0.385	0.148
Average relative humidity	-0.406	0.165	-0.684	0.468
Average daily minimum temperature	-0.136	0.018	-0.424	0.180
Average daily maximum temperature	0.442	0.195	0.443	0.196
Average daily minimum relative humidity	-0.537	0.288	-0.562	0.315
Average daily maximum relative humidity	0.003	0.000	-0.469	0.220


a)
Impacted
Undamaged
Veg_len
moisture
Veg_dens
Veg_heig
LOI
max_temp
Avg_temp
pH
Light_ab
Light_be
min_temp
max_RH
min_RH
Avg_RH
Axis 2
Axis 1
b)
Overgrazed / eroded
Undamaged
Cut-over
Veg_len
moisture
Veg_dens
Veg_heig
LOI
max_temp
Avg_temp
pH
Light_ab
Light_be
min_temp
max_RH
min_RH
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Axis 2
Axis 1

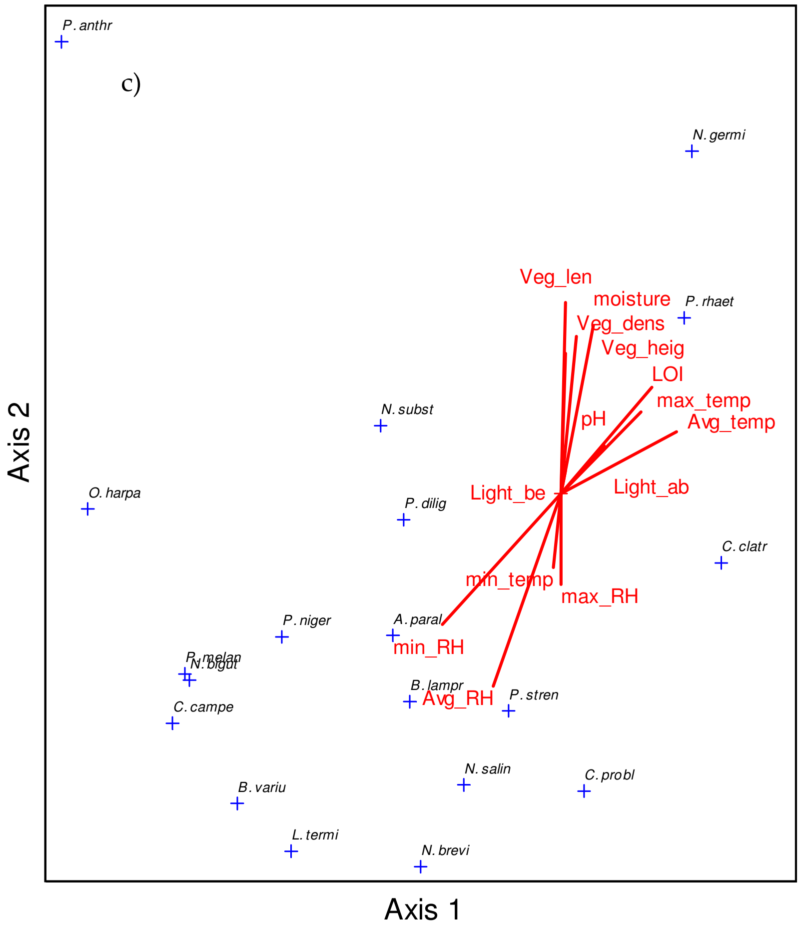

Figure 2.9: NMS plot of pitfall traps in species space overlaid with (a) habitat type and (b) impact type. Species vectors are shown in (c). Environmental overlays are shown in red. Axis 1 explains 44.6% of the variation in dissimilarities among traps and axis 2 explains 35.6% of the variation – measured as coefficients of determination for the correlations between ordination distances and distances in the original 19 species space. Orthogonality between axes = 93.8%.

Table 2.8: Indicator species analysis – significant indicators of particular impact types (Overgrazed eroded versus cut-over versus undamaged) on blanket bog sites.

Carabid species	**Impact type**	**Indicator value (IV) %**	**Significance (Monte Carlo) *P***
Bembidion lampros	Overgrazed / eroded	38.9	3.6x10^{-3}
Nebria salina	Overgrazed / eroded	76.6	2x10^{-4}
Pterostichus rhaeticus	Cut-over blanket bog	30.0	0.032

Autecological conclusions for Carabus clatratus

C. clatratus is a significant indicator of blanket bog traps as opposed to coniferous plots. However, it is not a significant indicator of any particular bog impact type (overgrazed / eroded versus cut-over versus undamaged) within the blanket bog sub-set of the data. Regression analyses[3] was performed on the abundance totals of *C. clatratus* at each location and the average values for the various measures of vegetation structure, edaphic characteristics, temperature and relative humidity measures. Totals were used on a location basis to avoid spatial pseudoreplication (Hurlbert 1984) and because only one point of temperature and relative humidity recording was in place at each location.

In all the regression analyses, the only monotonic relationship with the abundance of *C. clatratus* was a positive exponential relationship with average ground temperature (Figure 2.10). The equation for this relationship is:

Abundance *C. clatratus* = $2.303\text{x}10^{-13}$ ($e^{2.488.\text{temp}}$)……………………………………........(1)

Therefore, taking natural logarithms of both sides:

Ln (abundance *C. Clatratus*) = 2.488.temp. + Ln($2.303\text{x}10^{-13}$)……………………………..(2)

The regression of ground temperature explains over 74% of the variation in the abundance of *C. clatratus* of the blanket bog sites and even though replication is fairly low ($n = 6$), the relationship is statistically highly significant $P < 0.05$ (Figure 2.10).

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[3] logarithmic, polynomial – quadratic and cubic – and exponential.

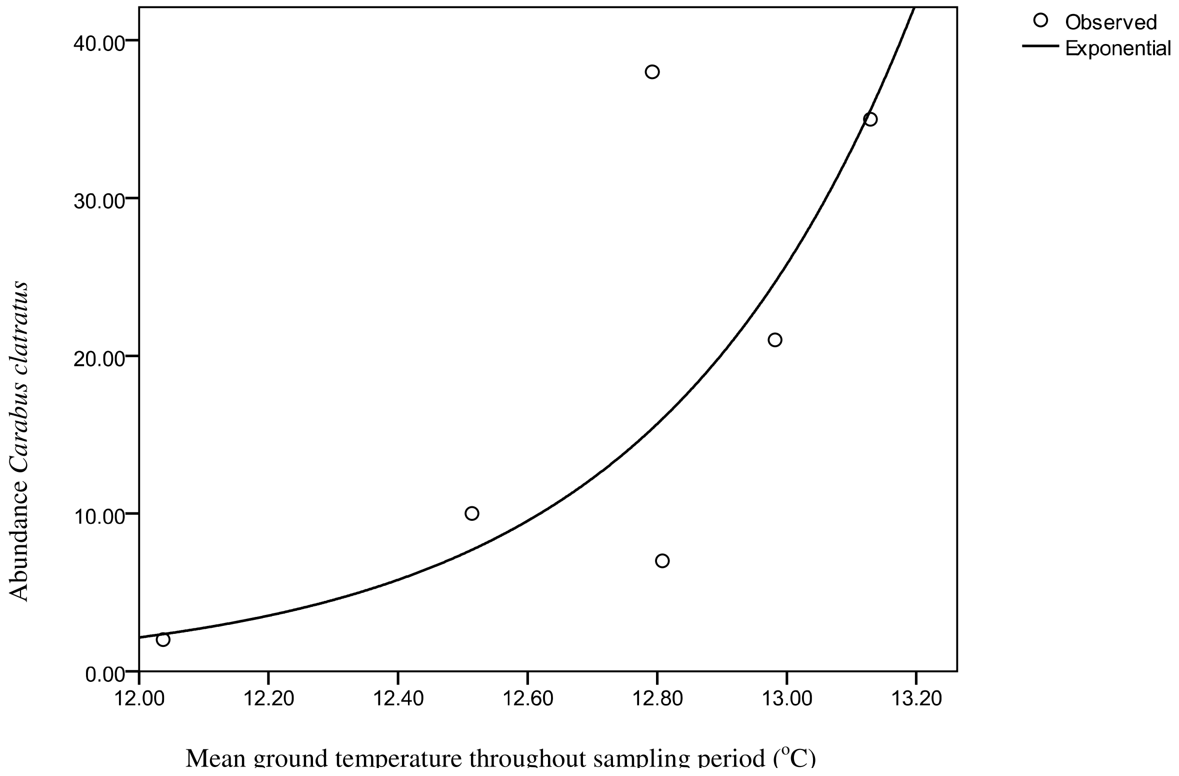

Figure 2.10: Exponential relationship between the total abundance of *Carabus clatratus* captured at each of the blanket bog sites and the mean ground temperature throughout the sampling period. Curve fit: Abundance *C. clatratus* = $2.303\text{x}10^{-13}$ ($e^{2.488.\text{temp}}$); $R^2 = 0.743$ $P = 0.027$.

Discussion

In a previous study, Luff (1975) detected differences among different trap sizes. However, Luff did note that, "the largest species was caught poorly by nearly all traps", which may explain why *C. clatratus* abundance did not significantly differ among different trap sizes in the blanket bog sub-set of the present study. It should also be noted that the difference in perimeter lengths of the traps were much greater in Luff's as compared to the present study, which may explain the lack of any significant trap-size effects within the ranges of trap lengths here investigated. The fact that community composition was not significantly different among trap sizes, as tested by MRPP, means that a change in catch from small to large species as trap length increases, cannot account for similar total abundance and species richness values (e.g. c.f. Work *et al.* 2002). It may be concluded that within the range of diameters of 6.5 to 9cm (trap lengths of 20.4 – 28.3), round plastic pitfall trap collections may be compared within blanket bog and conifer plantations.

The major difference between the coniferous forest ground beetles and their neighbouring blanket bog sites were consistent with Coll & Bolger's (2007) and Cameron's (1994) studies, which also showed a qualitative difference in the communities. Afforestation has a radical effect on the composition of the carabid fauna, but species richness and evenness were not notably lower in the coniferous stands, a result consistent with expectations (Coll & Bolger 2007). Changes in environmental variables of coniferous plots were notable. The relative humidity and temperature tended to be less extreme (i.e. lower maxima and higher minima) in coniferous sites, probably as a result of the canopy both sheltering the areas from rain and shading the area from the sun. These results are consistent with previous studies (Chen *et al.* 1993; Horung *et al.* 1987). The lower soil loss-on-ignition and moisture is probably due to drainage, fertilisation of the soil, protection from the rain and increased evapo-transpiration (Hornung *et al.* 1987), whereas the lower pH is likely a result of the acidifying effect of fallen needles (Billings 1964). Within the coniferous sites, the older mixed stand (pine and spruce) showed a different pattern of dominance-diversity from the younger (spruce only) sites, a result consistent with Mullen *et al.* (2008). Nevertheless, these differences were minimal when compared to the major conifer versus blanket bog division.

Differences between the blanket bog sites were less extreme. Interestingly, impact type was very important – as compared to simply impacted versus undamaged – with cut-over sites tending to cluster within the undamaged trap constellation. This provides further quantitative support to previous studies of Todd (1995), Meharg (1988) and McAdam & Montgomery's (2000) summary that, "limited (but not repeated) peat cutting may have only minimal environmental impact" on Carabidae. McAdam and Montgomery (2000) note that Meharg (1988) found *N. salina* to increase in abundance with repeated peat cutting. In the present study, however, this species tended to favour overgrazed / eroded sites rather than the cut-over site, though this may simply be a function of the relatively "good" environmental quality of cut-over sites in the present study or a lack of severely overgrazed areas at Douglas Top (Antrim) where Meharg conducted his studies. There were no significant indicators of undamaged blanket bog, highlighting the fact that whereas some species tended to do better under management there was none that did significantly better at undamaged sites.

Carabus clatratus was found to be a significant indicator of blanket bog (compared to conifer sites), but did not show a particular preference for any particular management condition. This is consistent with the work of Woodcock *et al.* (2004) who noted that this species was not noticeably affected by turf-cutting and grazing in the Beara Peninsula. Kirby (1992) has noted the importance of bare patches for basking invertebrates and the benefits of bare patches have been noted for a number of taxa including Lepidoptera (Reid *et al.* 2009) and ground nesting bees and wasps (Gregory & Wright 2005). Kaule *et al.* (in prep) hypothesise that the bare patches left after balanced grazing, which are darker and warmer, are important for large Carabidae such as *C. clatratus*. Distinguishing between a species' preference for particular habitats / microhabitats and methodological factors such as increased vegetation resistance that retards ground beetle movement in particular habitats is problematic. However, in the present study, continuous temperature recorders distinguished a positive relationship between *C. clatratus* and ground temperature, but no negative relationship with any of the vegetation structure metrics or soil characteristics, despite the latter having been shown to be important for egg laying (Huk & Kühne 1999). The reason that ground temperature did not vary consistently with vegetation structure is probably a result of temperature being a function of micro-habitat (i.e. vegetation structure) and other factors e.g. shading, aspect, altitude etc. The use of continuous temperature recording will be important to future studies aimed at testing this relationship.

It may be concluded that afforestation results in qualitatively different ground beetle communities as compared to surrounding blanket bog habitats, in contrast grazing / erosion and turf cutting result in mainly quantitative changes from the ungrazed condition, with overgrazing / erosion having a greater impact than limited turf cutting. Bare patches may be important for certain species of conservation interest e.g. *C. clatratus*, through the provision of basking areas, but it is important to note that this also depends on other factors linked to ground temperature.

3. A NATIONAL SURVEY OF *CARABUS* IN THE REPUBLIC OF IRELAND WITH THE PARTICIPATION OF NPWS STAFF.

Abstract

The first national entomological survey conducted by NPWS staff is described. Sixty-four conservation rangers were involved in the survey and 129 localities were surveyed. Surveys were conducted in wetland habitats that were thought most likely to harbour the rare *Carabus clatratus*. A management questionnaire was also completed by participants.

C. clatratus was collected in only ten of the localities surveyed. Although the species was generally collected in peatlands and moorlands, there was no noticeable preference for blanket bog and both raised and cut-over bogs were important for the species, as were habitats rated as "bad" ecological / environmental quality.

Carabus granulatus was collected in higher abundance, more frequently, and also possessed a broader niche in terms of habitat association. Contrary to this, *Carabus problematicus* and *Carabus glabratus* appeared to have a narrower niche and were collected less frequently and in lower abundance than *Carabus clatratus*, despite not being listed as a British Red Data Book species (as *C. clatratus* is).

Introduction

There is a paucity of baseline data on the distribution of Carabidae in the Republic of Ireland. In comparison with Northern Ireland, the problem is particularly noteworthy. For example, the ubiquitous *Abax parallelipipedus* (Piller & Mitterpacher) is considered eurytopic in its habitat affinities. It is, however, recorded in only 2.5% of the ten km squares in the Republic of Ireland, but recorded in 15% of the ten km squares in NI (post 2000 records). The concentration of records in the North (Figure 3.1) is evidently an effect of sampling intensity.

For the rare *Carabus clatratus* L. the following has been noted: "Locally common in wet pasture and bog in Fermanagh but elsewhere its status is unknown though it should still be widespread in the west in areas of undisturbed Atlantic bog." (http://www.habitas.org.uk/groundbeetles/). Also Luff (1998) notes that its "coverage in Ireland is still poor". The lack of baseline data together with its status in the UK as Nationally Scarce (A) points to a need for a national survey.

Although considered a Tyrphophile – i.e. a peat loving species (Thiele 1977) and having often been described as a specialist of blanket bog, it has been collected in marshy meadows close to the sea in Denmark (Lindroth 1992) and in the spray zone (shingle coast) of Omey Island (Kaule *et al.* in prep.). Hay meadows and lake shores in Fermanagh have also been found to support the species (McFerran *et al.* 1995). Thus, a national survey of wetlands may also help to more quantifiably establish the habitat affinities of the species on a national scale.

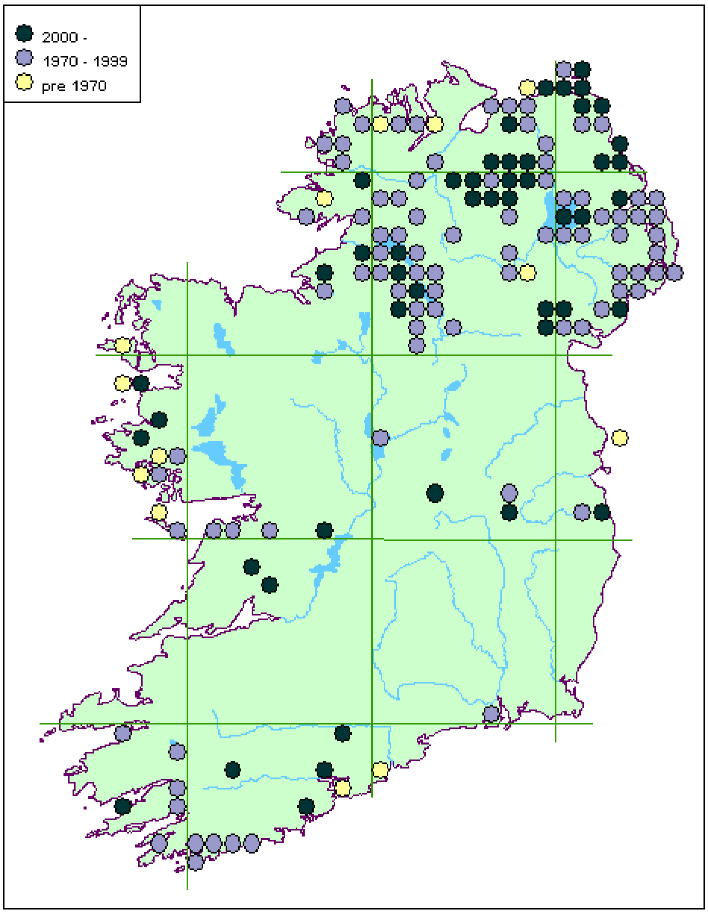

Figure 3.1: Concentration of records of the eurytopic *Abax parallelipipedus* in Northern Ireland versus the Republic of Ireland.[4]

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[4] available at **http://www.habitas.org.uk/groundbeetles/index.html**

Materials and Methods

As this is the first national entomological survey involving NPWS staff, it is worth describing the methods in some detail, so as to serve as a model for possible future surveys of its kind, particularly those involving pitfall trapping.

Conservation Rangers were requested to help in the national survey via e-mail. Four courses were presented throughout the country prior to the survey so that members of staff were able to attend their nearest centre. Courses were held in Galway City (Co. Galway), Charleville (Co. Cork), Portlaoise (Co. Laois) and Ballinafad (Co. Roscommon) on 20th, 21st, 23rd April and 1st May, 2009, respectively.

At the meetings a 2 ½ hour presentation was given covering the biology and ecology of Carabidae, especially focusing on *C. clatratus*. The rationale, aims and objectives of the national survey were also presented. A list of preferred habitats (in order of preference) was explained as was a management questionnaire. Attendees were given a handout including all the most relevant information. A question and answer session followed the presentation, which is given in Appendix 2. The Powerpoint presentation is available from the present author, on request. Following a lunch break, pitfall trapping and habitat classification (and completion of other details on the management questionnaire) was demonstrated at a local suitable wetland habitat.

In summary, regional staff were requested to sample two suitable wetland habitats in their respective vice-counties. Each sample consisted of three pitfall traps arranged two metres apart in a triangle. Samples were left for two weeks 18/5/09 – 1/6/09 (or dates as close to this as possible; dates of collections were noted on the management questionnaire).

Although the initial commitment was for one collection, staff were given the option to complete a second collection (1/7/09 – 15/7/09) in the same locations as the first. All participants were provided with all the equipment necessary for the survey (supplied in a shoe box) and were also given addressed padded envelopes in which to return the collections. The equipment consisted of the following:

- 1 x plastic trowel.
- 12 x plastic pint glasses (two for each trap, three traps for each habitat and two habitats for each participant).
- 24 x 4″ steel nails to support the rain covers.
- 6 x 15cm x 15cm black plastic corriboard® rain covers.
- 12 x 20ml sterile containers filled with vinegar for trapping (two used per trap).
- 2 x pairs of medium sized latex gloves.
- 2 x plastic ziplock® bags in which to store samples.

- 2 x plastic takeaway cartons to protect samples in the post.
- 1 x black indelible marker to label samples.
- Each participant was also given the handout (including the management questionnaires) – see Appendix 2 – and two large (A1) addressed padded envelopes, if the participant was willing to make two collections and one padded envelope, if the participant was willing to make one collection.

Results and Discussion

Participation in the project was excellent with 64 staff contributing samples from a total of 129 localities. The coverage throughout the country was very good with only four vice-counties in the east of the country not being surveyed (Figure 3.2). Also, the genus *Carabus* was collected throughout the full geographical range of the samples and in a high proportion (over 50%) of the traps (Figure 3.3). Original GIS data is too big, even for an appendix. These data are held by NPWS, The National Biodiversity Data Centre and by the lead author.

Despite wide coverage and intensive sampling in the most suitable habitats, only ten out of the 129 surveyed localities contained *C. clatratus*, indicating that the species is genuinely scarce – see Figure 3.4 (N.B. vice-county 4 – East Cork – has two samples very near each other both with *C. clatratus*). Nevertheless, East Cork and Roscommon appear to be new vice-county records (Figure 3.5). Many of the historical records date back to the 19th century and so the apparent reduction should be seen as a function of both a longer period of recording in a wider range of habitats as well as any real decrease in populations. A number of participating staff contributed "roving records" by photographing individuals that were later confirmed. A new vice-county record in Clare would not have been made were it not for this aspect of the project. These distributional data, however, should be treated qualitatively as biases probably exist.

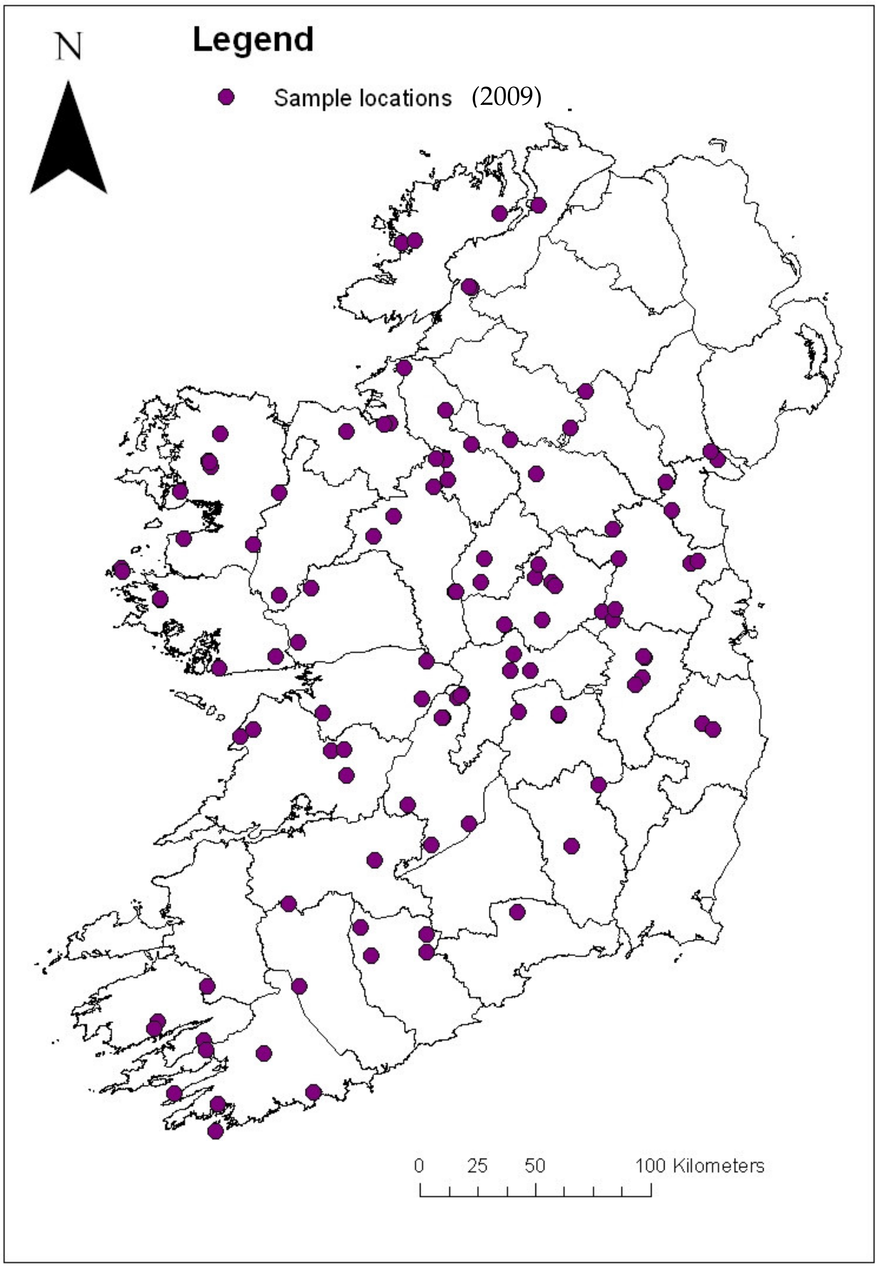


Figure 3.2: Sampling location distribution throughout Ireland also showing borders of Vice-counties.

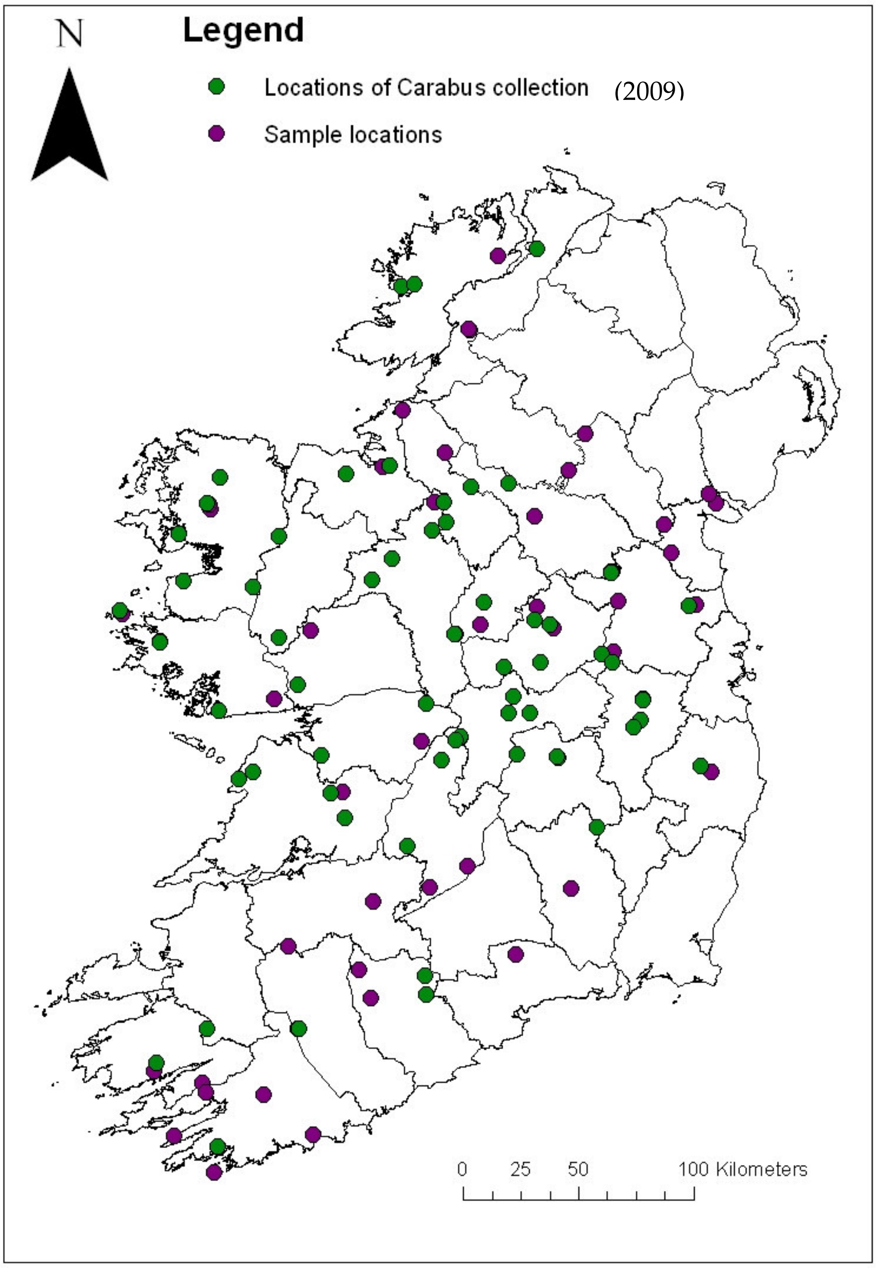


Figure 3.3: Sampling locations (as Figure 3.2), but highlighting those locations where the genus *Carabus* were collected.

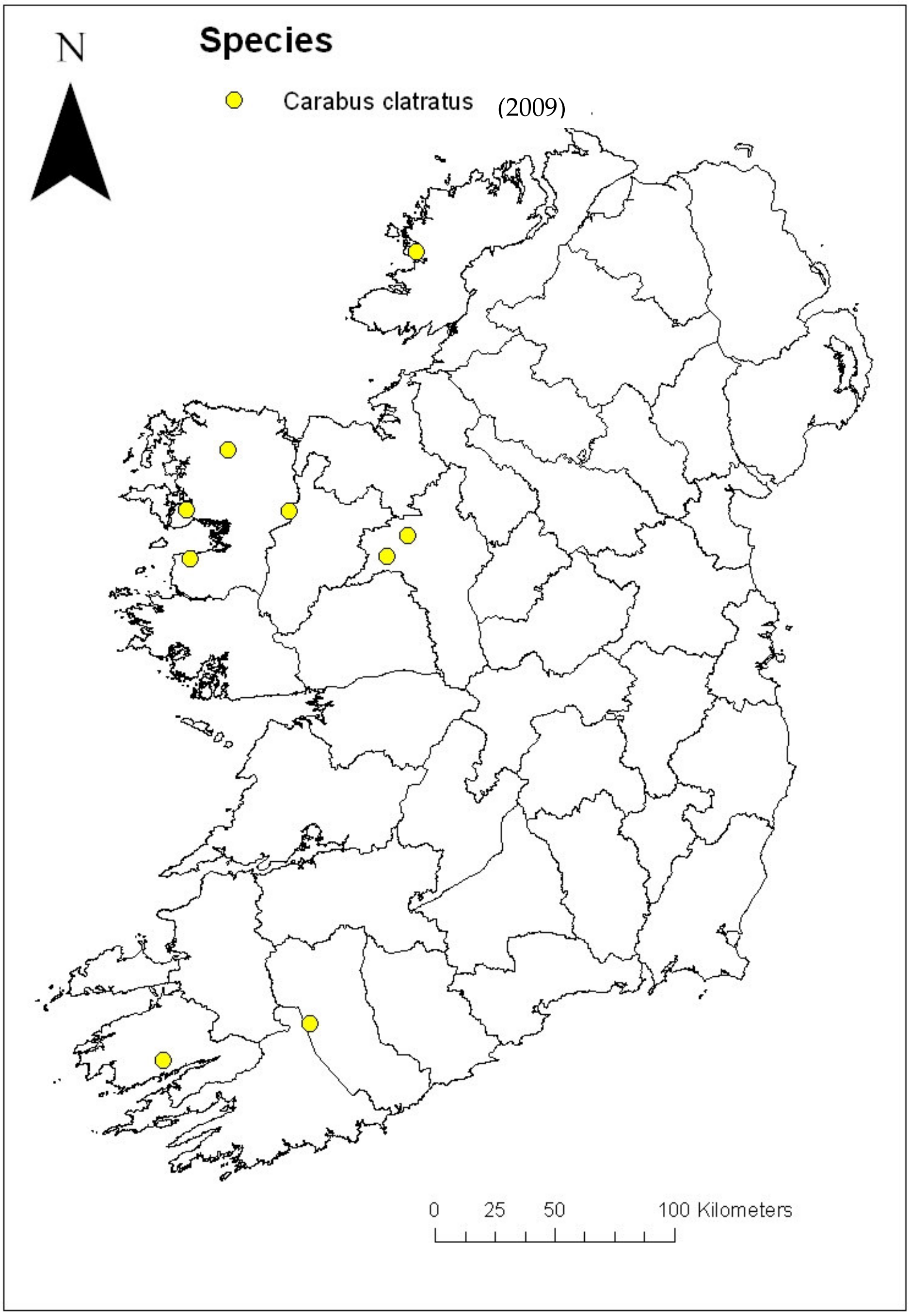


Figure 3.4: Distribution of *Carabus clatratus* in the National Survey (2009).

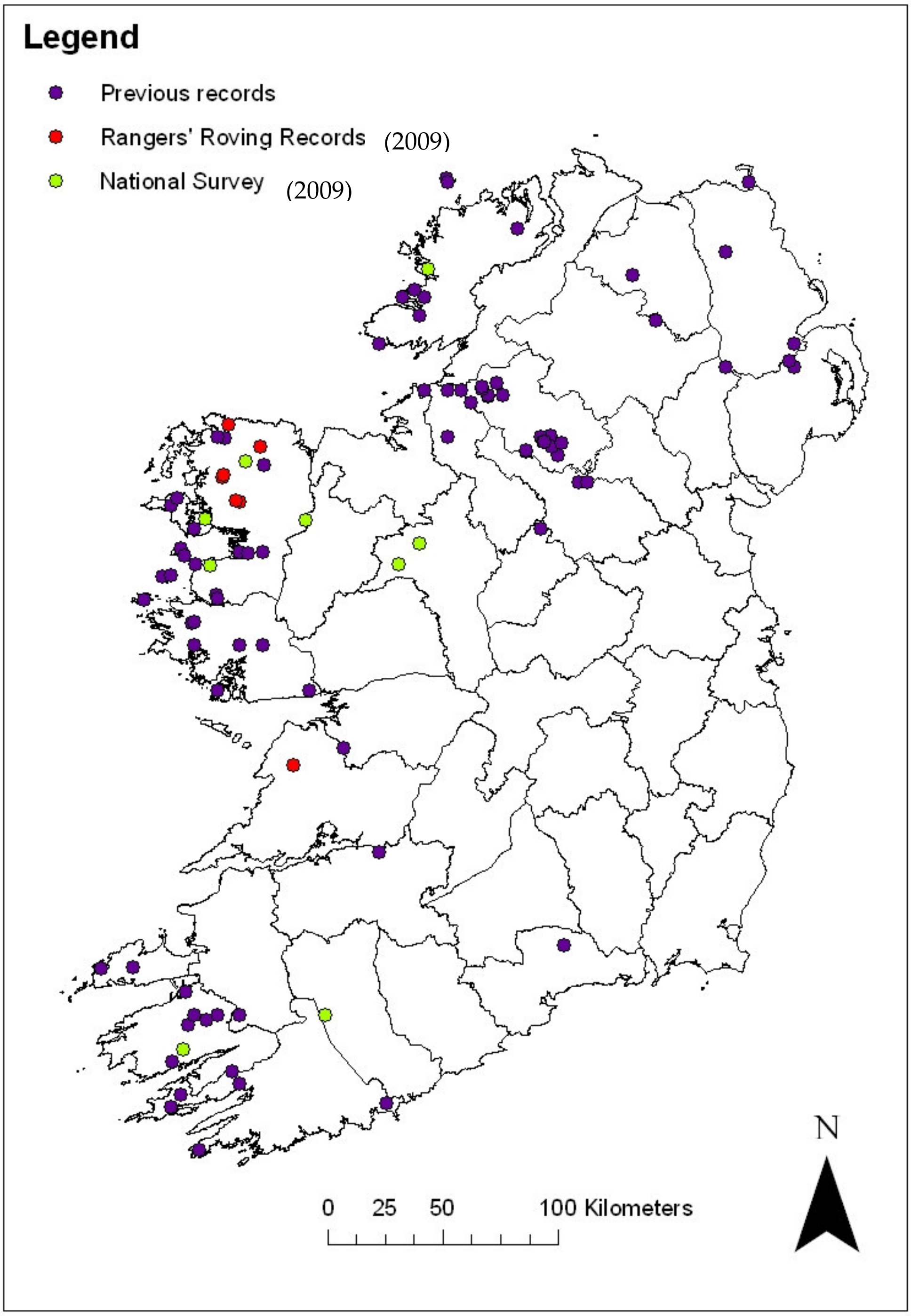


Figure 3.5: Collections of *Carabus clatratus* in the National survey, roving records and previous records kindly supplied by Dr. R. Anderson.

In contrast, *Carabus granulatus* L. has an extensive geographical distribution (Figure 3.6), which is not surprising since although generally hygrophilous, it has a somewhat eurytopic habit.

The other two species of *Carabus* collected in the present study show a fairly low level of occurrence. *Carabus problematicus* Herbst, although widely distributed, was collected in only eight of the samples (Figure 3.7) whereas *Carabus glabratus* Paykull was even more local, occurring in only three of the samples (Figure 3.8). It is worth noting that neither of these species are listed in the UK's red data list of Carabidae, whereas the apparently more common *C. clatratus* is listed as Nationally Scarce (A).

Despite previous assertions that *C. clatratus* is mainly a blanket bog specialist (Anderson *et al.* 2000), the national survey shows that, both in terms of frequency of collection (Figure 3.9 a) and even more so in the abundance of individuals caught (Figure 3.9 b), the species occurs in a variety of habitats with cut-over bog and raised bog being particularly important.

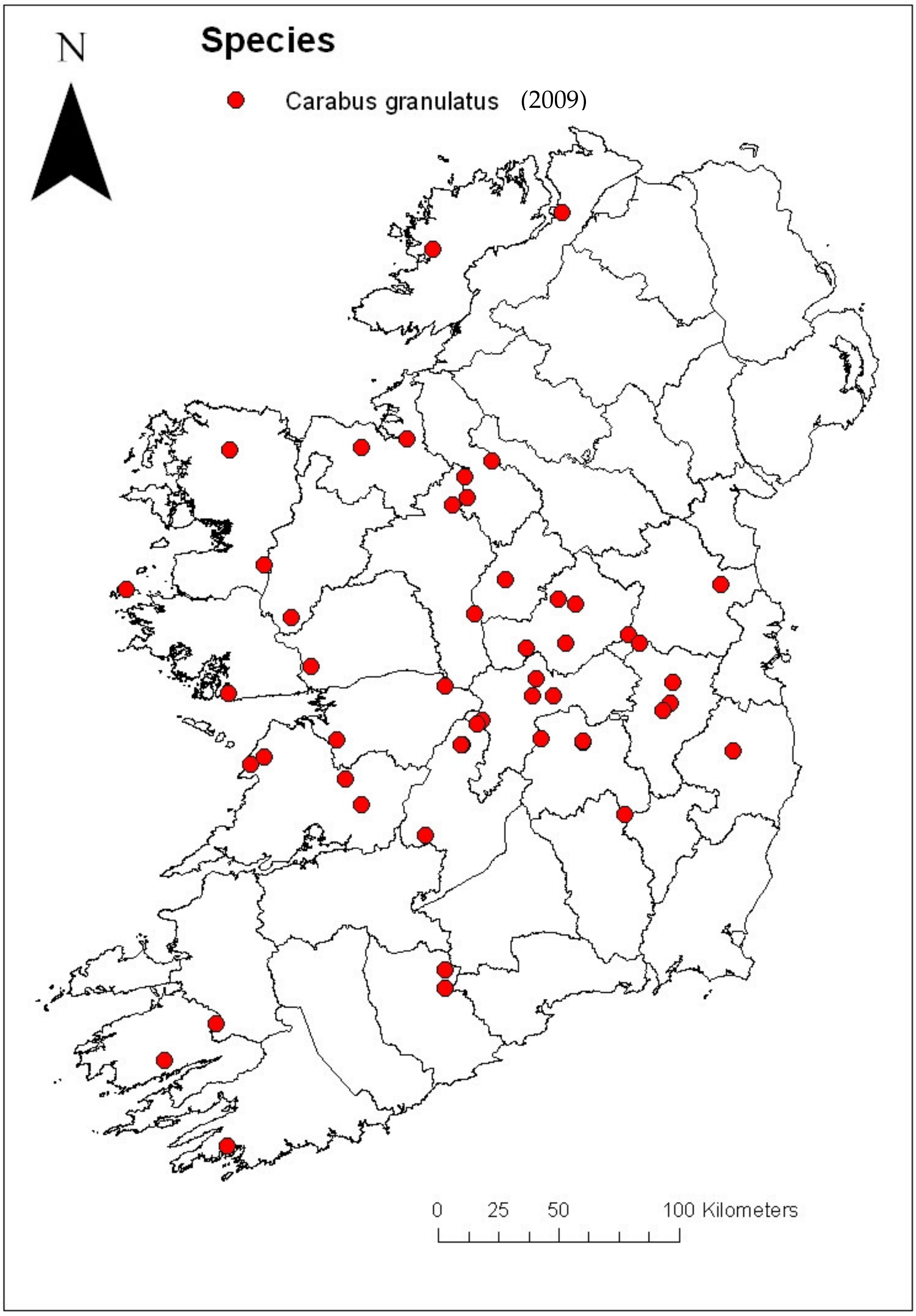


Figure 3.6: Distribution of *Carabus granulatus* in the National Survey (2009).

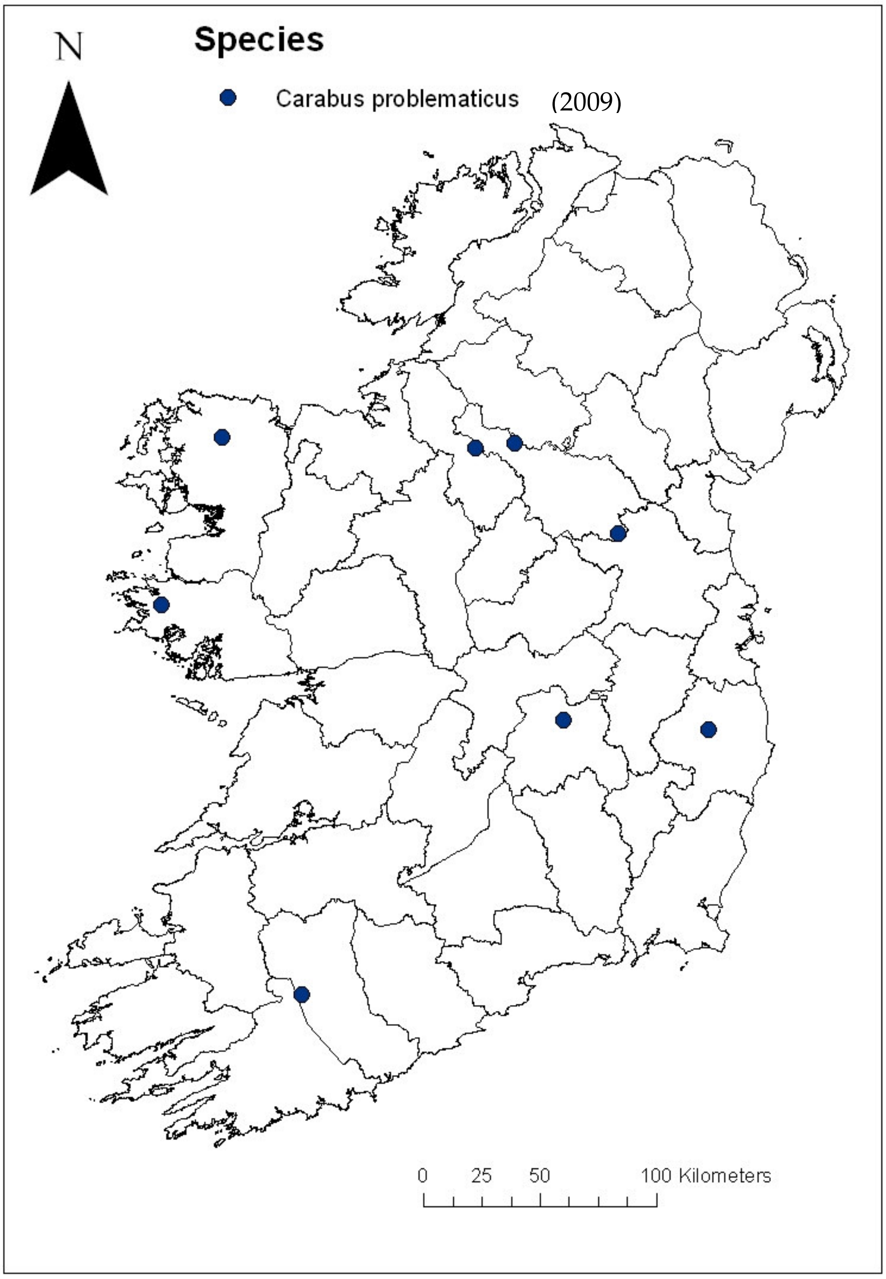


Figure 3.7: Distribution of *Carabus problematicus* in the National Survey (2009).

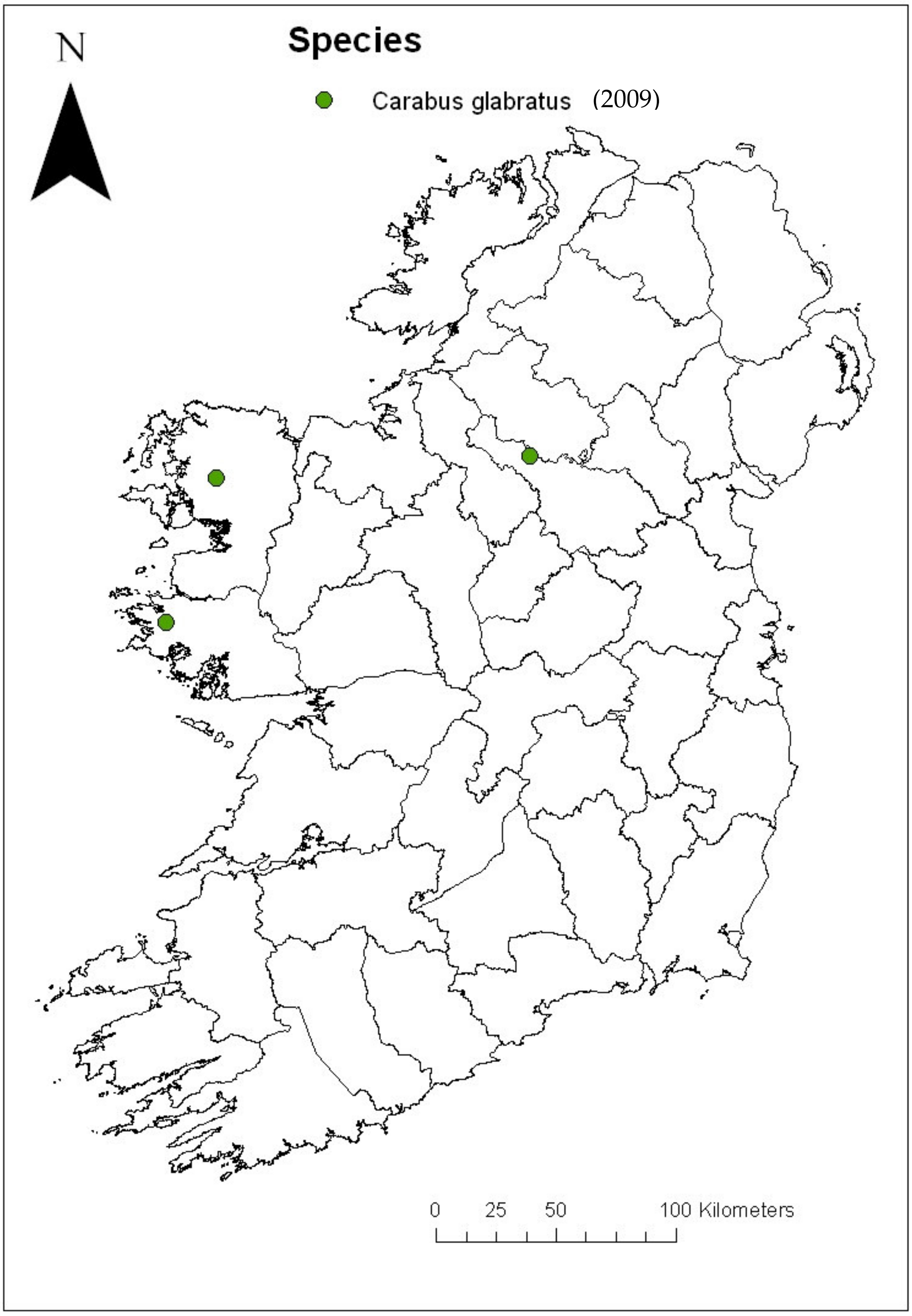


Figure 3.8: Distribution of *Carabus glabratus* in the National Survey (2009).

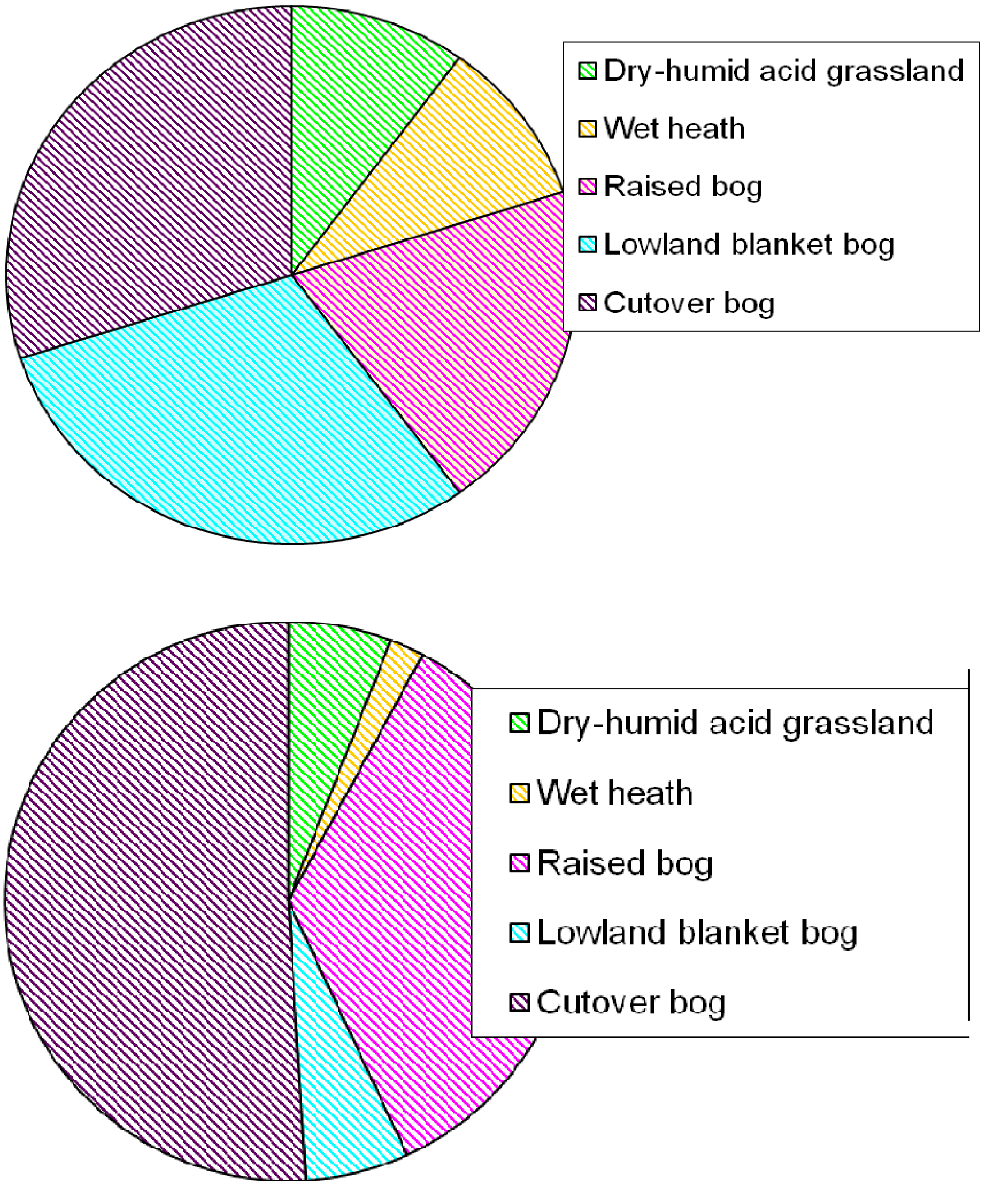


Figure 3.9: Frequency a) and abundance b) of *Carabus clatratus* in various habitats surveyed in the National Survey (2009).

Most samples were collected from habitats that were rated “good” in terms of the ecological / environmental condition of the site (Appendix 2 question 12) by the participating staff (Figure 3.10 a). However, the proportion of habitats in which *C. clatratus* were collected that were rated “good” was lower than this (Figure 3.10 b) and lower again when the total abundance of *C. clatratus* was considered (Figure 3.10 c) indicating a preference for habitats that were rated “bad”. This has important consequences for the way in which wetland habitats are perceived with respect to their ground beetle fauna.

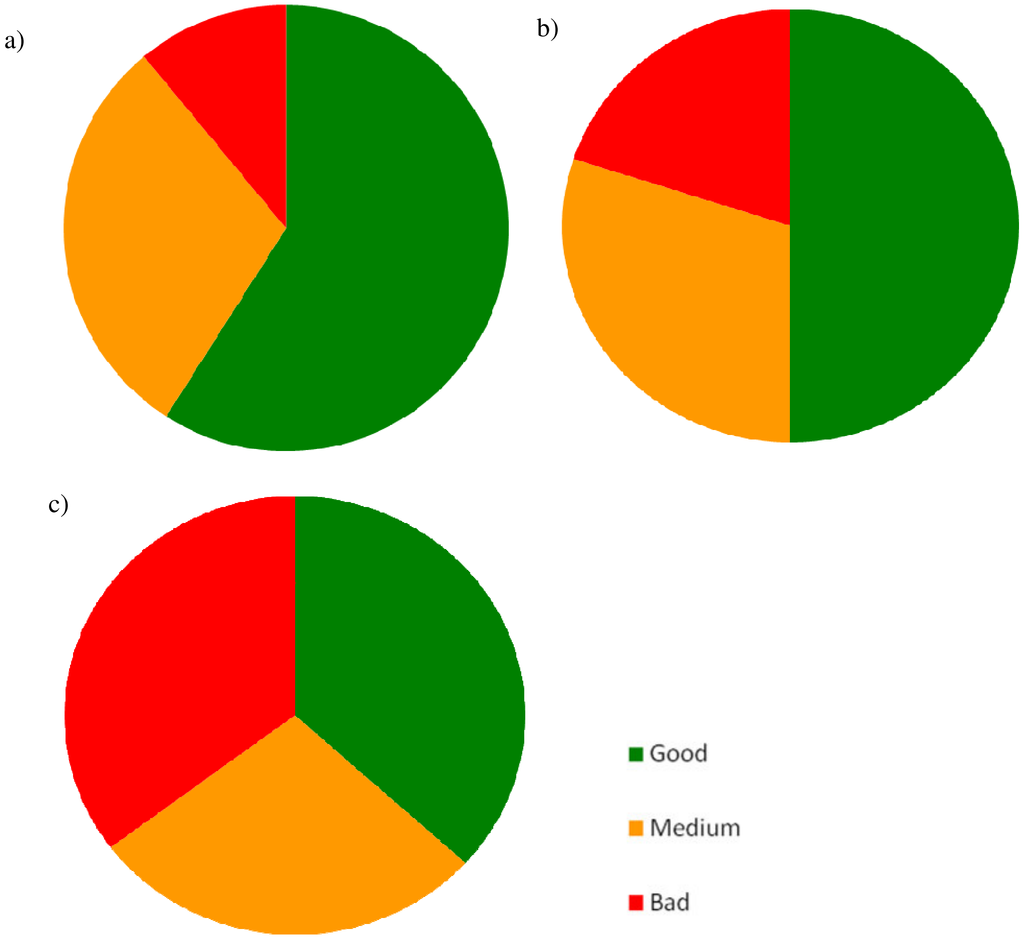


Figure 3.10: Proportion of habitats rated “good”, “medium”, and “bad” that were a) sampled in the survey, b) the frequency of those where *Carabus clatratus* was collected and c) the abundance of *Carabus clatratus* by habitat quality in which they were collected.

A General Linear model (univariate) was used to assess the effects of the various management regimes, habitat and the designation status of sites on the abundances of the various *Carabus* species. Table 3.1, below, shows that the only significant variable explaining *C. clatratus* abundance is that of perceived habitat quality. Figure 3.11 shows that *C. clatratus* tends to be maximal in habitat considered to be of “bad” ecological / environmental quality.

GLM’s of the same independent variables for the other species of *Carabus* did not detect a statistically significant effect for either the abundance or the square root of the abundance.

Table 3.1: Significance of predictor variables for *Carabus clatratus*.

Dependent Variable: *C_clatratus*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Model	150.539[a]	29	5.191	.750	.803	.237
Site_designation	18.770	1	18.770	2.712	.104	.037
Habitat	52.766	23	2.294	.331	.998	.098
perceived_habitat_quality	54.941	2	27.470	3.969	.023	.102
Veg_height	.156	1	.156	.023	.881	.000
Elevation	.338	1	.338	.049	.826	.001
Error	484.461	70	6.921			
Total	635.000	99				

a. R Squared = .237 (Adjusted R Squared = -.079)

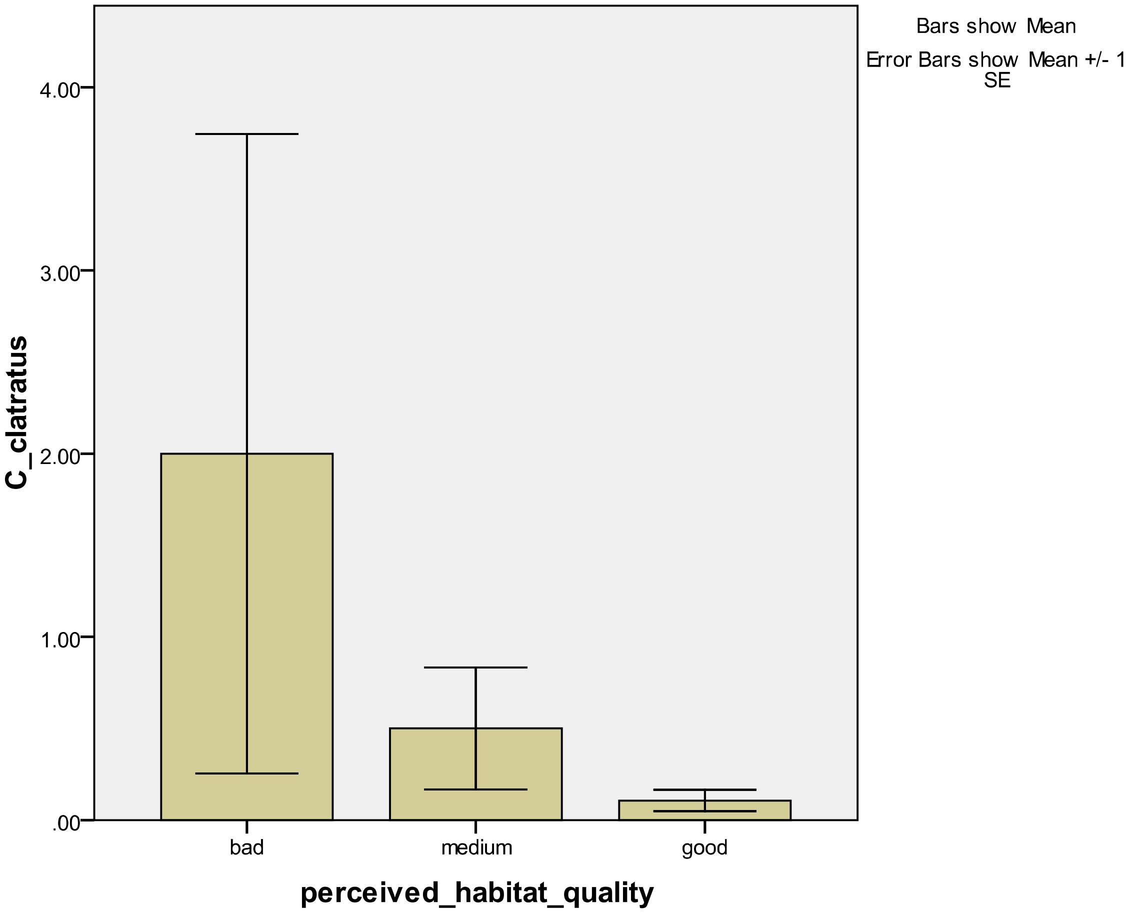
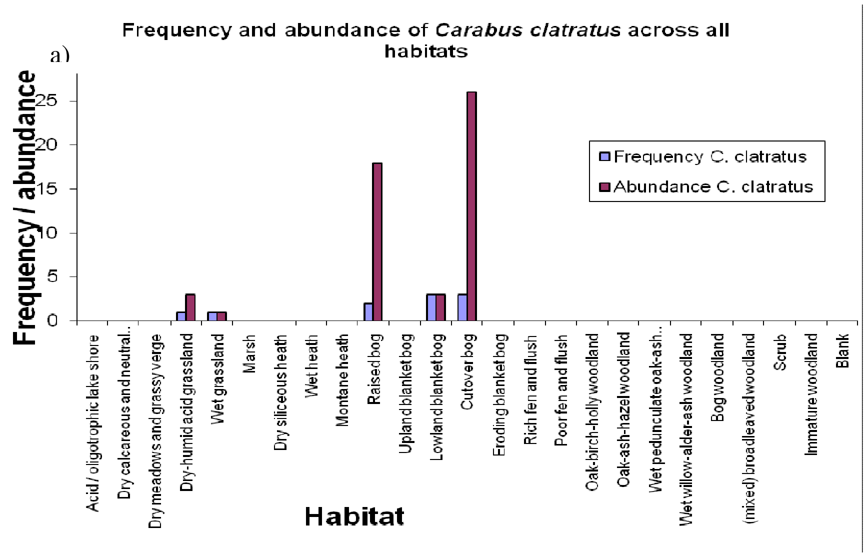
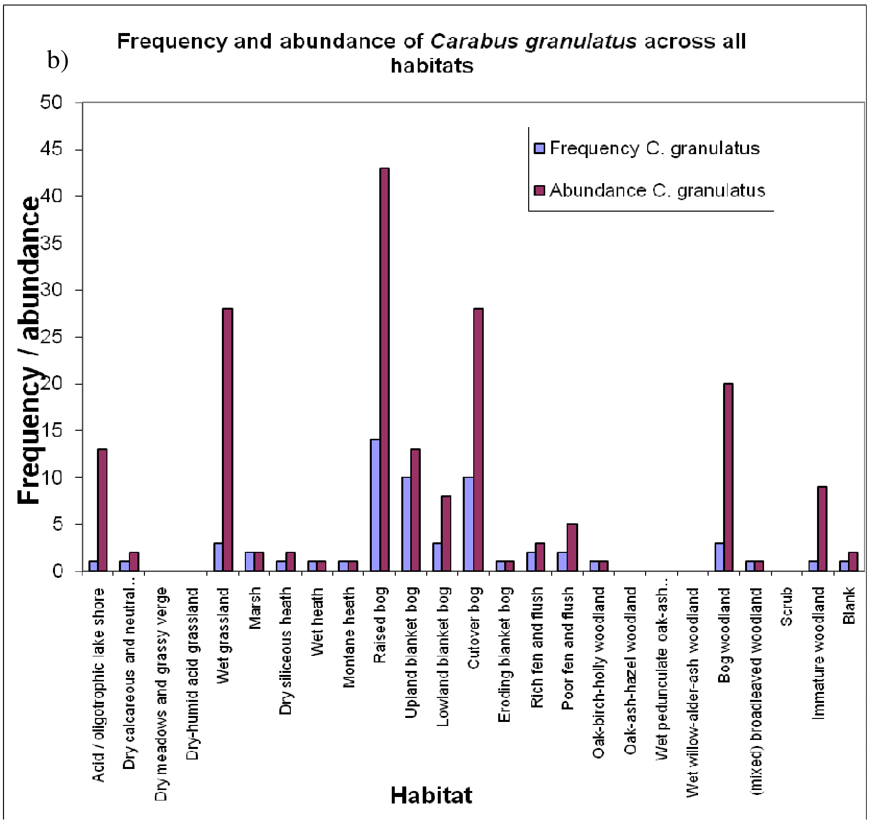


Figure 3.11: Effect of perceived habitat quality on *C. clatratus* abundance.

As noted above, within the genus *Carabus*, collections were also made of the more eurytopic (wider niche) *Carabus granulatus*, which occurred in most of the habitats surveyed at a higher abundance, compared to *C. clatratus* (Figure 3.12 b versus 3.12 a). The two other *Carabus* collected both have a lower abundance and frequency than *C. clatratus*. *Carabus problematicus* (Figure 3.12 c) being notably more restricted even than *Carabus glabratus* (Figure 3.12 d). The niche breadth of both these species, in terms of habitat associations, also appears to be more restricted than those of *C. clatratus*. As noted above, neither of these species is listed on the UK red data list. However, the current available data (Figures 3.7, 3.8, 3.13 and 3.14) appear to show a fairly restricted distributions and habitat associations, particularly in the Republic of Ireland.





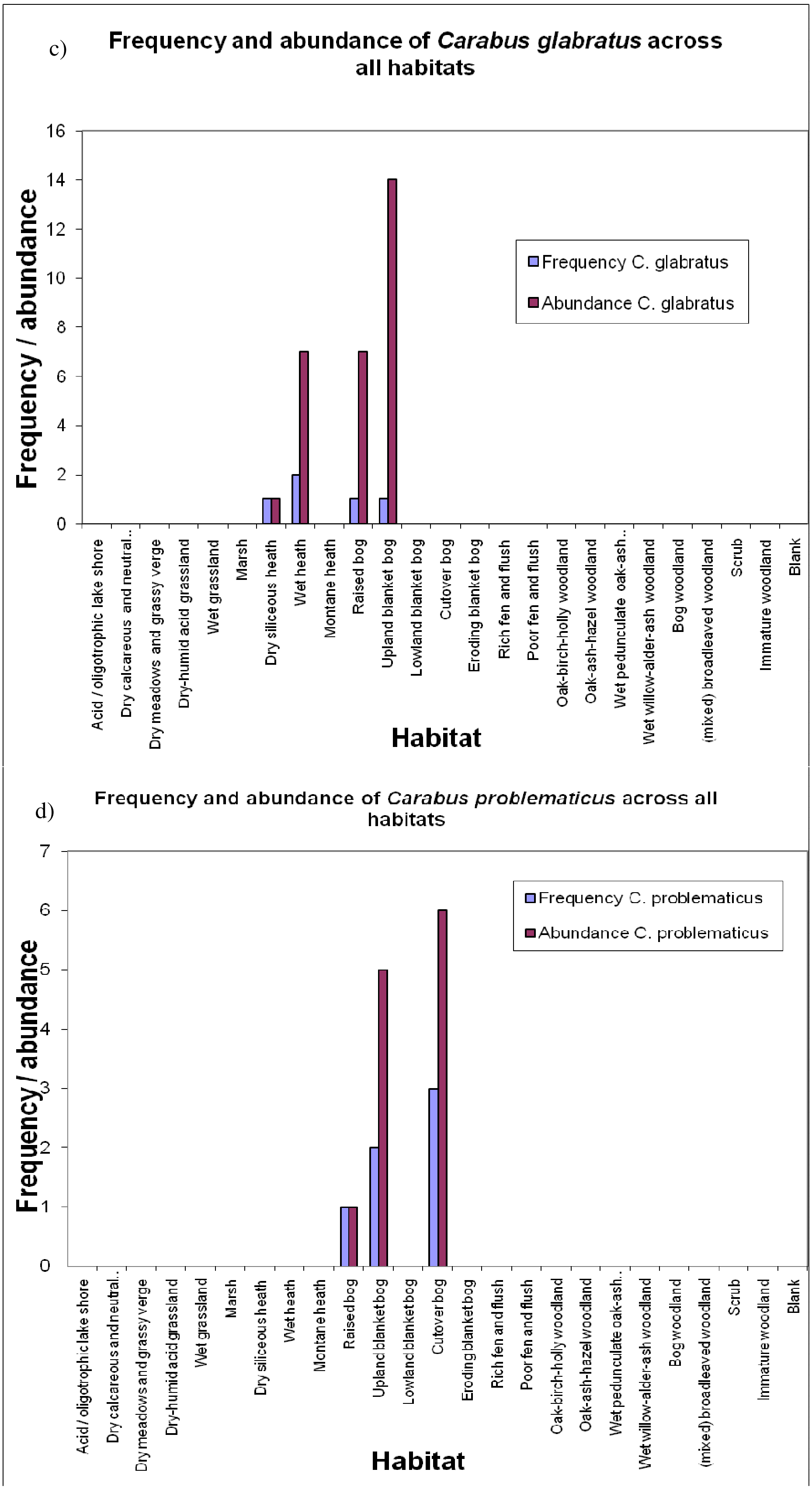


Figure 3.12: Frequency and abundance of a) *Carabus clatratus*, b) *Carabus granulatus*, c) *Carabus problematicus* and d) *Carabus glabratus* according to the habitat in where they were collected in the national survey.

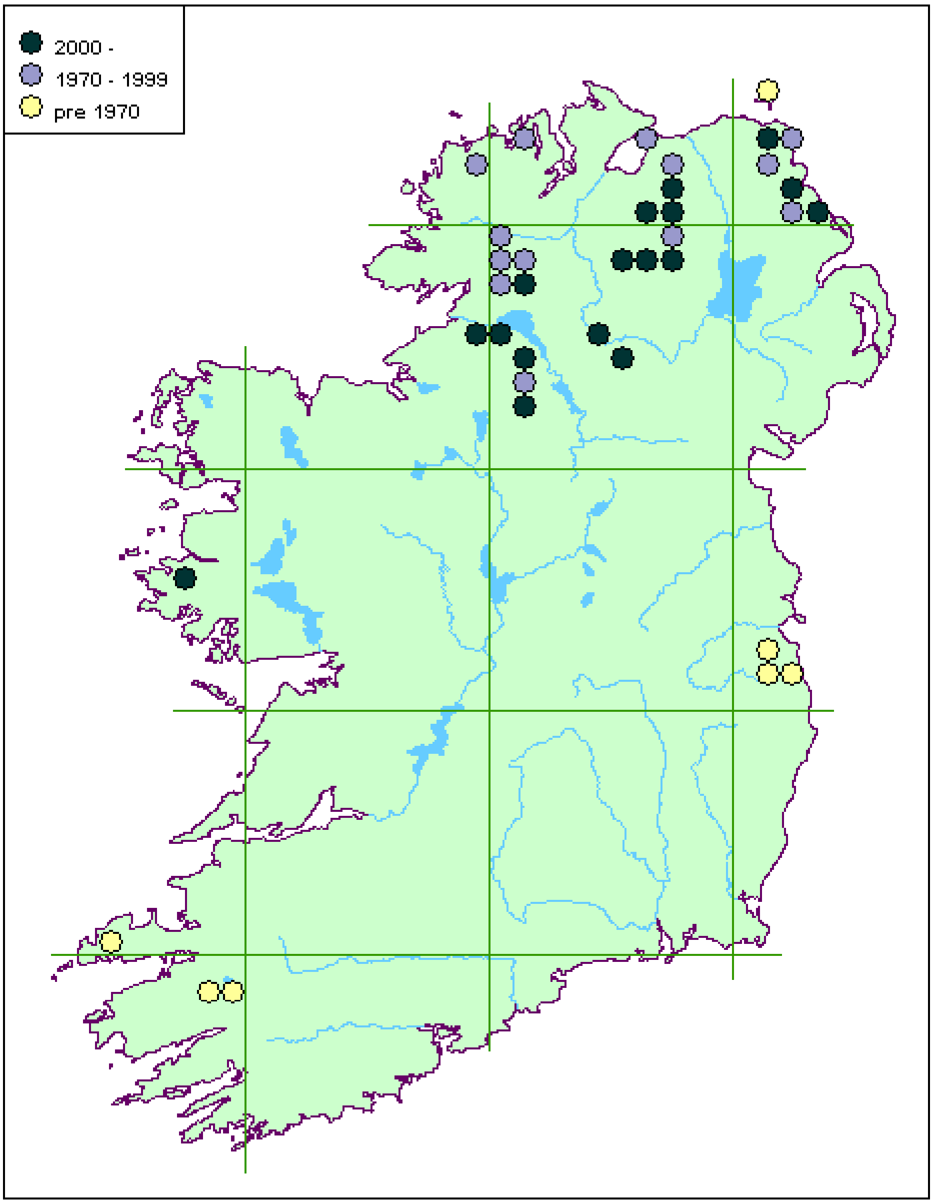


Figure 3.13: *Carabus glabratus* distribution records prior to the national survey[5]

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[5] available at **http://www.habitas.org.uk/groundbeetles/index.html**

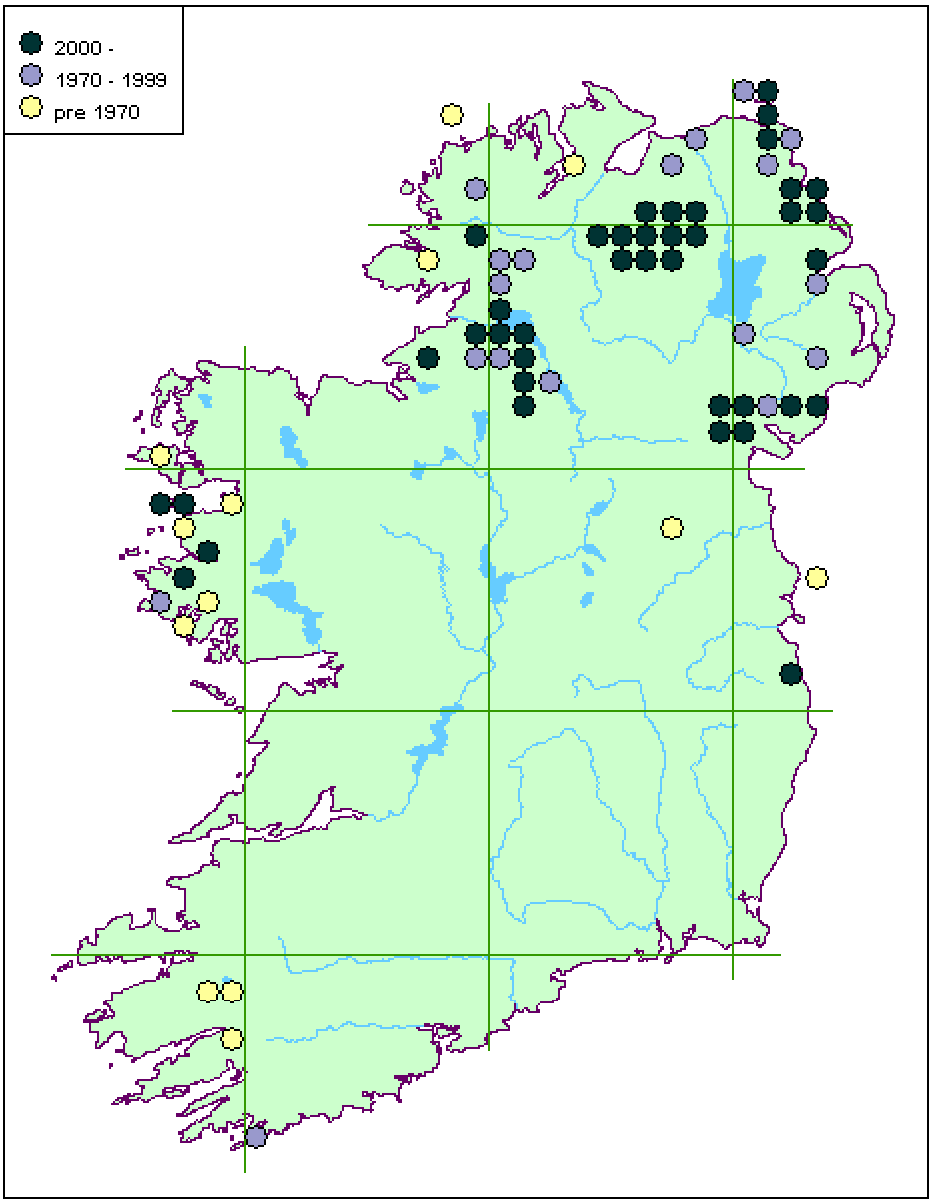

Figure 3.14: *Carabus problematicus* distribution records prior to the national survey[6]

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[6] available at **http://www.habitas.org.uk/groundbeetles/index.html**

Conclusions

Carabus clatratus has a restricted distribution in Ireland. However, in contrast to previous findings, it is not restricted to pristine blanket bog and it may be found very frequently, and in high abundance, on both cut-over and raised bog. Designation status, habitat type and vegetation structure did not appear to influence *C. clatratus* abundance, but the perceived habitat quality did, with *C. clatratus* tending to occur in habitats rated as of "bad" ecological / environmental quality, highlighting the importance of rating habitats from an invertebrate perspective. Other species, not listed in the British Red Data Book, namely *Carabus problematicus* and *Carabus glabratus*, may have a more restricted distribution, in the Republic of Ireland, both in terms of abundance / frequency of occurrence and habitat niche breadth.

4. GENERAL CONCLUSIONS AND RECOMMENDATIONS

The purpose of this section is to provide conclusions and recommendations based on the present study. Following this, however, more general recommendations will be considered together with some of the difficult choices that invertebrates may lead us to face.

The community study highlighted qualitative differences in Carabidae between coniferous forestry plantations and neighbouring blanket bog habitats. Whereas relatively common, widespread and rather eurytopic species were indicative of conifer plots, more restricted, stenotopic and rare species were indicative of blanket bog sites in general, with *Carabus clatratus* being the strongest indicator for blanket bog sites. A simple corollary of this conclusion would be the recommendation to extend the Coillte "Blanket Bog Restoration Project". This EU Life project ended in 2008 and is an example of what Samways (2005) describes as "landscape level" intervention. By blocking drains, and removing trees, blanket bog may be restored, which would benefit native peatland species in the ecosystem. In terms of "ecosystem triage" (Samways 2000), blanket bog appears to be a case of "do something" as opposed to "beyond repair" or "minimal impact".

Within the blanket bog sites, differences between management regimes were less pronounced than between coniferous forest sites and blanket bogs. The effect of overgrazing / erosion was more pronounced than hand turf cutting, the latter traps tending to ordinate with the undamaged traps. *Carabus clatratus* showed no preference for any particular type of blanket bog site, but did show a positive relationship to average ground temperature. This highlights the important point that with management for particular focal taxa, although vegetation structure can be important, it may be context dependent (e.g. temperature may be of importance in the case of *C. clatratus*).

In the national survey *Carabus clatratus* was very rare, and though it showed a preference for peatland sites, there was no notable preference for blanket bog as opposed to raised / cut-over bog sites. The species tended to occur in habitats that were rated as of "bad" ecological / environmental quality. The results highlight two possibilities: Firstly, *C. clatratus*, may be pushed out to the edge of its niche i.e. it no longer occupies its optimum niche gestalt (*sensu* James *et al.* 2001) which is "good quality blanket bog" or, more likely, that its realised ecological niche was always much broader. In either case, there is a need to change the way habitats are viewed where insects are considered.

Other *Carabus* species also appeared to have restricted habitat associations and occur in a low frequency of samples at a low abundance. These results were consistent with known distributions and suggest that these species may also require protection. The first step would be to draw up a red data list of Carabidae, which collates pertinent information, in a concise way, particularly with regard to their ecology. This has been done for Northern Ireland, but much more work is needed in the Republic. Species Action Plans should then be drawn up. Although not a Habitats Directive taxon, ground beetles require these measures.

Kirby (1992) notes that, even without a single invertebrate survey for a site, there are still simple measures that can be taken to monitor assess and improve the environment for invertebrates; for example noting micro-topography and critical ecosystem elements (Hunter 2005) such as dead decaying logs, small pools, south facing slopes and, critically, some measure of vegetation structure **and** variation in that structure. These latter factors are likely to be of extreme importance in wetland habitat. These elements could be easily incorporated into Conservation Plans and Management Agreements, where plans can be drawn up to maintain, or at least not to degrade, existing critical ecosystem elements. Furthermore micro-habitat creation may be considered a viable option, but this could be contentious e.g. it may be useful to allow some flood zones to develop on a mestrophic grassland by removing barriers to a river, but digging a pond in the middle of an already rare habitat may not be advised. In any case, these decisions should be made on the basis of adaptive management (Holling 1978), which requires close scrutiny and monitoring of ecosystem responses to management changes. Carabids and other invertebrates should be considered as well as vegetation, birds and mammals.

Re-introduction, re-wilding and "alien" species are currently important points for debate. We have to ask how far back we want to go? At what point is re-introduction desirable e.g. consider the large blue (*Maculinea arion*) in the UK, which has been a major success. Would it be prudent to try to expand the range of the protected marsh fritillary (*Euphodryas aurinia*) before re-introduction is necessary? And what about currently unprotected species, *C. clatratus* included? Alien species pose another problem – *Buddleja davidii* for example is certainly non-native, but really is enhancing the native invertebrate fauna whereas the native Cinnabar moth (*Tyria jacobaeae*) is dependent on the noxious weed ragwort (*Senecio jacobaea*). These are extreme examples, but a whole continuum of choices such as these will be necessary. With climate change insects will migrate – they surely then cannot be deemed "alien species"? Which species should we facilitate and which not? Either way, non-analogue insect assemblages will become a part of the biosphere under current climate change scenarios.

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APPENDIX 1: ORIGINAL DATA USED IN THE ANALYSIS OF CHAPTER 2

74 sample points
25 species

	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q	q
	A. parallelipiedus	P. melanarius	P. niger	P. rhaeticus	P. anthracinus	P. madidus	P. strenuus	P. diligens	C. granulatus	C. clatratus	C. problematicus	B. varium	B. lampros	N. salina	N. biguttatus	N. substriatus	C. campestris	N. germinyi	L. terminatus	O. harpaloides	C. caraboides	C. rotundicollis	T. obtusus	C. glabratus	N. brevicollis
AI(i)	5	3	11	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	18	0	0	0	0	1
AI(ii)	3	2	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	31	0	0	0	0	2
AI(iii)	25	3	22	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	42	0	1	0	0	3
AI(iv)	17	4	23	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	11	1	0	0	0	0
AI(v)	6	0	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	4
AI(vi)	21	2	15	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	25	2	0	0	0	2
AI(vii)	17	7	16	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	4	3	0	0	0	2
AI(viii)	23	5	14	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	0	1	0	0	2
AI(ix)	5	2	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	1	0	0	0	0
AII(i)	0	0	0	0	0	0	0	0	0	3	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0
AII(ii)	0	0	1	0	0	0	0	0	0	5	1	0	1	12	0	0	0	0	0	0	0	0	0	0	0
AII(iii)	0	0	0	0	0	0	0	0	0	11	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
AII(iv)	0	0	0	0	0	0	0	0	0	5	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
AII(v)	0	0	0	0	0	0	0	0	0	4	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
AII(vi)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AII(vii)	0	0	0	0	0	0	0	0	0	5	0	0	1	12	0	0	0	0	0	0	0	0	0	0	0
AII(viii)	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0
AII(ix)	0	0	0	0	0	0	0	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
AIII(i)	0	0	0	2	0	0	0	0	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
AIII(ii)	0	0	0	0	0	0	0	0	0	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

AIII(iii)	0	0	0	0	0	0	1	0	0	14	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
AIII(iv)	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AIII(v)	0	0	0	1	0	0	0	0	0	5	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
AIII(vi)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AIII(viii)	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AIII(ix)	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
BI(i)	2	0	1	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0
BI(ii)	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0
BI(iii)	0	0	0	0	0	0	0	1	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0
BI(iv)	0	1	0	0	0	0	1	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
BI(v)	0	0	1	0	0	0	0	1	0	0	0	0	2	1	1	0	0	0	0	1	0	0	0	0	0
BI(vi)	0	0	0	0	0	0	0	0	0	1	0	0	0	8	0	0	0	0	0	0	0	0	0	0	2
BI(vii)	0	0	1	0	0	0	0	1	0	0	0	0	0	6	1	0	0	0	1	0	0	0	0	0	0
BI(viii)	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
BI(ix)	0	0	0	0	0	0	0	0	0	0	0	0	2	9	0	0	0	0	0	0	0	0	0	0	1
BII(i)	9	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
BII(ii)	20	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
BII(iii)	14	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
BII(iv)	9	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0
BII(v)	30	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0
BII(vi)	16	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BII(vii)	22	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BII(viii)	9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BII(ix)	19	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIII(i)	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIII(ii)	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIII(iii)	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIII(iv)	0	0	0	0	0	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
BIII(v)	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

BIII(vi)	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIII(vii)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIII(viii)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
CI(i)	28	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CI(ii)	14	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CI(iii)	11	0	20	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0
CI(iv)	26	0	14	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
CI(v)	14	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CI(vi)	17	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CI(vii)	15	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CI(viii)	23	0	8	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CI(ix)	20	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CII(ii)	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CII(v)	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CII(vi)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CII(vii)	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CII(viii)	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIII(i)	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
CIII(ii)	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
CIII(iii)	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0
CIII(iv)	0	0	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIII(v)	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIII(vi)	0	0	0	1	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIII(viii)	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIII(ix)	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	c	c	c	c	c	q	q	q	q	q	q	q	q	q	q	q	q	q	q
	location	habitat type	trap size	sampling grid	forest/bog	Veg_dens	Veg_height	Veg_len	LOI	pH	moisture	Light_above	Light_below	Avg_temp	Avg_RH	min_temp.	max_temp	min_RH	max_RH
AI(i)	1	1	1	1	1	8.38	1.22	3.09	89	3.3	306.5	3.77	3.7	11.83561	44.93428	9.151659	15.05167	7.141808	82.39837
AI(ii)	1	1	2	1	1	8.75	0.69	1.41	5	3.35	69.85	4.43	3.82	11.83561	44.93428	9.151659	15.05167	7.141808	82.39837
AI(iii)	1	1	3	1	1	15.25	0.34	0.66	69	3.48	200.5	4.12	3.68	11.83561	44.93428	9.151659	15.05167	7.141808	82.39837
AI(iv)	1	1	2	1	1	23	0	0	74	3.8	335.18	4.6	4.05	11.83561	44.93428	9.151659	15.05167	7.141808	82.39837
AI(v)	1	1	3	1	1	10	1.31	2.63	17	3.8	73.94	5.36	4.84	11.83561	44.93428	9.151659	15.05167	7.141808	82.39837
AI(vi)	1	1	1	1	1	13.8	0	0	89	3.82	293.61	4.98	4.3	11.83561	44.93428	9.151659	15.05167	7.141808	82.39837
AI(vii)	1	1	3	1	1	11.5	0.28	0.56	90	3.6	376.03	1.93	1.88	11.83561	44.93428	9.151659	15.05167	7.141808	82.39837
AI(viii)	1	1	1	1	1	14	0.16	0.34	50	3.87	61.02	4.76	1.29	11.83561	44.93428	9.151659	15.05167	7.141808	82.39837
AI(ix)	1	1	2	1	1	22.63	0.06	0.22	83	3.69	244.07	5.54	4.18	11.83561	44.93428	9.151659	15.05167	7.141808	82.39837
AII(i)	1	2	1	2	2	4.63	5.53	15.03	92	4.19	902.01	23.35	16.73	12.79244	51.96507	8.160222	20.16294	4.057275	95.26031
AII(ii)	1	2	2	2	2	5	2.25	5.06	94	4.01	735.18	21.86	19.26	12.79244	51.96507	8.160222	20.16294	4.057275	95.26031
AII(iii)	1	2	3	2	2	4	2.19	6.63	90	4.08	671.35	23.53	17.73	12.79244	51.96507	8.160222	20.16294	4.057275	95.26031
AII(iv)	1	2	2	2	2	4.5	2.5	6.34	90	3.98	521.07	20.82	15.72	12.79244	51.96507	8.160222	20.16294	4.057275	95.26031
AII(v)	1	2	3	2	2	3.5	1.31	7.91	94	4.06	682.96	17.64	15.43	12.79244	51.96507	8.160222	20.16294	4.057275	95.26031
AII(vi)	1	2	1	2	2	5.13	4.5	12.44	91	4.02	912.67	19.2	15.23	12.79244	51.96507	8.160222	20.16294	4.057275	95.26031

AII(vii)	1	2	3	2	2	4.75	2.56	5.22	95	4.08	687.5	21.98	19.02	12.79244	51.96507	8.160222	20.16294	4.057275	95.26031
AII(viii)	1	2	1	2	2	3.75	4.06	9.34	93	4.02	722.69	25.6	20.2	12.79244	51.96507	8.160222	20.16294	4.057275	95.26031
AII(ix)	1	2	2	2	2	7	1.41	3.13	95	3.99	647.52	26.03	21.68	12.79244	51.96507	8.160222	20.16294	4.057275	95.26031
AIII(i)	1	3	1	3	2	11.63	12.75	24.34	97	4.1	814.24	31	17.15	13.12931	41.65071	7.503485	22.4351	2.71982	91.1259
AIII(ii)	1	3	2	3	2	11	11.88	21.59	95	4.06	642.64	31.7	22.5	13.12931	41.65071	7.503485	22.4351	2.71982	91.1259
AIII(iii)	1	3	3	3	2	14.25	17.56	24.91	93	3.87	697.61	36.15	19.55	13.12931	41.65071	7.503485	22.4351	2.71982	91.1259
AIII(iv)	1	3	2	3	2	14.63	15.88	24.78	96	3.87	1059.52	20.82	16.4	13.12931	41.65071	7.503485	22.4351	2.71982	91.1259
AIII(v)	1	3	3	3	2	13.13	15.06	27.19	94	3.92	766.38	14.62	39.35	13.12931	41.65071	7.503485	22.4351	2.71982	91.1259
AIII(vi)	1	3	1	3	2	14.25	19.06	30.88	95	3.99	764.29	15	46.5	13.12931	41.65071	7.503485	22.4351	2.71982	91.1259
AIII(viii)	1	3	1	3	2	17	17.56	28.97	94	3.94	978.6	24.25	8.38	13.12931	41.65071	7.503485	22.4351	2.71982	91.1259
AIII(ix)	1	3	2	3	2	18.38	20.31	29.22	94	3.96	1243.39	38.5	20.4	13.12931	41.65071	7.503485	22.4351	2.71982	91.1259
BI(i)	2	2	1	4	2	8.63	2.56	8.28	77	3.51	266.7	35.74	29.19	12.03739	54.28153	8.037635	19.02782	12.95147	92.4404
BI(ii)	2	2	2	4	2	3.25	1.94	4.56	77	3.6	533.2	35.73	33.71	12.03739	54.28153	8.037635	19.02782	12.95147	92.4404
BI(iii)	2	2	3	4	2	10.13	4.38	3.59	80	3.68	377.83	42.08	35.29	12.03739	54.28153	8.037635	19.02782	12.95147	92.4404
BI(iv)	2	2	2	4	2	9.88	12.25	20.91	75	3.84	842.3	33.2	23.9	12.03739	54.28153	8.037635	19.02782	12.95147	92.4404
BI(v)	2	2	3	4	2	4.63	4.81	12.5	79	3.7	415.69	35.32	27.13	12.03739	54.28153	8.037635	19.02782	12.95147	92.4404
BI(vi)	2	2	1	4	2	1.75	0	0	67	3.55	333.33	26.87	23.67	12.03739	54.28153	8.037635	19.02782	12.95147	92.4404
BI(vii)	2	2	3	4	2	5.13	1.94	7.31	68	3.23	472.36	26.35	17.88	12.03739	54.28153	8.037635	19.02782	12.95147	92.4404
BI(viii)	2	2	1	4	2	18.25	5.97	13.06	81	3.69	488.47	23	17.83	12.03739	54.28153	8.037635	19.02782	12.95147	92.4404
BI(ix)	2	2	2	4	2	2.88	1.25	3.66	73	3.83	521.33	22.13	21.87	12.03739	54.28153	8.037635	19.02782	12.95147	92.4404
BII(i)	2	1	1	5	1	12.5	4.75	16.69	81	3.75	559.45	2.41	1.7	11.12959	31.69227	9.120569	14.00379	10.2492	57.41122

BII(ii)	2	1	2	5	1	12	12.44	16.69	17	3.38	125.41	2.24	1.95	11.12959	31.69227	9.120569	14.00379	10.2492	57.41122
BII(iii)	2	1	3	5	1	14.38	4.5	21.06	15	3.4	92.52	2.33	1.68	11.12959	31.69227	9.120569	14.00379	10.2492	57.41122
BII(iv)	2	1	2	5	1	16.75	10.5	43.19	64	3.68	509.26	5.8	2.28	11.12959	31.69227	9.120569	14.00379	10.2492	57.41122
BII(v)	2	1	3	5	1	15.38	2.5	14.09	79	3.34	324.41	2.41	1.19	11.12959	31.69227	9.120569	14.00379	10.2492	57.41122
BII(vi)	2	1	1	5	1	17.5	13.56	46.59	63	3.51	459.45	2.71	2.25	11.12959	31.69227	9.120569	14.00379	10.2492	57.41122
BII(vii)	2	1	3	5	1	16.25	14.63	35.72	67	3.22	547.63	2.38	1.55	11.12959	31.69227	9.120569	14.00379	10.2492	57.41122
BII(viii)	2	1	1	5	1	21.63	20.75	53.72	26	3.35	161.85	3.12	1.9	11.12959	31.69227	9.120569	14.00379	10.2492	57.41122
BII(ix)	2	1	2	5	1	15.13	1.875	6.56	3	3.58	33.37	2.88	1.33	11.12959	31.69227	9.120569	14.00379	10.2492	57.41122
BIII(i)	2	3	1	6	2	12.38	7.94	19.56	89	3.51	1190.91	23.64	16.06	12.51393	41.3409	7.72521	20.54237	3.341707	86.26087
BIII(ii)	2	3	2	6	2	14.25	17.78	30.09	86	3.6	1337.39	21.67	15.92	12.51393	41.3409	7.72521	20.54237	3.341707	86.26087
BIII(iii)	2	3	3	6	2	17.5	14.63	28.81	90	3.92	1059.34	27.2	7.59	12.51393	41.3409	7.72521	20.54237	3.341707	86.26087
BIII(iv)	2	3	2	6	2	13	14.06	27.25	93	3.96	1288.69	21.73	12.38	12.51393	41.3409	7.72521	20.54237	3.341707	86.26087
BIII(v)	2	3	3	6	2	13.75	14.38	32.56	92	4	1251.01	25.8	6.47	12.51393	41.3409	7.72521	20.54237	3.341707	86.26087
BIII(vi)	2	3	1	6	2	10.63	15.19	23.38	94	3.86	1071.15	23.1	6.43	12.51393	41.3409	7.72521	20.54237	3.341707	86.26087
BIII(vii)	2	3	3	6	2	19	16.56	28.22	92	3.92	1114.74	17.7	10.7	12.51393	41.3409	7.72521	20.54237	3.341707	86.26087
BIII(viii)	2	3	1	6	2	15.25	15.38	26.31	93	3.93	1122.11	20.25	11.65	12.51393	41.3409	7.72521	20.54237	3.341707	86.26087
CI(i)	3	1	1	7	1	12.63	0.25	0.4	99	3.63	642.47	1.34	1.21	11.70394	21.98759	9.439341	14.12502	4.536988	39.92911
CI(ii)	3	1	2	7	1	10.13	0.16	0.19	98	3.52	468.28	1.25	1.13	11.70394	21.98759	9.439341	14.12502	4.536988	39.92911
CI(iii)	3	1	3	7	1	16.38	0.25	0.313	98	3.61	524.53	1.6	1.57	11.70394	21.98759	9.439341	14.12502	4.536988	39.92911
CI(iv)	3	1	2	7	1	9.13	0.31	5.63	98	3.54	468.19	1.59	1.82	11.70394	21.98759	9.439341	14.12502	4.536988	39.92911
CI(v)	3	1	3	7	1	10.88	0.25	0.63	98	3.55	458.89	2.13	1.97	11.70394	21.98759	9.439341	14.12502	4.536988	39.92911

CI(vi)	3	1	1	7	1	20	0.19	0.31	97	3.4	504.94	2.36	2.14	11.70394	21.98759	9.439341	14.12502	4.536988	39.92911
CI(vii)	3	1	3	7	1	6.75	1.16	8.22	94	3.81	452.57	1.48	1.35	11.70394	21.98759	9.439341	14.12502	4.536988	39.92911
CI(viii)	3	1	1	7	1	11.38	0	0	95	3.47	456.36	1.59	1.47	11.70394	21.98759	9.439341	14.12502	4.536988	39.92911
CI(ix)	3	1	2	7	1	9.88	12.19	29	96	3.15	898.37	2.6	2.52	11.70394	21.98759	9.439341	14.12502	4.536988	39.92911
CII(ii)	3	3	2	8	2	20.5	17.94	28.31	98	4.09	952.19	51.06	45.96	12.80821	38.35328	7.768222	20.81369	2.716335	86.96965
CII(v)	3	3	3	8	2	15	13.56	22.22	98	4.19	1783.64	56.68	29.43	12.80821	38.35328	7.768222	20.81369	2.716335	86.96965
CII(vi)	3	3	1	8	2	23.5	16.19	25.25	97	3.79	878.95	22.35	9.1	12.80821	38.35328	7.768222	20.81369	2.716335	86.96965
CII(vii)	3	3	3	8	2	18.75	11.63	21.69	96	4.02	1526.84	40.75	38.02	12.80821	38.35328	7.768222	20.81369	2.716335	86.96965
CII(viii)	3	3	1	8	2	23.63	12.97	21.59	97	3.97	912.99	38.2	25.54	12.80821	38.35328	7.768222	20.81369	2.716335	86.96965
CIII(i)	3	3	1	8	2	9.5	8.22	19.44	95	4.16	851.09	63.13	41.24	12.98194	41.75813	8.00879	21.97362	2.140707	94.38701
CIII(ii)	3	2	2	9	2	11.13	4.69	8.22	80	4.03	751.71	58.2	28.8	12.98194	41.75813	8.00879	21.97362	2.140707	94.38701
CIII(iii)	3	2	3	9	2	5.88	2.06	3.44	97	3.85	332.57	16.04	15.85	12.98194	41.75813	8.00879	21.97362	2.140707	94.38701
CIII(iv)	3	2	2	9	2	12.63	4.38	9.13	97	4.04	789.64	14.13	13.59	12.98194	41.75813	8.00879	21.97362	2.140707	94.38701
CIII(v)	3	2	3	9	2	7.13	4.56	8.91	97	3.96	777.84	15.94	15.71	12.98194	41.75813	8.00879	21.97362	2.140707	94.38701
CIII(vi)	3	2	1	9	2	8.5	6.88	10	92	4.02	765.04	16.9	14.82	12.98194	41.75813	8.00879	21.97362	2.140707	94.38701
CIII(viii)	3	2	1	9	2	10.5	3.72	13.88	96	3.93	590.68	58.6	42.34	12.98194	41.75813	8.00879	21.97362	2.140707	94.38701
CIII(ix)	3	2	2	9	2	11.5	7.22	18.56	97	4.02	693.46	63.25	16.37	12.98194	41.75813	8.00879	21.97362	2.140707	94.38701

APPENDIX 2: HANDOUT AND QUESTIONNAIRE COMPLETED BY RANGERS AS PART OF THE NATIONAL SURVEY (CHAPTER 3)

Methods for a National Survey of *Carabus clatratus* L.

Introduction and Background

Carabus clatratus L. is, on a continental scale, a rare species of ground beetle (Carabidae) with some of its largest populations in Ireland due to its restricted distribution to moist soils and, in particular bogland habitats. The species is quite large (22-28mm) and is fairly distinctive with conspicuous depressions in the elytra (wing cases) (Anderson *et al.*, 2000). See Figure 1 (below) and more information at the following web-site:

http://www.habitas.org.uk/groundbeetles/species.asp?item=7132

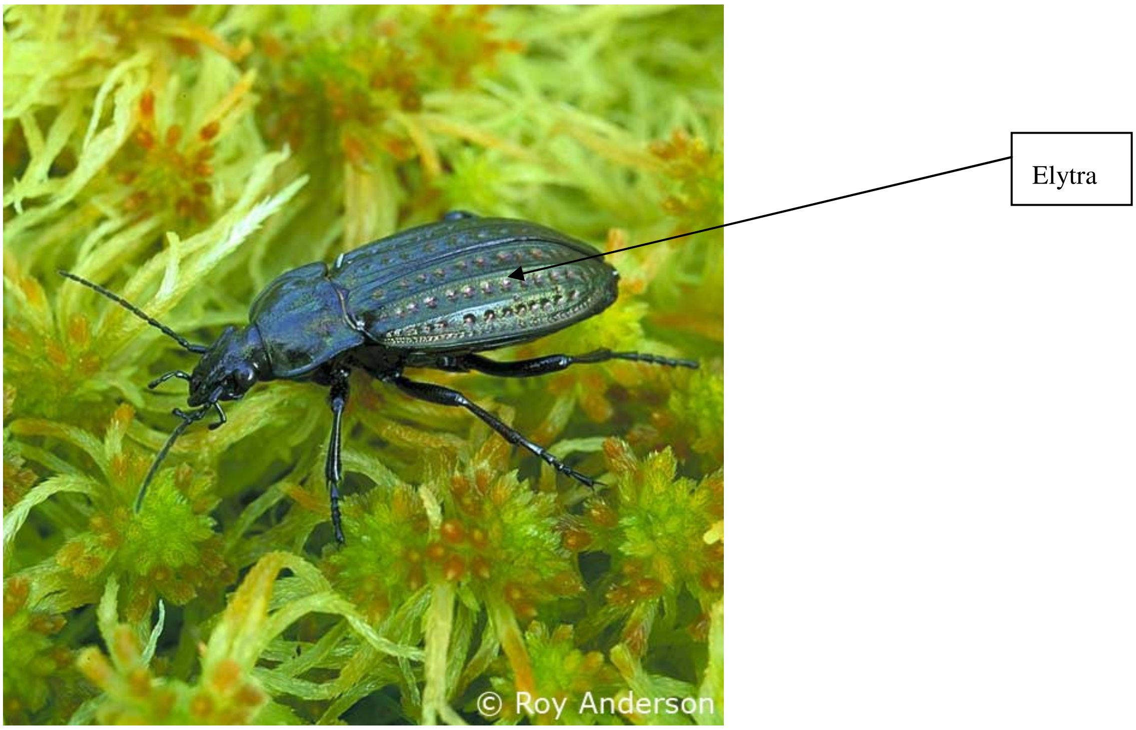

Figure 1: Carbus clatratus L. Photograph courtesy of Dr. Roy Anderson

In an effort to gain a better understanding of the ecology of this species of conservation importance, The National Parks and Wildlife Service have sponsored a two-year study to examine the community ecology and population dynamics of this species on Western blanket bog and a national survey of the species. Pitfall trapping is the preferred method as the chance of catching the species is much higher than other methods, though any occasional observations would also be very welcome.

Scope of study

It is hoped that it will be feasible to trap at a number of locations within each vice-county (Figure 2). See Webb (1980) and the following web-site for details on some ambiguous boundaries between vice-counties:

http://www.botanicgardens.ie/herb/census/webbvcs.htm

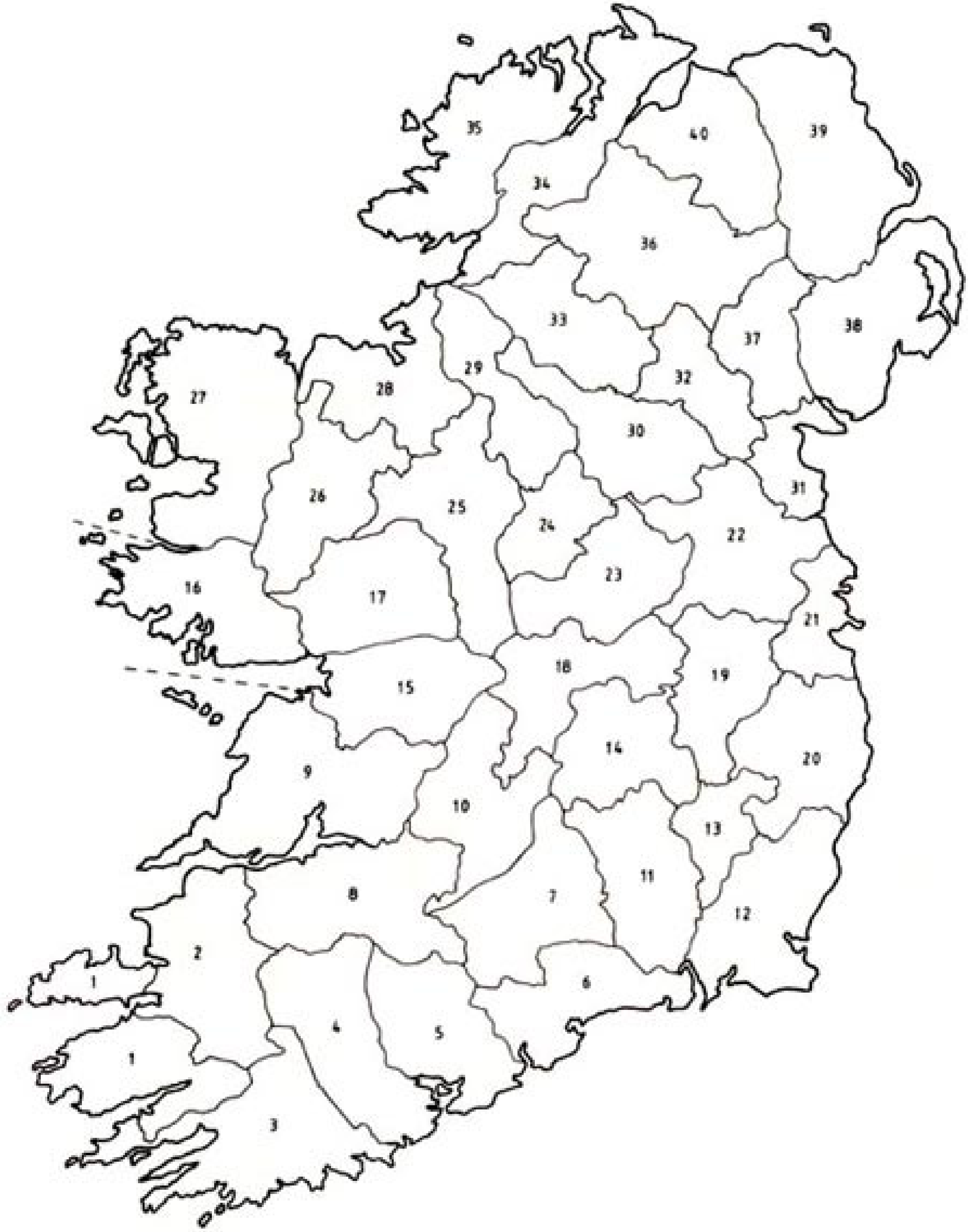

Figure 2: The Vice Counties of Ireland

As Rangers are in the best position to select appropriate habitats within their area, we list below, some of the likely habitats where the species may be found. They are in order of preference.

1) Atlantic Blanket Bog
2) Mountain Blanket Bog
3) Raised Bog
4) Cutaway Bog
5) Fens
6) Seepages with wet soils
7) Lakeshores / slow-flowing river banks
8) Wet meadows
9) Wet-woodlands
10) Other habitats

Obviously, many areas will have limited, if any, bogs and here it is suggested that wet-soil habitats e.g. fens and seepages be sampled or habitats close to water-bodies e.g. small lakes, pools or slow-flowing rivers. The species has been recorded in lakeshores and hay meadows in Fermanagh by McFerran *et al.* (1995) so these habitats may provide an alternative when other wetlands are absent. In each case, traps should be placed in uniform plots of habitat / vegetation. What look like relatively poor quality wetlands can be sampled since data to-date and previous studies (Woodcock *et al.* 2004) have shown that these areas may also be important

If time / resources permit and more than one location may be sampled within a vice-county we suggest that contrasting habitats be chosen so that the total range of habitats sampled will be maximized. Of course locations of traps will depend on ease of access, permission, if necessary etc. Areas heavily grazed by cattle should be avoided.

Period of sampling and protocol

1) Pick two locations in each vice county and place three pitfall traps in an appropriate habitat (see above).

   Date: 18/5/09 or nearest available date of that week.
2) Pick up samples and empty into ziplock bags (provided) and label with marker (provided). Use Vice County number (see Figure 2) and a letter corresponding to the questionnaire (see below). Also, we advise placing a small piece of paper with this code (written in pencil) in the bags. Put bags in the lunch box provided. If the sample has a dead shrew please remove and discard before posting (gloves provided)

   Date: 1/6/09 or two weeks after date of putting down trap.
3) Answer questionnaire (2 pages) provided for each location (i.e. two questionnaires per vice county surveyed).

   Date: Week of the 1/6/09.
4) Post pitfall trap material and questionnaires in addressed envelopes.

   Date: Week of the 1/6/09.
5) Feedback on the results and outputs and recommendations of the project will be provided to everyone involved.

Methods – Pitfall trapping

We suggest that three pitfall traps be arranged in a 2x2x2m equilateral triangle (see Figure 3 below):

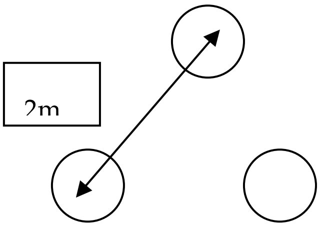

Figure 3: Trap set up in each site

Each trap consists of two cups one. The traps should be buried so that the tops of the cups are just below the surface and they should be flush with the ground so that there is no gap between the surface of the ground and the side of the trap. Rain covers should be used. We suggest using plastic "corriboard" covers. The rain cover should be about 2cm above the trap (see Figure 4 below):

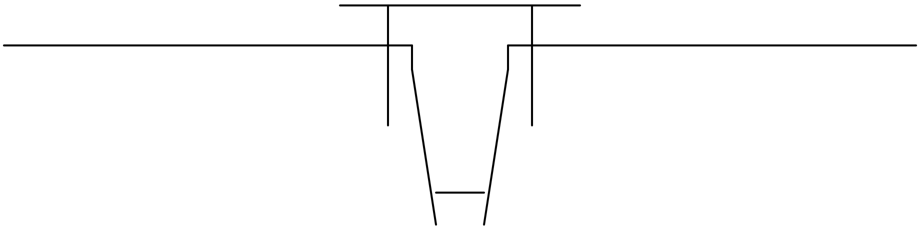

Figure 4: Cross-sectional diagram of pitfall trap in situ showing rain cover, supported by nails and the trap below the surface.

The traps should be filled with two plastic containers of Vinegar, which should be retained in the ziplock bags when the traps are emptied.

Other important information

In order that the data may be meaningfully interpreted, we request additional information on the accompanying form relating to habitat type, management and quality.

Occasional records

Other records of *C. clatratus* will be very welcome. Ideally specimens should be taken and preserved. If this is not possible, however, digital camera images / mobile phone camera photos can be e-mailed to the following address:

chris.david.williams@gmail.com

Local landowners and members of the public known to the NPWS can also be encouraged to help in this way. Ideally records should be accompanied with GPS points. However, if this is not possible a six figure grid reference or accurate description of the location would be sufficient.

References

Anderson, R., McFerran, D. & Cameron, A. (2000) The Ground Beetles of Northern Ireland, Ulster Museum, Belfast.

McFerran, D. M., Cameron, A. & Anderson, R. (1995) The distribution and status of *Carabus clatratus* L. (Coleoptera: Carabidae) in the West Fermanagh and Erne Lakeland Environmentally Sensitive Area. *Irish Naturalists Journal* **25:** 67-71.

Webb, D. A. (1980) The biological Vice-counties of Ireland *Proceedings of the Royal Irish Academy*, **80B**: 179-196.

Woodcock, B. A., McCausland, K. A., Mann, D. J., McGavin, G. C. (2004) Management of Irish oceanic blanket bog and its effect on ground beetles: implications for the conservation of the threatened *Carabus clathratus* L. (Coleoptera: Carabidae). Bulletin of the Irish Biogeographical Society **28**: 63-84.

APPENDIX – OTHER THINGS THAT MAY BE USEFUL WHEN SAMPLING THAT ARE NOT CONTAINED IN THE KIT

1) GPS
2) Fossitt's guide to Habitat's in Ireland
3) Flora (Webb / Rose etc.)
4) Digital camera
5) Ruler
6) Tape Measure
7) Spare trowel
8) Pen Knife

Sampling Information / Management questionnaire (Please complete for each trapping location)

1) **Collector's name and e-mail address______________________________________**

2) **Label (Letter) given to site____**

3) **Vice County Number ____**

4) **GPS point of site (Irish Grid): ____**

5) **If there area is in a designated site (NHA, SAC, SPA etc.) or national park / nature reserve, please state its designation and site code_______________________**
   ____
   ____

6) **Altitude of site (if available on GPS)______________________________________**
7) **Dates of collection ____**
   ____
   ____

8) **Habitat type (Fossit level three – list more than one if it falls between a number of habitat types):____**
   ____
   ____
   ____

9) **Vegetation height close to each trap**

Trap	**Vegetation Height (cm)**
(i)	
(ii)	
(iii)	

10) **Dominant vascular plant species (count bare ground/exposed rock as a species)____**
    ____
    ____

11) **Management practices (include turf cutting, trampling/erosion and grazing)____**
    ____
    ____

12) **In your opinion what is the ecological / environmental condition of the site**

    Good ☐
    Medium ☐
    Bad ☐

13) How do you think management should be changed, if at all (please be as general or specific as you like, but there is no need to mention changes in grazing regime as these are dealt with in question 14 and 15 below)_______________________

14) To the best of your knowledge is the site grazed by wild / feral animals? If so which animals and to what extent (i.e. heavily, moderately or lightly)___________

15) To the best of your knowledge is the site grazed by domestic livestock?

Yes definitely grazed ☐
No definitely not grazed ☐
Don’t know, but evidence of grazing (browsed shoots and/or dung present) ☐
Don’t know, but no evidence of grazing ☐

16) If the site is grazed, what domesticated livestock graze it (cattle, sheep, horses etc. or mixed)? If mixed, please state what livestock are present __________________

17) If known, please give stocking density of the habitat _________________________

18) In your opinion is the site stocked at an appropriate level?

Yes ☐
No ☐

19) If no, how do you feel it should be changed (please be as general or specific as you like i.e. state actual changes in stocking density and seasonal changes etc. or whether grazing should increase or decrease)___________________________

MANY THANKS FOR ALL THE HELP COLLECTING BEETLES AND ANSWERING THESE QUESTIONS. IT IS VERY MUCH APPRECIATED