AN EVALUATION OF DOWNLAND TURF RE-CREATION, USING INVERTEBRATES AS INDICATORS

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Abstract

An evaluation of downland turf re-creation, using invertebrates as indicators.
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Seven study sites within the South Wessex Downs Environmentally Sensitive Area (SWD ESA) were used to evaluate re-created downland turf, a habitat created under one of the scheme management options. The novel habitat was compared to adjacent areas of established downland and to the edges of arable fields, by collecting vegetation data, and using invertebrates as indicators of habitat quality. The re-created downland sites were re-seeded 1 to 3 years before the study.

The new habitat was influenced by adjacent established downland and calcicolous species were found colonising the edges of the re-created downland. The edges of established downland were degraded in terms of plant species richness, probably by previous arable use in adjacent fields. It was found that the re-created downland was being used by several butterfly species for breeding as well as for nectaring and that these activities were concentrated around the edges of the habitat. A second indicator group, the Homoptera, were also found on the re-created downland and, although no evidence of breeding was gathered, some of the species found on the habitat were characteristic of established downland.

A third aspect of the study focused on the effect on associated herbivores of the non-native varieties of downland species which are sown into the re-created downland. It was found that these were not as easily digested as a native variety and that although the larvae gained more weight they pupated later, thus increasing their chances of predation. This has not previously been demonstrated and it is hoped that they will help improve the management of the SWD ESA in future years.

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Author's declaration

I declare that, unless otherwise acknowledged in the text, the work presented in this thesis is wholly my own.

Chapter 1 – Literature review, study rationale and aims.

This first chapter sets the work presented in this thesis into context, and also presents the rationale and aims of the research carried out.

The work has relevance to three particular subject areas;

- Common Agricultural Policy reform and the UK Agri-Environment Scheme programme,
- the science and practise of habitat re-creation (in particular that of chalk grassland), and
- the use of invertebrates as indicator species for habitat quality.

After a short introduction, a review of the literature relevant to the three categories mentioned above is presented, discussing previous research and exploring theory and opinion in these fields. Other subject areas relevant to the research carried out in this thesis are briefly reviewed at the start of the appropriate chapters. There then follows a discussion of the shortfalls in the current knowledge on these main subject areas which leads to a rationale for the work carried out in this thesis and the presentation of the aims.

Plant species nomenclature follows Stace (1997) and Hubbard (1992), Lepidoptera species nomenclature follows Emmet (1990) and Hemiptera species nomenclature follows LeQuesne (1981).

1.1 Introduction

In 1987 the first Environmentally Sensitive Area was designated. There are now a total of 43 ESAs in Britain, covering 15% of the agricultural land area (Swash 1997) and statutory monitoring programs are in place as well as independent surveys and research programs to evaluate the effects of the different management regimes used within the schemes.

The ESAs have a particular remit for the conservation of grasslands, and cover a wide range of these habitats, including moorland, grazing marsh and calcareous grassland. As well as conserving existing habitats, the schemes include habitat re-creation options, which aim to link fragmented habitats and re-create threatened habitats as a way of conserving rare species. Habitat re-creation is becoming more widely used as a conservation tool in the UK and the ESAs have the potential to become a major part of this movement.

The South Wessex Downs ESA was designated in 1993 and is characterised by steep scarp face and long sweeping slopes of chalk downland, divided by small stream valleys (MAFF 1994a). The area is noted for its archaeological and landscape interest as well as for several rare species, such as the Early Gentian (*Gentianella anglica)*, the Marsh Fritillary (*Eurodryas aurinea)*, the Grey Partridge (*Perdix perdix)* and the Brown Hare *(Lepus europaeus)*.

One option within the scheme management guidelines is the reversion of arable land to chalk downland (Appendix 1 details the scheme guidelines). Agreement holders are required to sow an approved chalk downland seed mix (Appendix 2 lists approved seed mixes) and manage the resulting sward by a mixture of cutting and grazing, with no fertiliser inputs and only judicious use of herbicides. Fig 1.1 shows established and re-created downland at two of the sites used in this study; Coombe Bisset Down and Huish Farm (see Chapter 2 for further descriptions). Habitat re-creation is generally used as a one-off or small scale management tool, and because of this there is much variation between different projects, in every aspect of the methodology. The comparatively large uptake of chalk downland re-creation within the SWD ESA (887ha by 1998 (ADAS 1997b)), which involves strict management guidelines and a limited choice of seed mix for initial sward establishment, should be seen as a good opportunity for structured research into the success of a particular habitat re-creation methodology. However, the full potential of this management option will only be realised if the guidelines are shown to be based on tested ecological theory and well developed principles.

The main limitation inherent in using the ESA re-creation sites to study this technique is that the sites are still relatively young (1-3 years after re-seeding). It is difficult to comment on the development of the chalk grassland sward at this early stage, and to treat them as replicates given the varied time of re-seeding but it was felt that much information could still be gained from the sites, informing the habitat re-creation process. Chapters 2 and 3 further address these issues.

Fig 1.1: Established and re-created downland at Huish Farm and Coombe Bisset Down.

There is much research already in place within the South Wessex Downs and other ESAs, as well as within the field of chalk downland re-creation and the use of invertebrates as indicator species. The following sections review this research, and are then followed by an assessment of the opportunities for new research. This leads to the development of a rationale for the work carried out in this thesis and the presentation of the aims.

1.2 Literature Review

1.2.1 Agriculture, Environment and Common Agricultural Policy

The review presented below gives a brief history of the development of the Common Agricultural Policy, in the context of pre- and post-World War II agricultural developments, and then continues with sections discussing the growing environmental concerns of the 1980s and the designation of ESAs (Environmentally Sensitive Areas), both in Britain and the rest of Europe. Monitoring and research in the South Downs (SD) and South Wessex Downs (SWD) ESAs is discussed in detail.

i) Background

The modern perception of agriculture is based on practices which have only been present for the last 50 years. These practices, which comprise today's farming tradition, were accelerated into every day use during and after the Second World War. Phrases such as "food mountain", "intensification" and "habitat loss" are now a part of our popular culture and the emerging science of habitat restoration can be seen as a response to the increasing pressures on our environment, with modern farming as one among many.

Agriculture in pre-war Europe varied immensely from region to region, as well as between countries. It was generally a low input-low output system, making use of crop rotations, mixed farming and 'natural' feeds and fertilisers such as grass, hay and dung. This is not to say that it was a stagnant industry; in Britain Harry Ferguson's tractors began production and George Stapledon developed grassland management via the grass ley in the 1930s (Seddon 1989). However, it was the advances in chemical synthesis and biochemistry that went alongside these which had the greatest impact; in particular the Haber process of fixing nitrogen as ammonia (originally for use in explosives during the First World War) which enabled the large scale manufacture of artifical nitrogen fertilisers.

The Second World War, with its concurrent restrictions on trade and shipping put enormous pressure on the agricultural community to produce enough food. In Britain shortages led to the invention of Woolton Pie (a meat free pie consisting mainly of root vegetables, named after the Minister of Food in the 1940s) and an announcement from the Secretary of the Shire Horse Society that "if the slaughter of horses for food continued, there would be hardly any working horses left in Britain in 10 years" (Seddon 1989).

Post War, an Agriculture Act (1946) was passed to; "maximise farming output to try to counteract the effects of the war" and this included a policy calling on farming to double pre-war production by 1951/2. Artificial fertilisers had been experimented with at Rothamsted Research Station as far back as 1843 but in 1947 there was still deep scepticism from some who refused to use them, claiming they poisoned the soil (Seddon 1989). However, the new Agricultural Act forced an increase in fertiliser use and by the 1950s increased yields resulted in a change of opinion.

ii) The European Union and the Common Agricultural Policy

Food supply became even more of a problem after the war when the allied nations diverted many of their resources to those countries who had been left with no reserves. At the same time there was a desire among a nucleus of western European countries to establish political and economic union as a guarantee of peace. With the inauguration of the Council of Europe in 1949 (and the first General Agreement on Trade and Tarrif or GATT in 1947) the scene was set for removal of trade restrictions and price fixing across many different areas of production. Six countries (Belgium, the Netherlands, Luxembourg, France, Germany and Italy) formed the new European Union under the Treaty of Rome in 1957 (Ritson and Harvey 1997). Services are now organised under the Directorates General (DG) in Brussels, with DGVI dealing with farming and DGXI with the environment.

The objectives for the first Common Agricultural Policy (CAP) were included in the Treaty of Rome but the the CAP was not finally ratified until 1962, as part of the general common market agreement within the European Economic Community (EEC). The CAP dealt with such issues as price regulation and stabilisation of imports as well as supporting regional economic growth via intervention and guaranteed prices. Due to the fact that all the signatories already used intervention within their own agricultural practice, it has been said that "the common policy would be more a matter of accommodating national interests than of requiring radical adjustments" (Pearce 1983). Nevertheless, for the first time agriculture ceased to be a purely national concern.

It was under Edward Heath (Conservative Prime Minister) that Britain (along with Ireland and Denmark) finally entered the EU in 1973, despite initial reservations about the viability of policies which aimed to integrate the widely divergent interests of member countries. The EEC was emerging as a body of equal political and economic power with the US and USSR and by this year the British farming lobby was in total support of accession to the EU, seeing many benefits to their industry from being part of a stable market (Fearne 1997).

It is now recognised that the 1970s and 80s were a good time for farmers; prices were guaranteed for both crops and livestock, while increasing use of fertilisers, pesticides and herbicides meant higher yields and the government (through the CAP) paid for those commodities which were surplus to trade (this was called intervention) (Ritson and Harvey 1997). Even if concern was voiced over levels of production the following quote demonstrates the general attitude of the times:

> Never mind the surpluses, just keep on producing as much as possible - that's the message to arable farmers from senior ADAS (Agricultural Development and Advisory Service) farm management adviser Bill Mitchell. He told Lincs and Humberside farmers last week to forget about reducing crop inputs to help

cut Common Market surpluses. "Will the chap in Germany or France cut back if you do? The answer is no, so you get on and produce it," he said.
(Mitchell 1984)

It was also in 1970s that the European Community (EC) published its first Action Plan for the Environment, which identified modern farming as a threat to the conservation of biodiversity (Baldock and Lowe 1996). The processes of price support and intervention, outlined above, had led to increasing overproduction, along with environmental and economic problems. Although there were attempts at limiting production, such as the introduction of milk quotas in 1984 and set-aside in 1988, these did not have an effect on the overall processes of the CAP. The MacSharry reforms (via EEC regulation 2078/92) and Britain's 1992 Agriculture Act modified the application of quotas and Set-Aside, and brought in the Arable Area Payments Scheme as well as headage payments for beef, sheep and pigs. These measures were designed to control production in different agricultural sectors but still linked production with subsidy while avoiding direct payments for the first time (Scheele 1996).

In July, 1997, Agenda 2000 was published, detailing the new proposals for reform of the CAP. These included decoupling agricultural support from production and instead using methods such as cross-compliance to integrate environmental concerns more strongly into farming practise, and modulation to support farmers while prices adjusted to world levels (Select Committee on Agriculture 1998). It is now recognised that the EU must reduce production based support to farmers if it is to compete in the world market with nations such as the US where support has already been decoupled from production (OECD 1998).

iii) Environmental Concerns: a wider context.

Baldock (1996) stated that in the 1970s the CAP had three emerging environmental agendas: the prevention of desertification from land abandonment in France, controlling the intensification of agriculture in Europe and, in Britain, preserving the traditional landscape. This escalated during the 1980s to a much wider concern and led in the UK to the Wildlife and Countryside Act (1981), which has been seen as "the first conservation law to be passed since the voluntary movement became politically aware" (Evans 1992). The early 1990s saw the continuing of this trend with the Habitats Directive (92/43/EEC) which required the protection of 169 habitat types and 623 species considered under threat within the EU member states.

The 1980s saw the founding of many environmental organisations in Britain, including the SAFE (Sustainable Agriculture Food and Environment) Alliance, a member of the European Network of Alliances for Sustainable Agriculture in Europe, and an umbrella for more than 40 other organisations. These all reflected the increasing trend towards concern for the environment which had started with such books as Silent Spring (Carson 1962) and The Theft of the Countryside (Shoard 1980) and continue today with those such as Killing of the Countryside (Harvey 1997). The development and rational of the science of nature conservation is admirably summarised in publications such as Evans (1992), Sheail (1997) and O'Riordan and Voisey (1998) and some of the statistics on habitat and species loss in Britain are summarised in Section 1.2.2. It is worth also considering some of the economic reasons for preventing loss of biodiversity (traditionally linked with good conservation practise), as summarised below:

- Biodiversity facilitates ecosystem functions that are vital for continued habitability of the planet.
- Biodiversity is the source of many of the world's products, including foodstuffs.
- The uniqueness and beauty of diverse ecological systems has value for a wide range of recreational uses and for eco-tourism. (OECD 1996)

Finally, it would be difficult to review this period without mentioning the United Nations Conference on Environment and Development in Rio de Janeiro (1992), which carried forward the issues first raised at the Conference on the Human Environment (Stockholm, 1972) and for the first time produced concrete plans for action. The Earth Summit, as it became known, dealt with biodiversity, climate change, sustainable development and forestry. One hundred and fifty nations signed conventions on these issues (although not all were ratified), and agreed to draft Agenda 21 documents detailing action towards sustainability.

It is from this that the UK Biodiversity Action Plan (Department of the Environment 1994) was drawn up (as part of Britain's Agenda 21) and conservation via the Biodiversity Process was initiated, involving national and local effort. Progress was by no means easy, involving much NGO lobbying of the government (Evans 1992) and heavy criticism of the Department of Transport and Ministry of Agriculture, Fisheries and Farming (MAFF) by a House of Lords Select Committee (HMSO 1995) but a coherent network of plans and actions are emerging.

Among these are a series of national Biodiversity Action Plans for all key habitats present in the UK and over 400 most highly threatened species. Many of these include actions to restore habitats and manage them in an environmentally sensitive way, with MAFF and Government conservation agencies identified to take the lead. This has given a fresh impetus to habitat restoration, notably in existing land enhancement schemes such as Environmentally Sensitive Areas.

iv) Environmentally Sensitive Areas

As mentioned above there were concerns about the surpluses and high subsidies involved in farming in the eighties. These led to the eventual passing of EEC regulation 797/85 which authorised member states "to introduce special national schemes in environmentally sensitive areas (ESAs)".

The authorisation to introduce ESAs led to the 1986 Agriculture Act and MAFF started to designate ESAs in Britain. This scheme is quite different to preceding area designations. National Nature Reserves (NNR), Areas of Outstanding Natural Beauty (AONB) and Sites of Special Scientific Interest (SSSI) attempt to separate conservation from agriculture, in some cases by taking land out of agricultural production. ESAs integrate farming and the environment, by grant aiding farmers an annual payment to modify farming practise and also by re-creating habitats which are shown to be threatened (MAFF 1994b). Unlike Countryside Stewardship (launched in 1991) the scheme runs in specially designated areas where "farming practices have helped to create or protect distinctive landscapes, wildlife habitats or historic features" which are of national importance (MAFF 1995a).

In 1987 the first round of ESAs were designated, including the chalk downland area of the South Downs. A further five were decided on in 1988 and these were followed in 1993 by the third tranche which included the South Wessex Downs ESA (SWD ESA).

There are now 43 ESAs in the UK, covering 15% of the agricultural land area. Of these 22 are in England (Fig 1.2), the fourth and final tranche being designated in 1994 (Swash 1997). The first three tranches were funded entirely by British taxpayers money but the final tranche is half funded by the EU as the areas were designated after the MacSharry reforms of 1992 (the 1993 designations are included in pre-MacSharry reform funding regulations). In 1996/7 £28 million were spent on the English schemes alone and it is expected that this will rise to £43 million in 1999/2000 (Coates 1997).

The schemes have a particular remit for the conservation of grasslands. These range from the chalk grassland of the South and South Wessex Downs ESAs to the grazing marshes of the Somerset Levels ESA, the moorland of the Cambrian Mountains ESA and the ancient hay meadows of the Blackdown Hills ESA. In addition other threatened habitats such as heathland, woodland, hedgerows and coastal wetland are provided for (MAFF 1994a). The total number of agreements in England is well over 8000, covering 33% (353.999ha) of the land area within ESAs (Swash 1997).

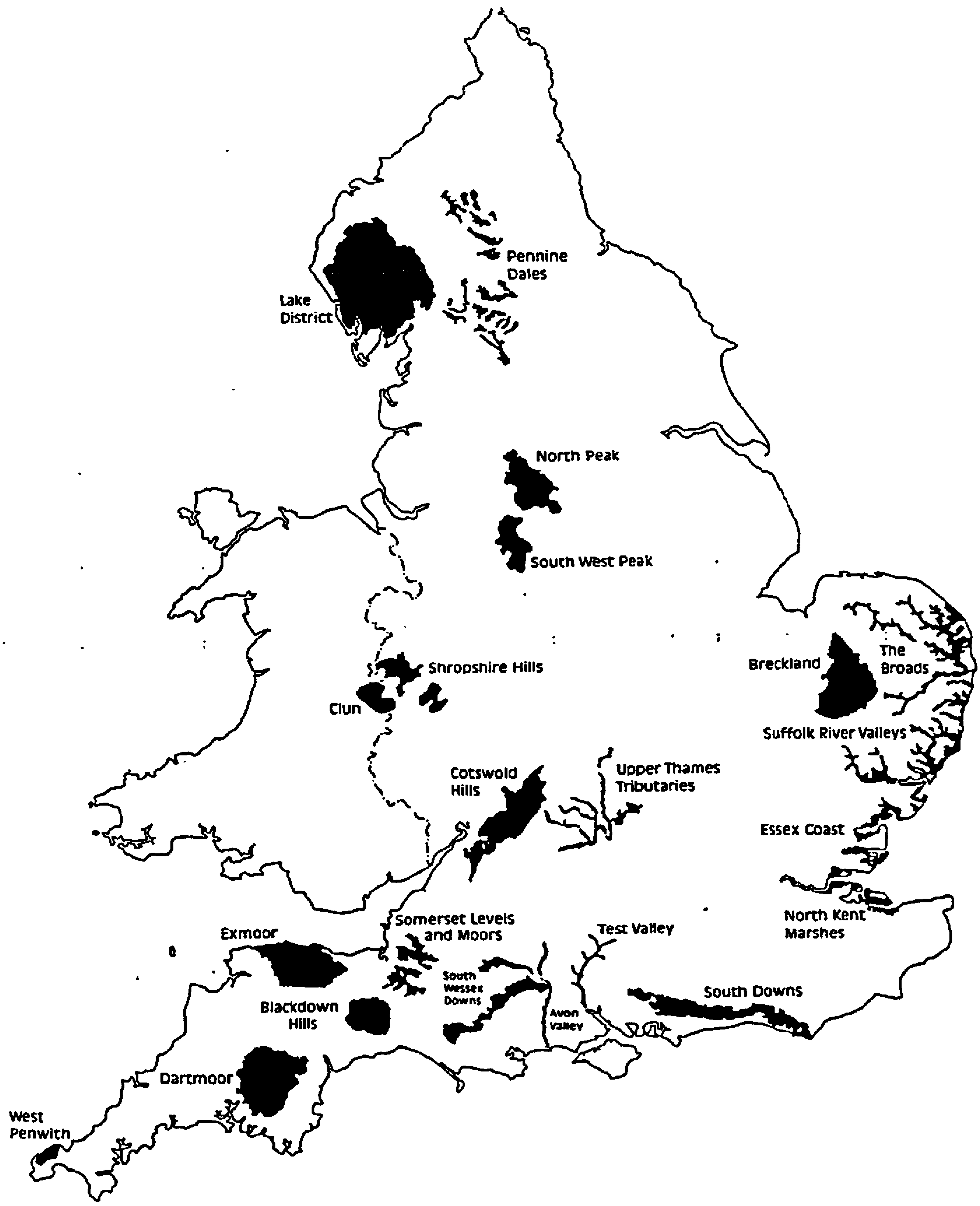


Fig 1.2: The 22 Environmentally Sensitive Areas in England.

Although the guidelines of each scheme are tailored towards the characteristics of each ESA there are certain common themes. The later ESAs take a whole farm approach, with different management options organised into a tiered structure. The basic tiers have low payment levels and involve little or no change in management practise. Higher tiers include changes in management of the land, including extensification of grazing and habitat creation. Agreement holders all sign a 5 year agreement, after which they or MAFF may terminate or renew the contract for a further 5 years. The option of a farm conservation plan is becoming increasingly popular (and was introduced into the SWD ESA after its review in 1997 (MAFF 1998)) as it promotes the whole farm approach and gives an element of coherence to how the scheme guidelines work within individual land holdings.

v) Monitoring and Research in the South Downs and South Wessex Downs ESAs

The government is required to monitor schemes in order to assess the impact (positive or negative) which they have on the areas affected, and these findings feed into the review which each scheme undergoes at 5 year intervals after its inception. Ecological monitoring methodology has been detailed in the following publications; (MAFF 1991; ADAS 1996a; Critchley et al. 1996; MAFF 1996; ADAS 1997b; Critchley 1997). Socio-economic monitoring methodology is detailed in MAFF (1991) and an overview of all ESA related monitoring is provided in MAFF (1995b) and Hopkins (1997). Critiques of these are to be found in Bonnieux (1996) and Willis (1994) where the lack of socio-economic monitoring when compared to ecological monitoring is highlighted.

a) Ecological

The findings of statutory monitoring in both the South Downs and South Wessex Downs ESA have been published in several reports (MAFF 1991; ADAS 1997b). These are generally positive; the South Downs monitoring report states that "the implementation of the ESA management prescriptions have had a direct beneficial effect on the ecological value of some grassland habitats" and "there do not appear to have been any adverse effects caused by the prescriptions" (MAFF 1991). Similarly the South Wessex Downs report states that "the scheme has been successful in maintaining the landscape, wildlife and historical resources of the area, and that there has been a limited amount of evidence of enhancement of the landscape and wildlife value" (ADAS 1997b).

Other monitoring has not been as straightforward in its conclusions and there has been criticism about the failure of ESAs to address the priority biodiversity species present, including internationally threatened butterflies (Warren and Bourn 1997). It has also been shown that ESA schemes which include chalk grassland restoration are not particularly useful to birds, due to the structure of the developing turf. Wakeham-Dawson (1997) found that downland reversion grazed to the initial MAFF prescription of 10cm (in the SD ESA) provided insufficient cover for foraging skylarks and inhibited the germination of arable weed seeds. However, the report also found that if reversion was grazed less intensively it provided good habitat for skylarks and this is supported by Belben (1997) who showed that they were found at a significantly higher density on restored downland than established downland or pasture in the SWD ESA.

There is also widespread agreement that the schemes' main aim of increasing the area of available chalk downland habitat is an optimistic one, given the timescale of most agreements. Research has shown that re-creation of species rich, ancient habitat such as this takes many years, even if species are introduced into the sward initially, and that the subsequent management is crucial in determining the sward composition (Hutchings et al. 1989; Wells 1989; Gibson and Brown 1991a; Gibson 1995; Hopkins et al. 1995). Recent evidence shows that the initial seed mixture with which the restored grassland is sown is the most important factor in determining sward composition in future years (Pywell et al. 1997) and this highlights the importance of sowing a seed mixture of both the right composition and provenance.

b) Socio-economic

Alongside the conservation aspect of ESAs is the economic interest for farmers. This is often cited as a main reason for joining the scheme (Potter and Gasson 1988) and statutory research shows that during 1988/89 agreement holders within the SD ESA enjoyed an average rise in income of £1,630 per holding (MAFF 1991) with Stage III ESA (including SWD ESA) agreement holders also showing an average increase in income per farm (CEAS Consultants Ltd et al. 1997). But for the schemes to realise their full potential as conservation tools it is essential that agreement holders do not view the programme as merely an additional money making enterprise. This is especially important given the public interest in the schemes, via their centralised tax funding (Crabtree and Barron 1997). Morris (1995) surveyed 101 farmers in the SD ESA who were classified as adopters and non-adopters. The study looked at differences in attitude within the adopter group and found that a dichotomy existed; there were those who joined the scheme because they saw it would not change their management practice and was an "easy" way of making extra money and those who joined because they welcomed government intervention in farming practise if it meant they could farm in a more environmentally friendly way.

This was also a conclusion in a study looking at all the lowland ESAs (Froud 1994) and highlights one of the main faults of ESA schemes in general, that they have to compete with arable area payments (AAP) of, for example, £427.29/ha for an oilseed crop (Harris 1998) compared to the highest payment rate within an ESA of £330/ha for downland creation (MAFF 1998). Even this direct comparison is not a simple one for to obtain the ESA payment involves much outlay, both of time and capital, from the farmer whereas the AAP is paid simply for maintaining normal farming practise. Studies have shown that farmers experience difficulty in complying with management guidelines within the SWD ESA, especially those which restrict weed control and the choice of grazing grasses to be sown (CEAS Consultants Ltd et al. 1997).

Unless this disparity is resolved agri-environment schemes based on voluntary participation will continue to be seen as a fringe activity by many farmers (Baldock et al. 1990) or to be at risk of failure if payment levels fall slightly (CEAS Consultants Ltd et al. 1997; Clark 1997).

vi) ESA and agri-environment schemes in other countries.

Although Britain was the first nation to implement ESAs (Whitby 1996) they have since been designated in other European countries. Organisations such as the SAFE Alliance, the Organisation for Economic Co-operation and Development (OECD) and the Institute for European Environmental Policy (IEEP) as well as academic instutitions regularly report on developments within these schemes, analysing their impact on farming in each country (SAFE Alliance 1995; Baldock and Lowe 1996; Dixon 1996; OECD 1996; Onate et al. 1998).

Environmentally Sensitive Areas can now be found in Sweden and the Netherlands as well as the UK. In the Netherlands they have been incorporated into part of the Less Favoured Areas (LFAs) legislation and play a secondary role to measures improving the training of farmers and setting up demonstration projects (van der Bijl and Oosterveld 1996). In both countries they include measures to extensify farming and conserve permanent grasslands (OECD 1997) and Sweden includes rare breeds protection and restoration and establishment of wetlands and ponds on arable land, reflecting its own environmental priorities (Rundqvist 1996).

This is not to imply that other countries have not used regulations 797/85 and 2072/92 to develop their own agri-environment programmes. The schemes which have arisen in each country reflect the political processes as well as environmental concerns of that particular area: in Spain the diversity of agricultural practice and production systems has led to the development of a zonal programme encompassing erosion and fire control, rare breeds preservation and conservation of abandoned lands (Garrido and Moyano 1996) which is implemented with varying success by regional and national government (Onate et al. 1998).

In Germany national measures were first aimed at reducing surpluses through extensification and were then refined under reg 1072/92 to include incentives for managing land for environmental gain (Plankl and Neander 1997). These are contained within the umbrella agri-environment scheme; "Gemeinschaftsaufgabe Verbesserung der Agrarstruktur und des Küstenschutzes" (Common Task of Improving Agricultural Structures and Coastal Protection) or GAK and have been generally successful, especially in promoting organic farming which takes up over 5% of the agricultural area in three of the 13 German Länder and is seen as playing a key role in the agri-environmental policies (Holl and von Meyer 1996).

If predictions about the future of agricultural policy in Europe are correct, and agricultural subsidies are decoupled from production, it would seem that this is an unrivalled opportunity for agri-environment schemes to expand. It is widely recognised that present agricultural practice is neither economically sustainable in the world market or environmentally sustainable on any level. However, whether environmental goals are integrated into policy reform or continue to play a side-role to the economics of farming is still being decided and the prevention of habitat and species loss, through effective land management and habitat restoration within agri-enviromental measures depends on this.

The next section of this review concentrates on one particular aspect of the Environmentally Sensitive Areas Scheme in Britain; habitat re-creation. This management tool will be placed into a wider context and the techniques and flaws which are emerging through its increasing use will be explored.

1.2.2 Habitat Re-creation.

It is estimated that under Roman occupation only 2-3% of the potential agricultural land and pasturage in England was being used (Hoskins 1985) . The changes which have occurred since then are chronicled in books such as The History of the Countryside (Rackham 1986) and The Changing Countryside (Blunden and Curry 1985) and we now find ourselves in a position where farmers are paid to re-create habitats in an attempt to preserve them and their species.

Although there is some disagreement in defining habitat re-creation the following definitions are used in this thesis. Habitat re-creation is seen as being half way between habitat creation and restoration (Parker 1995a). Habitat creation is "the construction of interesting and attractive ecological communities on sites which currently support little of nature conservation interest" (Parker 1995b) and can be political (amenity areas in towns) or ecological (Baines 1989), whereas habitat restoration "attempts to restore existing degraded semi-natural vegetation" (Gilbert and Anderson 1998). Habitat re-creation is distinct from all these in that it re-creates the habitat which once occupied the area in question and is often used to 'patch up' the holes created by fragmentation of the landscape (Newbold 1989).

This review will look specifically at the *re-creation* of chalk grassland habitat, encompassing the history and rationale underlying the science, methodologies and some of the issues involved. It will also evaluate the need for further work in these areas.

i) Why habitat re-creation?

Between 1930 and 1984 the area of unimproved lowland grassland in England and Wales was reduced to 3% of its former size (Fuller 1987; Nature Conservancy Council 1987). The causes of this loss are varied and reflect both the intensification of agriculture and increasing pressure from population growth leading to the expansion of towns and building of new settlements, as well as afforestation and industrial development (Blunden and Curry 1985). Jefferson (1996) states that this loss and damage is continuing and between 1970 and 1980 there was a 21% loss of chalk grassland nationally (Keymer and Leach 1990). Moreover, a subsequent survey of the chalk grassland in Dorset shows that since 1973 a further 773.1ha have been lost (out of the original 3388ha (Blackwood and Tubbs 1970)), leaving only 3.03% of the total area of chalk outcrop unimproved or semi-improved (Edwards 1998). Not surprisingly the potential for habitat re-creation in Britain is correspondingly high (Bunce and Jenkins 1989; Gilbert and Anderson 1998).

It should be stressed that the preservation of ecosystems is far less expensive than restoring or re-creating them (Cairns 1993) but given the losses of unimproved grassland it seems vital to include measures for habitat re-creation in the legislation designed to protect and preserve our threatened habitats, especially as it has been shown that site protection is not enough to maintain biodiversity in fragmented landscapes (Warren 1993a). Indeed, it has been suggested that these measures are already implicit in many documents such as the Agriculture Act (1986) and the Wildlife and Countryside (Amendment) Act (1985), where the words 'conserve and enhance' are used (Box 1996).

This leads to what could be seen as one of the main reasons for using habitat re-creation as a management tool in the UK (OECD 1996). The government is committed to conserving habitats and species by signing the Rio Convention on Biological Biodiversity (1992) and is also looking at ways of updating farm support mechanisms to comply with World Trade Organisation regulations and of making farming more competitive in the world market. Integrating measures such as habitat re-creation into a modern farming policy, perhaps via cross compliance, could aid the UK in meeting these targets and obligations.

Habitat re-creation can also help tackle the growing ecological problem of fragmentation. Much research has been carried out on this process, and its influence on the distribution and conservation of wildlife (Webb and Rose 1994; Kirby 1995; Hanski et al. 1996). Habitat re-creation presents a good opportunity for creating 'wildlife corridors' linking these fragments of original habitat as well as facilitating further research into the effects of fragmentation (Newbold 1989; Bell et al. 1997). Therefore, in the case of the Lepidoptera, while newly created habitat may not be of direct benefit to rare, more specialised species (Warren and Stephens 1989), it may prove a key tool in linking remaining fragments of suitable habitat. Certainly the Environmentally Sensitive Areas scheme has promoted this linkage as an aim of its habitat creation component (MAFF 1995a).

ii) Can habitats be re-created?

Despite the many forms of habitat re-creation which are currently in use in the UK there is still some debate over whether habitats can successfully be re-created. A major point of contention is over the time-scale needed to successfully re-create a habitat such as chalk grassland. As mentioned in Section 1.2.1.v research has indicated that many decades are needed before the new habitat approximates its original, if this can ever happen. Wells (1989) asserts that this is not necessarily so:

> The view that species-richness, as measured by the number of species per unit area, is somehow associated with the age, or antiquity of a grassland, is one which is still held by some ecologists, despite much evidence to the contrary. It probably has its origin in Tansley's classic work "The British Islands and their vegetation" in which the chalk downlands are described as "having been used as sheep-walks for many centuries and probably from Neolithic times". Although Tansley did not explicitly state that all floristically-rich grasslands are of great age and can only be created after a long period of grazing or cutting for hay, this is what has been tacitly accepted and seized upon by subsequent workers.

In addition to this work, a study carried out at Porton Down in Wiltshire showed that much of the chalk grassland has been disturbed in the last 200 years and in fact traditional chalk downland may have been managed by regularly shallow ploughing it on a long rotation (Wells et al. 1976).

Recent research shows that chalk downland re-creation depends on many different factors, including local availability of propagules as influenced by adjacent habitat type (Gibson and Brown 1991b; Mitchley et al. 1997). A multi-purpose experiment was carried out at Martin Down NNR in Hampshire in the early 1990s (Wells et al. 1994). It looked at different seed mixes sown on bare ground surrounded by ancient chalk grassland and also evaluated established chalk grasslands of different ages. One conclusion drawn was that the very oldest chalk grasslands are characterised by a set of indicator species, including the sedges *Carex caryophyllea*, *C. flacca* and *C. humilis* and forbs such as *Euphrasia nemorosa*, *Hippocrepis comosa* and *Succisa pratensis*. It is known that these species have an extremely slow rate of spread (Hodgson and Grime 1990; Hutchings and Booth 1996b). These species were not recorded on the re-seeded plots or on an area of chalk downland which had been ploughed during World War II and then left to revert. Similar work at Parsonage Down NNR in Wiltshire, contained in the same report, also found that there were species which characterised only the very ancient downlands, but that *C. flacca* and *S. pratensis* were found very locally on grassland which had been ploughed during the war and then left to revert.

It is interesting to compare these conclusions with observations made in the South Wessex Downs ESA, where *S. pratensis* and *E. nemorosa* have been observed on four year old chalk downland re-creation, albeit growing singly (R. Belding *pers. comm.*). These apparent discrepancies might be said to reinforce the idea that re-created chalk grassland is dependent on the communities which surround it and that in a relatively short time a sward containing chalk grassland indicator species can be re-created. Subsequent sections of this review will address the issues of achieving local distinctiveness through seed supply or natural seed rain.

In addition to the study mentioned above there are other long-term projects which have been set up to investigate the viability of re-creating chalk grassland. These include work by Gibson and Brown at Wytham Wood, Oxfordshire (Gibson et al. 1987) and by Morris on the Hemiptera of a re-seeded grassland at Grange Farm, Royston, Herts (Morris 1990c; Morris 1990a; Morris 1990b). A report has been published looking at the invertebrate fauna of two re-seeded sites, one at 'Greys', Royston, Herts and the other at Rectory Farm, Great Chishill, Cambs (Welch 1994). The monitoring of chalk downland re-creation for the M3 cutting at Winchester presents extremely detailed information on both invertebrate and plant colonisation (Snazell et al. 1996; Ward and Snazell 1996). Both the South Downs and South Wessex Downs ESA run monitoring projects and these are reported in publications by the monitoring agency; (ADAS 1996a; ADAS 1996b; ADAS 1997b). Gibson (1995) also contains a review of current and past chalk grassland re-creation projects.

iii) Methods of chalk grassland re-creation and some of the issues involved.

There have been many publications giving detailed instructions on how to re-create chalk grassland (Wells 1990; Highways Agency et al. 1993; Gibson 1995; Gilbert and Anderson 1998). While it is not the intention of this review to discuss all the methodologies available, some of the issues are discussed below.

Recommended techniques for chalk grassland re-creation depend on the site parameters at the start of work, and upon the desired outcome. For downland habitats the end goal is a habitat which is rich in calcicolous vegetation and its associated fauna, typically based on a soil with very low nutrient status (Gibson and Brown 1991b). Methods vary widely; there are those taking a minimum intervention approach - natural colonisation and no follow up management (see Gibson (1995) for a description of the potential successional processes) and those which involve site preparation, total re-seeding and a complex programme of follow up management and monitoring. Basic techniques include:

* Using the existing seed bank,
* Reseeding, with or without a nurse crop,
* Slot seeding into existing vegetation,
* Plug planting, either with reseeding or into existing vegetation,

Preparation and follow-up management techniques include:

* topsoil stripping,
* cutting and grazing to promote denutrification and
* weed control via the selective use of some herbicides or mechanical means such as topping.

a) Propagule supply

By definition re-creating a habitat involves trying to create something as close to the original as possible. Therefore one of the best ways to re-create chalk grassland is to use local resources (Wells et al. 1994). This can be done in several ways.

Existing seed bank

The most obvious is to use the existing seed bank and let colonization occur gradually. However, research has shown that this is not always the best method, because many chalk grassland species do not persist in the seed bank for more than a few years (Hutchings and Booth 1996b). It has also been postulated that the seed bank below existing chalk downland has no real similarity with the vegetation above it (Dutoit and Alard 1995) due to the long lived nature of these plants and the fact that they spread vegetatively rather than producing seed (Graham and Hutchings 1988a).

Areas where chalk downland is re-created are often ex-arable and therefore have a high available nutrient content as well as many seeds from vigorous annual weeds (Gibson 1995). In such cases, species-rich grassland will not result unless there is follow-up management, perhaps coupled with the introduction of an appropriate seed mix to supplement those propagules already present (Graham and Hutchings 1988b; Hutchings et al. 1989; Hutchings and Booth 1996a). However, if these management principles are adhered to it is possible to create a diverse sward within several years (Jones and Hayes 1997b), although it will only resemble chalk grassland superficially.

Hay strewing

This method of habitat re-creation has not been used extensively but is discussed in Baines (1989) and Wells (1986). It has advantages in that the seed is of known provenance, and will not have been stored, thus avoiding a reduction in viability over time (Jones et al. 1995).

An experiment was carried out looking at the viability of using hay, collected locally, to re-seed a species-rich grassland (Atkinson et al. 1995; Jones et al. 1995). The donor meadow was harvested once and green hay spread thinly on the area for re-seeding. It was found that when compared to plots re-seeded with a commercial mix chosen for its similarity with the hay seed content, the hay plots established a wider range of species and at higher frequencies.

Seed collection

In contrast to the use of hay as a seed source, direct seed collection for use in tailored seed mixes for habitat re-creation has become increasingly popular. (Fig 1.3 shows a tractor drawn seed harvestor of the type developed for downland seed collection). Butterfly Conservation's Magdalen Hill Down Reserve, in Hampshire, includes a section of chalk downland re-creation which was sown with locally harvested seed. Subsequent establishment has been extremely good with 30 of the 35 sown forb species recorded in the first year

(G.Yorke *pers. comm.)*. However, research has shown that a high proportion of so called native wild-flower seed sold in Britain is non-native in origin (Akeroyd 1994), coming from central and southern Europe, or even New Zealand and South America (Gilbert and Anderson 1998). As well as obvious differences in appearance these plants could constitute a threat to the genetic base of Britain's flora, and cases of hybridisation have already been observed (Gilbert and Anderson 1998) as well as one study where it was shown that non-native material outperformed native strains of the same species (Jones and Hayes 1997a). With particular relevance to chalk grasslands, Berger (1993) states:

> Although it is well known that many non-indigenous species can invade disturbed areas, some weeds that reproduce vegetatively, are capable of invading natural grasslands and other relatively undisturbed closed grasslands in the British Isles.

However, there can be disadvantages to using harvested seed. The mechanical process of taking seed from established chalk grassland risks damaging the soil and vegetation, as well as harming local invertebrate populations. Also, mechanical seed collection via brush harvester is not selective and will collect weed species and a percentage of non-viable seed, all of which is then sown (Gibson 1995).

Native seed is less widely available than the seed of commercial varieties, as well as being more expensive (Gilbert and Anderson 1998). However, there is a third type of seed available; that of 'native origin'. This seed is originally from wild varieties but is then crossed with non-native varieties for vigor and ease of propagation. As long as seed is native in origin it can be sold as native stock, even though it is grown and harvested on a commercial scale by the seed houses, cutting overheads to a minimum. High prices are still charged for this type of seed; in 1996 when there was no native grass seed available for sale in

Fig 1.3: A tractor drawn seed harvester.

seed mixes (M.L.Hall, *pers. comm.*) prices varied from £2.64/kg for commercial *Cynosaurus cristatus* to £30/kg for 'native origin' *C.cristatus* and from £2.05/kg for commercial *Festuca ovina* to £35/kg for 'native origin' *F.ovina*. These varieties could pose as much of a threat to our native flora as non-native varieties do.

Finally, another criticism of the use of native seed has been that it does not give the instant amenity value of a commercial seed mix, which may contain a high percentage of *Leucanthemum vulgare* and other attractive flowering species. However, as mentioned above, habitat re-creation for ecological purposes should be a different process from habitat re-creation for 'political' purposes.

In the last few years demand has grown for native seed, in part through large scale habitat recreation in schemes like the ESAs. This has led to an increase in supply from local nurseries and the inception of a group called Flora Locale, with the aim of establishing a series of standards governing native seed collection and production (Everett 1996). It has also been shown that far lower sowing rates than those which are standard at the moment can be used to successfully establish a chalk downland sward (Stevenson et al. 1995); this would help promote the use of native seed and reduce project costs although it might lead to an increase in arable weed growth in the first years of establishment.

b) Grazing

Stock grazing is the traditional management of both chalk and limestone grassland in Southern England (Smith 1980). It is also recognised that grazing is only one form of herbivory (Edwards and Gillman 1991) and there has been much research looking at the effect of invertebrate herbivory on various habitats (Mattson 1980; Hulme 1996; Mitchell and Wass 1996). However, it is not the intention of this review to detail these studies.

Chalk grassland is described as a plagioclimax community produced by the deflection or modification of successional processes by the grazing activities of large herbivores, such as sheep, cattle or horses. Hope-Simpson (1940) postulates that without grazing to deflect succession to a sub-sere grassland community, herbaceous scrub would develop in all but the most dry or exposed situations. Experiments at Oxford University's Wytham Estate, refined this idea of how chalk grassland develops from ploughed land (Gibson and Brown 1992). It was found that the most important factor determining vegetation composition is time since abandonment from agriculture and that grazing had a very limited effect (in early successional stages) on the speed with which chalk grassland developed. Instead, inherent species composition was found to be far more important and they concluded that grazing created opportunites for 'relatively small departures from the usual process of change' which had a cumulative effect in modifying the vegetation. Only the heaviest grazing treatment caused large enough changes in the vegetation to be classed as a deflection from successional processes.

Herbivores each have different grazing methods, which cause variations in the resulting sward (Gibson 1995). Sheep are known to create a close even sward with interest to few specialised invertebrates such as *Lysandra bellargus* which requires high temperatures for larval development and therefore selects warmer microclimates for oviposition (Thomas 1983). Cattle, being heavier, larger animals, create a patchier sward which can lead to poaching and habitat degradation if overgrazing occurs (Gibson 1997) but is also known to be of use to a wider range of invertebrates (Fry and Lonsdale 1991). They are less selective grazers and are favoured by a few butterfly species (Warren 1993b). In addition to variation in stock type, other factors such as time and duration of grazing and the number of stock involved can all lead to variations in the sward over time (Bacon 1990).

However, all grazing can be seen as a method of nutrient removal and traditional sheep grazing systems involved a two stage process; nutrients were first removed by grazing on downland during the day and the stock were then folded onto arable land at night where most of the dunging occurred. This prevented any return of nutrients to the downland and a gradual transfer of nutrients from grassland to arable took place (Cunliffe 1985). Modern stock management generally involves the use of a fenced-in flock or herd which are moved on at regular intervals. This eliminates one stage of nutrient loss which could be of value in chalk grassland re-creation but grazing is still used as the primary management tool to reduce the nutrient status of formerly arable fields. Cutting is also used for this purpose (Rizand et al. 1989; Kleijn 1996), and is becoming increasingly popular as it removes the time and expense spent on the husbandry of grazing animals. However, it does not have the same effect as grazing due to the non-selective nature of the treatment (Bradshaw 1989).

In addition to removing nutrients, grazing and cutting are often used as a way of restricting growth and therefore competition from more vigorous species and have been discussed in Wells, (1980). As with grazing, cutting at different times has different effects on the sward; research looking at a typical *Lolium perenne-Trifolium repens* ley showed that cutting early did not affect *T.repens* but cutting late led to a subsequent decrease in abundance (Barthram and Grant 1995). This type of work aids habitat restoration techniques by informing landowners and managers and enabling them to manipulate management techniques more accurately towards the desired end result.

It is likely that grazing plays an equal if not more important role in the re-creation of chalk grassland by introducing plant and animal species onto the new habitat and then aiding their establishment. Fischer (1996) studied the distribution of diaspores on the fleece of sheep. On one half of the fleece of a single sheep they found a total of 8511 diaspores, representing 85 vascular plant species. Although most of these belonged to the Poaceae, including *Koeleria pyramidata* and *Bromopsis erecta*, forb seeds from *Thymus pulegioides*, *Galium verum*, *Scabiosa columbaria* and *Clinopodium vulgare* were also recorded. It was also determined that the sheep behaviour was an important influence on number and species of diaspore which attached to the fleece and that, once attached, significant numbers were still present several weeks later. This has enormous implications for the use of sheep in chalk grassland re-creation, not only are they important in sward establishment and nutrient removal but they can also be seen as a potential source of native, local seed for re-colonisation, especially if they are deliberately grazed on species-rich chalk grassland prior to being moved to the new habitat.

This study contrasts with work carried out by Gibson (1987). In a multi-plot experiment it was found that different grazing treatments did not affect the chance of species colonising the ex-arable field, but that species establishment was better in grazed areas, leading to increases in species richness, diversity and the abundance of individual plant species in the developing sward. Again this shows how grazing should be an integral part of the restoration of species rich grasslands, favouring slow growing, relatively unpalatable species such as those characteristic of chalk grasslands.

c) Invertebrate presence on re-created chalk grassland

Re-created grasslands are valuable for many resources apart from their flora, including invertebrates. However, opinions differ as to whether a closed sward or the initial stages of colonisation and succession (involving bare ground) is more desirable. Kirby (1992) notes that early colonisers of bare ground can arrive before the plants do and that they are often interesting and uncommon species, whereas Morris (1990a) has stated that Hemiptera benefit from rapid sward establishment. It has been shown that any kind of intensive management, such as cutting or grazing, leads to impoverishment of the total invertebrate fauna (Morris and Plant 1983; Butterflies Under Threat Team 1986). On chalk downland this kind of management is essential to maintain the floristic diversity (Grime 1990), which in turn affects the invertebrate species richness.

These findings promote the idea that successful re-creation should aim to create a varied sward, both in terms of plant species mix and niche availability, so as to support a wide range of different species, in all their growth stages (Fry and Lonsdale 1991). With reference to chalk downland re-creation, where the new habitat does not have all the variety of established downland, one would not expect the rarest species to colonise (Morris and Thomas 1990) but this habitat will still be of use to generalist species and could improve in suitability for more specialised species if managed correctly.

It is likely that achieving a more diverse invertebrate fauna will also aid the re-creation process, because different invertebrates exert an influence on different stages of colonisation and succession, as is shown in the following two studies. Ants have been shown to bury seeds during their nest building activities which leads to increased germination and possibly reduced predation (Culver and Beattie 1980). In another study Hulme (1996) has shown that the simultaneous influence of different herbivores (arthropod, mollusc and rodent) may have an impact on plant community composition. Those plants which are influenced relatively little by herbivory were found to be abundant in the grassland studied whereas those which suffer high mortality and poor growth from herbivory were rare. This may be significant because those plants not influenced by herbivory include 'desirable' calcicoles such as *Plantago lanceolata*, whereas those which do suffer from herbivory include *Trifolium repens* and *T.pratense* which have been shown to dominate sown swards if not correctly managed (Boyce 1995).

d) Soil Fertility

Perhaps the most important factor determining successful habitat re-creation is ground preparation. This includes the preparation of a suitable seedbed for germination and establishment of seedlings (Gilbert and Anderson 1998) but also encompasses the issue of soil fertility. For chalk grassland re-creation on ex-arable the latter is of paramount importance.

Arable land is perceived as having a high fertility, due to the quantity of fertilizers which are added during the cultivation cycle. Studies have identified this high nutrient status as a problem when re-creating chalk grassland (Marrs and Gough 1989) because many characteristic plants can only survive in nutrient poor situations. Recent work (presented here and (ADAS 1997a)) has shown that in fact arable soils on calcareous substrate are capable of losing their fertility extremely quickly once taken out of use, and can end up with lower fertility than adjacent chalk grassland. This is thought to be due to the immobilisation of soil nutrients in organic matter which has a greater effect than mineralisation at low organic matter concentrations (Brady 1990). The high fertility of soils with a low organic matter content when in cultivation can be attributed strictly to fertiliser inputs.

However, in the first years after abandonment from arable use this residual fertility, coupled with the seed bank of pioneer arable weed species can lead to problems for the developing chalk grassland sward. For these reasons various techniques are employed to reduce fertility. These include grazing and cutting treatments after the sward has been established, which not only control weeds (Berger 1993) but also aid establishment of the sward (see section 1.2.2.b). Another technique is top soil stripping and continuous cropping before the habitat is re-seeded (Marrs and Gough 1989; Gibson 1995) . These techniques are also used in Environmentally Sensitive Areas; continuous cropping is used in the Brecklands ESA and grazing and cutting are part of the SWD ESA management prescriptions.

Of the soil macro-nutrients, extractable or available phosphorus has been found to be a limiting factor determing what plants survive in or colonise a new habitat. Gough (1990) showed in glasshouse trials that levels of extractable P were significantly higher in arable, improved grassland and woodland soils than in adjacent semi-natural grasslands, and these high levels will encourage more competitive species in re-created habitat. It has been postulated that it could take up to 12 years for levels of extractable Phosphorus in arable soils to fall to semi-natural levels (Gough and Marrs 1990).

Nitrogen was also examined in the same soils but, in contrast to phosphorus, it was found that total nitrogen concentrations were higher in semi-natural soils than in nearby arable and improved grassland soil, although this was not found for mineralisable N. However, it cannot be assumed that soil nitrogen content is unimportant in the establishment of species rich grasslands as it is known that high levels of nitrogen encourage species uniformity. Work at Rothamstead has shown that ammonium based fertilisers reduced the number of species in a hayfield from twenty-four to two over a study period of about 140 years (Williams 1978).

It seems from these experimental results that there are complex interactions which occur between soil fertility and species richness, and it will be difficult to predict the outcome of habitat re-creation on ex-arable land (Marrs and Gough 1989). The only conclusion which can be drawn with some confidence is that the initial higher nutrient status of ex-arable land will encourage fast growing, competitive species (Grime 1979).

It is important that the effects of soil nutrient status are not viewed in isolation from other factors involved in habitat re-creation. Just as the sward provides invertebrates and other animals with suitable habitat, so these creatures aid the establishment and enrichment of the sward (Petal et al. 1970; Hulme 1996). Similarly the right soil conditions will aid germination and establishment of the sward, but vegetation also plays an important role in influencing soil development and bringing about the right conditions for growth (Bradshaw 1989). These processes are poorly understood and more research is needed before the interactions are fully unravelled. For instance, it is known that the soil biotic community plays a key role in regulating organic matter breakdown and nutrient availability but recent work has shown that there are close associations between the numbers of a particular fungal spore and the fertility of the soil; more fertile soils restrict the number of spores present. Given that these fungi are linked with seedling establishment and plant species diversity it may be that this is one of the mechanisms by which fertiliser applications reduce plant species diversity (Bardgett et al. 1997). In recent months this situation has been clarified further in work by van der Heijden (1998) who showed that a major factor contributing to the maintenance of plant biodiversity and ecosystem functioning is the below ground diversity of mycorrhizal fungi.

It is only through carefully planned monitoring and evaluation of habitat re-creation, as well as an holistic approach to the process, that improvements in methodology and technique will be made (Handel 1997; Gilbert and Anderson 1998). The next section of this review concentrates on the use of indicator species, in particular the Lepidoptera and Hemiptera, as a way of evaluating changes in habitat quality.

1.2.3 Invertebrates as indicator species

i) Indicator Species

An indicator species is one which responds rapidly to environmental change and can be used to evaluate habitat quality (Fry and Lonsdale 1991; Williams 1997). Indicator species are useful where the changes in habitat quality are slight, or infrequent and therefore hard to measure (Watt 1998). For some species these changes will have a direct effect on their population size (perhaps even leading to the disappearance or reappearance of a species on site) and it is these responses which make that species a good indicator.

The work carried out in this thesis has used invertebrates (specifically the Lepidoptera and Homoptera) to evaluate re-created chalk downland and identify factors which affect invertebrate presence in the new sward. It is easy to state that there has been a change in habitat from arable to re-created chalk downland within the SWD ESA, which has obvious implications for invertebrate species in terms of a potential expansion of habitat. However, the nature of that change initially and with time, and its advantages for invertebrates and other animals is harder to quantify. Indicator species can be used as milestones to evaluate subtle stages in the re-creation process as well assessing how far it re-creates the characteristic species assemblages and ecological conditions of the target community.

ii) Insects as indicator species

Insects are one of the most abundant life-forms on earth (Campbell 1990), occupying almost every available habitat. They adapt quickly to new situations and exploit an enormous variety of niches. It is these attributes, along with their exacting habitat requirements which make them good indicator species. They are frequently the first animal to arrive and colonise a new habitat and subsequent insect species composition mirrors changes in habitat closely.

Phytophagous insects have co-evolved in partnership with their host plant species (Mattson 1980) making them extremely sensitive to changes in the flora surrounding them, to the extent that they have been used as indicators of changes in plant nutrient status (White 1984). For instance when a plant is under environmental stress it responds by mobilising increasing amounts of soluble nitrogen, the principal requirement of an insect larval food source (Scriber and Slansky 1981). This leads to an increase in herbivory (Scriber and Feeny 1979; Dale 1988) and may even occur seasonally, such as in the recorded instances of pest outbreaks following drought or unusually low winter temperature (White 1984).

The work presented here concerns insects as indicators of changes in successional process or vegetation composition and builds upon previous studies of this theory. Erhardt (1985) investigated butterfly species diversity on sub-alpine meadows in Switzerland and correlated this with plant diversity on abandoned and cultivated meadows. In England, work carried out in conifer plantations showed that butterfly abundance and species richness was strongly related to shade (Greatorex-Davies et al. 1993) and transect counts at Castle Hill, Sussex have shown links between butterfly species distribution and the type of vegetation present (Pollard and Yates 1993). Butterfly abundance has also been linked to decrease in plant cover, when measured along an urban gradient (Blair and Launer 1997) as well as to changes in climate and seasonality (Pollard 1988).

The number of insect species present at a site is not a good indication of the species diversity, due to the fact that a simple species count says nothing about the number of individuals representing each species: without including a measure of individual abundance the measure of diversity on two different sites could be the same, even though one site supported very few individuals and the other a large population. Therefore a true representation of diversity must include some measure of the number of species and the population size of each species present and consequently different species-abundance indices have been developed (Magurran 1988).

It has been argued that these indices should not be accepted as a true representation of site diversity, because no one count of the number of species and their abundance can be truly representive of all species, and indices do not include measures of species rarity (Shapiro 1975). Despite this, tested methodologies have emerged for recording species number and abundance; for example the Pollard Walks (Pollard 1977) which involve counting number and abundance of butterfly species along a fixed transect route throughout the adult flight period, and expressing this as an annual or site index.

iii) Butterflies and grassland

The easily seen and identified adult form of most butterflies, coupled with their link to a particular habitat or management regime facilitates data collection and promotes their use as an indicator species, both of changes in habitat management and of changes occurring in other invertebrate populations (Fry and Lonsdale 1991). However, there are disadvantages to using butterflies as indicator species; they are seasonal and while adults are easy to record, their location may not indicate breeding habitat (Shreeve 1992).

Over three quarters of British butterflies use low growing herbaceous hostplants which are characteristic of early or mid-successional seres including chalk grassland (Porter et al. 1992). Within this group it is estimated that half of those which use chalk grassland are highly threatened (>50% decline in 25 years) or in steep decline (>25% decline in 25 years) (Warren et al. 1997). Each species has highly specific habitat requirements which make them valuable indicator species, as shown by the examples below.

Hippocrepis comosa is the food plant of *Lysandra bellargus* but the larvae only use those plants which are low growing and in warm positions. These requirements mean that it is restricted to hard grazed, south facing slopes of chalk downland and the butterfly is an indicator species for chalk downland which fits these conditions (Thomas 1983). A similar species, *L.coridon*, uses the same foodplant but can tolerate taller swards and is generally more widespread (Butterflies Under Threat Team 1986). There are a growing number of autecological studies determining the habitat requirements of individual species of butterfly (Shreeve 1986; Warren 1987; Bourn and Thomas 1993; Warren 1994; Brereton 1997), summarised in the following publications; (Thomas 1989; Warren 1992; New et al. 1995).

The work carried out in this thesis has been designed to evaluate re-created downland and focuses on the use of butterfly species richness and abundance as a measure of habitat quality, as discussed in the section below.

Most work using this technique has been carried out on farmland habitats where butterflies have been used to evaluate the impact of conventional farming on invertebrates. Davis (1991) tested four insecticides against four butterfly species and concluded that the results could be extrapolated cautiously to other groups of invertebrates, and that *Pieris brassicae* was most suitable as an indicator species. Rands (1986) showed that there were significant reductions in butterfly species and abundance on sprayed field edges when compared to unsprayed edges and similar trends were found by Feber (1995) when comparing organic and conventional farms.

Butterflies have also been used to identify the underlying factors which affect invertebrates; Dover (1996) found a range of abiotic and biotic factors which influenced their distribution and abundance, including shelter, isolation and the abundance of certain flowers. Although this research was on field margins it has relevance to other habitats and also demonstrates how butterflies are linked to certain habitat conditions.

It can be seen from this section that, although butterflies present a relatively quick way of drawing basic conclusions about habitat quality, comparatively little has been published on the use of butterflies as indicator species in habitat restoration. The next section focuses on the use of Hemiptera as indicator species, as they have also been used as indicators of habitat change in this study and elsewhere.

iv) Homoptera and grassland.

Homoptera (Auchenorhyncha) show close correlations with particular plant and habitat types, and are also easy to sample. Individual species and assemblages have been used to evaluate habitat quality and many studies have linked specific species assemblages with different grassland biotopes (Morris 1971; Waloff 1980). Like the Lepidoptera they can be evaluated by presence of particular indicator species or in terms of species richness and abundance and both methods have been used. However, there is one major difference in the use of Lepidoptera and Homoptera as indicator species, which stems from the way in which they are sampled. Lepidoptera are most easily sampled by recording adults, for example on fixed transects, and these are dependent on weather and habitat conditions, leading to an index of abundance whose relationship with population size may vary with these factors. Homoptera are often sampled using the D-Vac technique which is not dependant on the movement of individuals or any environmental conditions and records abundance and species richness passively (without relying on species participation), giving potentially less biased data (Greenwood 1996).

Studies have demonstrated how Homoptera species richness and abundance fluctuates with soil fertility, cutting treatment, grazing regime and stage of succession (Morris 1971; Morris 1973; Morris and Plant 1983; Morris 1992). It is also known that Homoptera reach highest abundance on established grasslands and that following cessation of management the species assemblages undergo a succession of changes, with particular species indicating particular conditions (Morris 1990c; Morris 1990a; Morris 1990b).

It has been shown that Lepidoptera and Homoptera can be used successfully as indicator species, providing that the limitations discussed above are understood. The work in this thesis has concentrated on using Lepidoptera to evaluate re-created chalk downland. However, the identification of Homoptera assemblages found on re-created chalk downland and established downland has been used to provide additional information about sward and habitat quality and also to verify results from the Lepidoptera research.

1.3 Opportunities for new research

Within the South Wessex Downs ESA, those areas reverted to chalk grassland have been found to enhance adjacent areas of existing chalk downland by acting as buffer zones (ADAS 1997b). However, their intrinsic conservation value is not as easily evaluated and ongoing statutory monitoring projects focus on how the ESA scheme is affecting existing chalk downland. There is a need for research which evaluates the developing species richness (botanical and otherwise) of re-created habitats.

Non-statutory research is summarised in section 1.2.1.v and the non-botanical work is seen to focus on the use of re-created chalk downland habitat by birds. While some of this research has also included analysis of the invertebrate presence (Wakeham-Dawson and Aebischer 1997), this has been in the context of invertebrate use as a food resource, rather than as an indicator species for habitat quality. There is a need for more research to investigate which invertebrates colonise re-created chalk downland and how they use this new habitat, both because the SWD ESA is within the range of several threatened invertebrate species and also because they are good indicator species of what other species might be present and of the habitat quality (see section 1.2.3).

Section 1.2.1.v also highlights the amount of botanical monitoring (statutory and non-statutory) which is carried out within the SWD ESA. This has tended to focus on the seed bank as a resource for habitat re-creation, and also on the germination and establishment of various re-seeding treatments. However, questions of how the soil nutrient status affects these processes and how soil nutrient status changes after withdrawal from arable use have only recently been looked into (ADAS 1998) and it has been demonstrated that this is one of the key issues determining germination and success of a sown sward (Marrs and Gough 1989).

In addition, the use of non-native seed for habitat re-creation has been raised as a potential problem (Akeroyd 1994) but quantitative research into the affects of these plant varieties on native plants and the herbivores which use them (in particular invertebrates) is limited. Jones (1997a) showed that non-native species are capable of out-performing native strains of the same species, but this is the only work which has quantitatively evaluated the affect of using non-native species in a 'wild' situation. There is an urgent need for research in these areas given the amount of habitat re-creation in progress.

Ecological theory (the principle of competitive exclusion) predicts that if two or more species compete for the same limiting resource, then all but one of the species will go extinct (see Begon (1990)). In the context of non-native introductions as part of habitat re-creation schemes, this has implications for the development of the re-created sward and also for adjacent established swards which might be invaded by more vigorous non-native variants. In addition to effects on other plant species, it is not known whether invertebrate herbivores use non-native variants as food plants, if they show any bias towards these variants or if they are affected by differences in the plant chemical composition.

1.4 Rationale for the research presented in this thesis

As the previous section has shown there is still much work which needs to be done to fully evaluate the effect of habitat re-creation within the SWD ESA (and within a wider context).

The work presented in this thesis was designed to evaluate the ecological efficacy of chalk downland re-creation within the SWD ESA, but also to enable experimental results to be extrapolated for wider relevance. In particular it focused on areas where there are gaps in the current knowledge and this led to the development of the following aims which guided experimental design and methodology:

1.5 Aims

The aims of this study were;

1. To evaluate the soil nutrient status of re-created downland turf and compare these findings with those from established downland and arable soils.

2. To assess the botanical species richness of re-created downland turf in terms of its resemblance to established chalk downland.

3. To determine whether invertebrates (Lepidoptera and Hemiptera) use re-created downland turf within the SWD ESA, and to investigate the extent to which this habitat is used by invertebrates.

4. To evaluate the extent of non-native seed use in downland turf re-creation and to then investigate the use of non-native plant varieties by invertebrates (Lepidoptera).

5. To evaluate critically the re-creation of chalk downland within the SWD ESA.

Chapter 2 presents information on the landscape of the SWD ESA, its soils, vegetation and general ecology. It then gives a rationale for the choice of study sites used in the research presented, and goes on to describe each site using previous survey and mapping information.

Chapter 2 - Soils, vegetation, landform and study sites.

2.1 Introduction

Chapter 1 set this study in its historical context and showed the scope for work in the area of habitat re-creation, leading to the presentation of the research aims. This next chapter explores the physical history and current land use within the South Wessex Downs Environmentally Sensitive Area, focusing on the areas used for this research.

Chapter 2 presents information on the geology and soils of the South Wessex Downs Environmentally Sensitive Area, its landscape and land usage, statistics on uptake within the ESA scheme and vegetation classifications. It also presents a rationale for the choice of study sites used, and describes each site using existing survey and map information.

2.2 Landscape and Vegetation

2.2.1 Formation of the Landscape.

The SWD ESA covers two separate areas of chalkland within the counties of Dorset and Wiltshire. As Fig 2.1 shows, it extends from Dorchester, along Cranborne Chase to Salisbury, and then west from Salisbury into the area loosely termed the West Wiltshire Downs.

Within these areas are many of the characteristic habitats to be found on calcareous substrates, but before discussing them a brief synopsis of the geology of the area is presented.

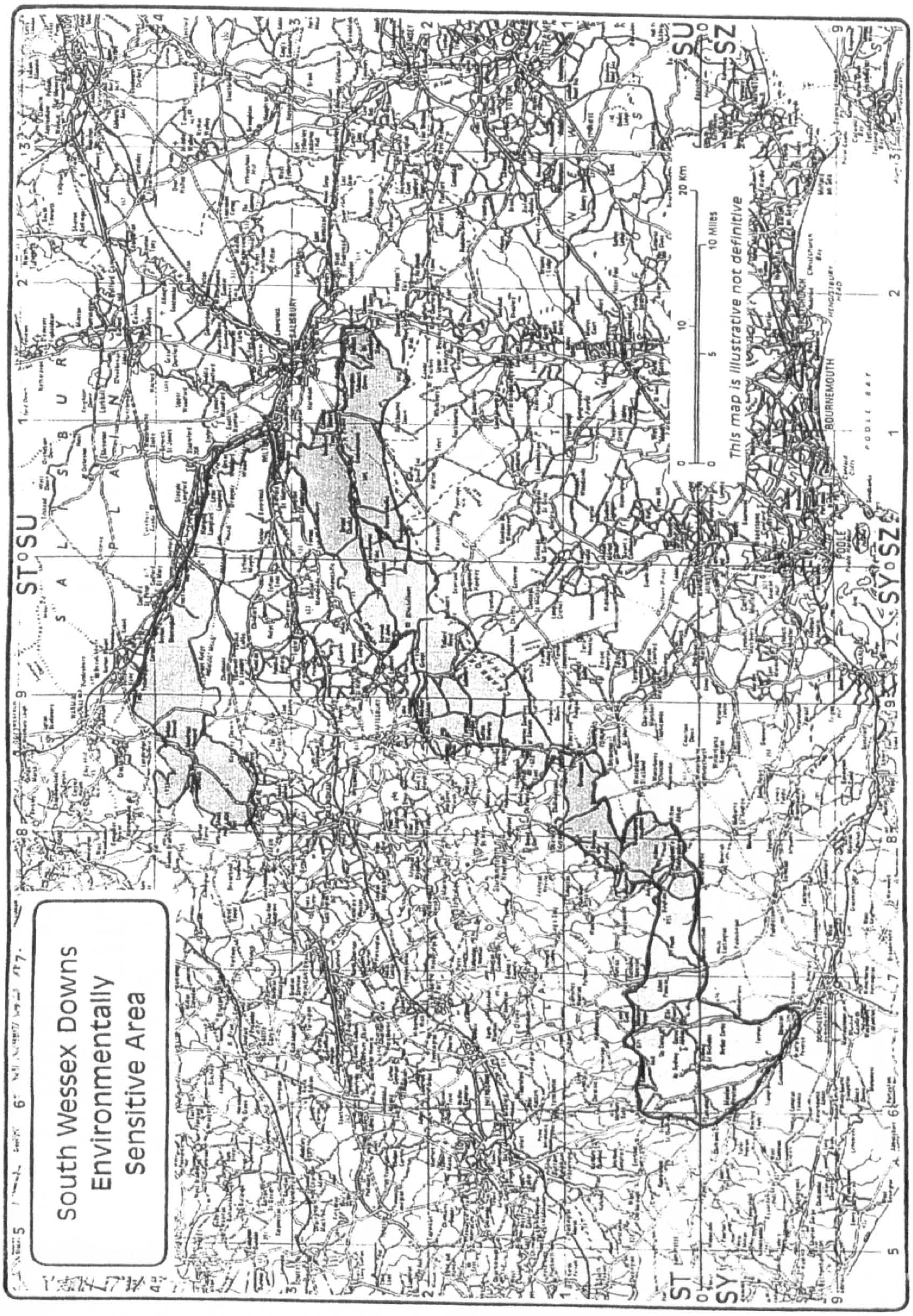


Fig 2.1: The South Wessex Downs ESA (Source: MAFF, 1998).

2.2.2 Geology

During the Jurassic period (starting 200 million years ago) Britain was part the North Atlantic continent of Laurasia. Much of southern England was under water, part of a warm shallow sea which advanced and receded over the millennia. Deposits from this sea formed much of the Jurassic limestone to be found in the area today, such as Purbeck Marble and Portland Stone. In the subsequent lower Cretaceous period, Greensand (a marine sandstone) and blue Gault (a marine clay) were laid down but eventually the sea became so shallow and calm that by the upper Cretaceous (ending 60 million years ago) the only deposits settling on the sea bed were the tests of floating micro-organisms and bottom dwellers (ammonoids and pelecypods). These formed a 'calcareous ooze' which gradually consolidated into chalk, often containing characteristic flint nodes which are thought to have formed around the remains of sponges in the sediment (Bennison and Wright 1970; Edmonds et al. 1975). Fig 2.2 shows the extent of the chalk in southern England.

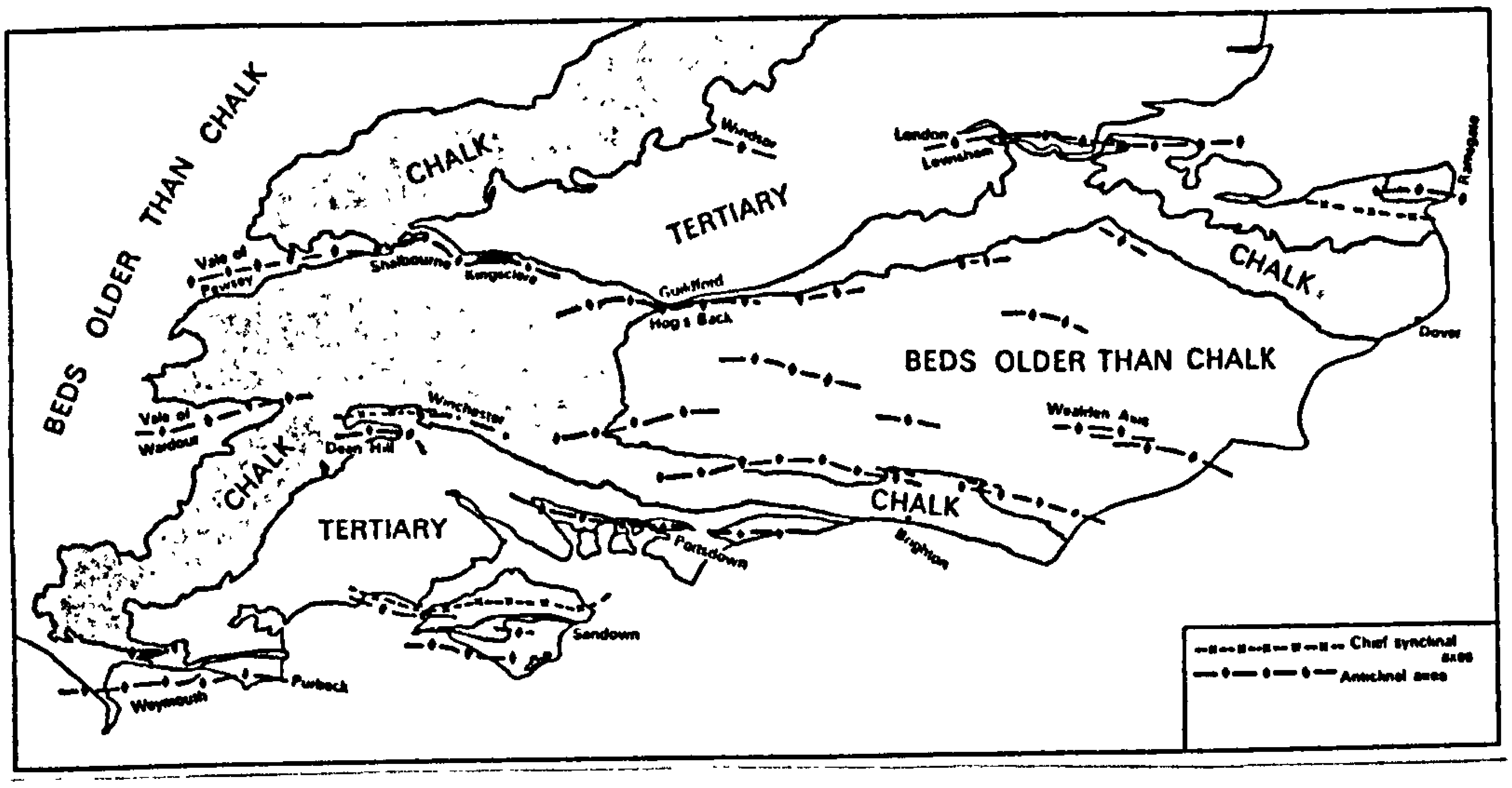


Fig 2.2: The southern chalk (Bennison and Wright 1970).

Twenty-five million years ago Africa collided with southern Europe, pushing up the Alps and Pyrennees but also crumpling the chalk and limestone in England. At the same time forces of erosion exposed the Greensand in valleys and along the scarp edge of the chalk and deposited gravel and clays on top of the chalk, which have led to the characteristic 'clay caps' of neutral or acidic material found on top of many hills in these areas.

Two million years ago the Earth entered the last of a series of four ice ages. Southern England was never under ice but tundra conditions persisted and the seasonal melting of snow and permafrost led (via solifluction) to the erosion of valleys present today in the SWD ESA (Trueman 1971; Brunsden and Goudie 1997). As the ice melted Britain tilted and the southern part of the island sank, establishing much of the present day coastline (Watts 1961; Burden and Le Pard 1996).

These processes have led to the soft rounded landscape which characterises the chalklands of Dorset and much of Wiltshire. Geological weathering has developed particular soil types and these in turn support a unique and specialised flora and fauna.

2.2.3 Soils

The soils within the SWD ESA are representative of all types of soil to be found on the chalk. These soils have been classified by the Soil Survey of Great Britain (Avery 1980) into major groups which are then divided into associations on the basis of a set of criteria which includes the type of parent material (substrate) present. These are further divided into series but for the purposes of this introduction, information on the associations will be presented.

All the chalk soils can be divided into three broad categories.

- Chalk marl/chalk clay (consisting of a mix of clay (deposited by erosion) and chalk material) is found mainly on hill tops where it forms brown earths and podzols.

- On the slopes are thin soils called rendzinas, characterised by the way they grade sharply into the chalk and divided into humic and non-humic types by the amount of organic matter they contain.

- In valleys deep, fertile alluvial deposits form loams and gleys; some of the richest soils on the chalk substrate.

The soils present at the study sites used in this research fall under seven associations, and a short description of each is given below:

Table 2.1: Classification and description of the soils present at study sites in the SWD ESA (Findlay et al. 1984).

Association		**Geology, description and main land use**	**Site found at:**
Number	**Name**		
341	Icknield	Chalk. Shallow, mostly humose, well drained calcareous soils over chalk on steep slopes and hill tops. Deeper flinty calcareous silty soils in small coombes and valleys. Permanent grassland, downland and woodland on steep slopes. Cereals and short term grassland on plateaux.	2, 3, 6, 7.
342a	Upton 1	Chalk. Shallow, well drained calcareous silty soils over chalk. Mainly on moderate steep, sometimes very steep land. Deeper fine silty calcareous soils in coombes and dry valleys. Permanent grassland, rough grazing and woodland on scarps. Cereals and short term grassland on gentle slopes.	5, 7.
343h	Andover 1	Chalk. Shallow, well drained calcareous silty soils over chalk on slopes and crests. Deep calcareous and non-calcareous fine silty soils in valley bottoms. Striped soil patterns locally. Winter cereals and short term grassland with dairying and stock rearing, some woodland.	1, 2, 3, 4, 6.
343i	Andover 2	Chalk and clay-with-flints. Shallow, well drained calcareous silty soils over chalk. Associated with deeper non-calcareous variably flinty well drained fine silty and fine silty over clayey soils. Winter cereals, cereal and grassland rotations with dairying and stock rearing. Woodland.	5.
511d	Blewbury	Chalk. Well drained calcareous clayey and fine silty over clayey soils over argillaceous chalk. Some fine silty over clayey soils with slowly permeable subsoils and slight seasonal waterlogging. Cereals and short term grassland with dairying and stock rearing.	3.
581d	Carstens	Plateau drift and clay-with-flints. Well drained fine silty over clayey, clayey and fine silty soils, often very flinty. Winter cereals, often in rotation with grass. Stock rearing. Some deciduous and coniferous woodland.	1, 2, 4, 5, 7.
582a	Batcombe	Plateau drift and clay-with-flints. Fine silty over clayey and fine loamy over clayey soils with slowly permeable subsoils and slight seasonal water logging. Some well drained clayey soils over chalk. Variably flinty. Cereals and dairying.	3.

2.2.4 Landscape and Land-Use within the SWD ESA

The landscape of the SWD ESA is dominated by chalk outcrop which runs along the Dorset Downs and continues into Salisbury Plain and the West Wiltshire Downs (Chatwin 1960). The area is characterised by scarp and dip; scarp slopes gradually away to the east into the Hampshire Basin and the steeper western edge of the outcrop dips into the greensand and clay dominated beds below the chalk (Woodcock 1995) to form valleys such as the Blackmoor Vale. As well as valleys formed from past erosion, chalk rivers still cut through the chalk, leading to the formation of steep, narrow valleys and further exposure of the greensand (ADAS 1994).

The chalk plateaux areas are characterised by wide, open expanses of what was once rolling downland and is now mostly arable land. This is broken by patches of woodland (predominantly beech, oak and ash) and conifer plantations as well as valleys centred on chalk rivers such as the Frome, Stour, Nadder and Ebble. Traditional management of this landscape would have involved grazing the downland of the open plateaux, scarp and dip, as well as hazel coppicing in many of the woodlands which were kept as 'coppice with standard' woods. The main areas of arable farming would have been on the deeper, fertile valley soils, but have now spread onto the plateaux areas as well, although occasional arable use of the downland in the past, perhaps on a long rotation, is well documented (Wells et al. 1976; Gibson and Brown 1991; Wells et al. 1994). Much of the woodland has lost its traditional value through the cessation of coppicing and the contrast between patches of managed woodland and open expanses of grazed downland is gradually being eroded.

The areas of chalk downland in Dorset and Wiltshire, including those in the SWD ESA are subject to a relatively low rainfall of 800-1100 mm per year (ADAS 1994). The soils are workable and, on the chalk plateau, landform is open and easy to farm. Historically this area was dominated by sheep based systems, associated with the development of the 'Downs' and their distinctive flora and fauna, but this has now changed (Gibson 1995). The present situation within the ESA is one of large scale dairy farming, as well as arable and mixed farming units with the addition of several large sheep flocks. Within the 45000ha of the SWD ESA, 38300ha are eligible for agreement and 20253ha are actually under a management agreement (MAFF *pers. comm.*). This represents 45% of the area of the SWD ESA or 53% of the area eligible for agreement. Agricultural land (including arable, permanent grassland and downland) covers 86% of the ESA with downland covering 11% of the total area. Most farms are over 200ha in size and 70% are owner occupied (ADAS 1994).

It is mainly sheep and cattle grazing that has led to the formation of the chalk downland turf which forms the baseline for this study (see section 1.2.2 in Chapter 1). The SWD ESA is estimated to contain about 15% of the national area of 40000ha of chalk grasslands (ADAS 1994). A large proportion of this 5900ha of chalk grassland within the ESA (only 2400ha of which is designated SSSI) is to be found on the steepest scarp and dip slopes which have proved too difficult to plough for arable use. One of the aims of the ESA is to promote the re-instatement of traditional grazing regimes on these areas to prevent them being abandoned and continuing through the successional process to scrub and eventually woodland. This will also help conserve the large number of sites of archaeological and historic importance, ranging from old field systems, to large and complex earthworks which also characterise the ESA. The classification of the plant associations which develop in these particular conditions of climate, soil type and depth, aspect and grazing is described below, using the National Vegetation Classification scheme.

2.2.5 Vegetation

The NVC classification of chalk grassland is described in Rodwell (1998). Briefly, discrete vegetation communities and sub-communities are identified on the basis of their homogeneity and species composition, and then given a letter code (for example; CG=calcareous grassland, MG=mesotrophic grassland) and number (referring to the type of grassland within the letter code category). Sub-communities are identified by adding a letter code after the number.

Calcareous grasslands of the south-east of Britain (those below a line running from Durham, across Derbyshire and to Wales) are found to be floristically distinct from those in the north-west. The basic calcareous community is represented by *Festuca ovina - Helictotrichon pratensis* dominated grassland (CG2) and within this Rodwell identifies variations and trends which are dependent on grazing intensity, soil depth and drainage and climatic conditions such as variation in rainfall. In the south this is further divided into those swards which are exposed to maximum sun and found on those south and west facing slopes with longer growing seasons and mild oceanic climate (CG1 - *F. ovina - Carlina vulgaris*) and those swards which are associated with very dry and shallow rendzinas and significant levels of disturbance (CG7 - *F. ovina - Pilosella officinarum – Thymus polytrichus/pulegioides*).

In areas where grazing has been interrupted, either from a decrease of livestock use or through a decline in rabbit populations after myxomatosis, four herbaceous calcicolous communities are distinguished. All are characterised by an increase in dominance of the ranker grasses and a corresponding decrease in the light-demanding more diminutive herbs. CG3, CG4, CG5 and CG6 swards are all dominated by various combinations of *Bromopsis erecta, Brachypodium pinnatum, F. rubra* and *Helictotrichon pubescens*. Where there is an abundance of *Arrenatherum elatius* the sward is classified as a calcicolous MG1 (Rodwell 1998).

The most important chalk grassland communities within the SWD ESA have been identified as;

- CG2 *F. ovina - H. pratensis*
- CG3 *B. erecta*
- CG4 *B. pinnatum*
- CG5 *B. erecta – B. pinnatum*

- CG7 *F. ovina – P. officinarum – T. polytrichus/pulegioides*

with sub-communities which are described in subsequent sections where relevant (ADAS 1994). On deeper less calcareous soils mesotrophic grassland communities such as MG5 (*Cynosurus cristatus - Centaurea nigra*) occur, and develop into MG6 communities (*Lolium perenne - C. cristatus*) where there has been agricultural improvement (Edwards 1998).

These communities are described in more detail below (summaries are taken from Edwards (1998) and Rodwell (1998)):

CG2 *F. ovina - H. pratensis* grassland

The 'typical' short species-rich grassland, comprising short springy turf with fine leaved herbs forming a compact ground cover between the grasses. The sward is dominated by *F. ovina* but constant species include *H. pratensis, Briza media, Carex flacca, P. officinarum, Koeleria macrantha, Leontodon hispidus, Linum catharticum, Lotus corniculatus, Plantago lanceolata, Sanguisorba minor, Scabiosa columbaria* and *T. polytrichus*. Found under rabbit and sheep grazing and favouring southerly aspects.

CG3 *B. erecta* grassland

A distinctive grassland dominated by *B. erecta* (>10% cover) which, especially in ungrazed sites, often forms conspicous tussocks. Other species are much the same as those found in CG2 but *Filipendula vulgaris* is a typical associate. This type of grassland is the most common community on the Wiltshire chalk but in Dorset is confined to the north-east.

CG4 *B. pinnatum* grassland

This community includes all swards in which *B. pinnatum* exceeds 10% cover in the virtual absence of other tussock forming grasses such as *B. erecta* and *H. pubescens*. It does not contain as many of the Festuca-Avenula association species (although *C. flacca* and *F. ovina* are found throughout) and often occurs outside the range of other British calcicolous grasslands, as well as in those areas where grazing has been relaxed and wetter conditions prevail.

CG5 *B. erecta - B. pinnatum* grassland

A rare community described as comprising an open or closed, tall, sometimes rank and tussocky mixed sward or *B. erecta* and *B. pinnatum*. *C. flacca, F. ovina* and *B. media* are constant and can be locally abundant.

CG7 *F. ovina - P. officinarum - T. polytrichus/pulegioides* grassland

A short, broken turf community which lacks the dense, plush quality of the *Festuca-Avenula* swards, instead being characterised by an abundance of large pleurocarpus mosses such as *Hypnum cupressiforme,* lichens and the isolated tussock formations of *F. ovina*. *K. macrantha* is common throughout and *P. officinarum*, *L. hispidus* and *T. polytrichus/pulegioides* are good indicators. The open form of this community can lead to the growth of weeds such as *Senecio jacobaea* but also encourages rarities such as *Gentianella amarella*.

MG5 *C. cristatus - C. nigra* grassland

Often found in calcareous dairy pastures or old meadows and pastures where it comprises a tight, low-growing sward or a fairly lush growth depending on the grazing regime. Common grasses include *Agrostis capillaris, Dactylis glomerata, Holcus lanatus* and *F. rubra* as well as several legumes and rosette forming plants such as *L. corniculatus, Trifolium pratense/repens* and *P. lanceolata*. *Rhinanthus minor* can form infestations in these swards which are typical of deeper, less calcareous soils and many other species are found intermittently, such as *Potentilla erecta, Hypochaeris radicata* and *Leontodon autumnalis.*

MG6 *L. perenne - C. cristatus* grassland

This community comprises a short, tight grass dominated sward often found in improved re-sown pastures. As with MG5 grasslands, *F. rubra, A. capillaris, H. lanatus* and *D. glomerata* are frequent but the dicotyledonous component of the sward is less varied, being made up of common species such as *T.repens/pratense, Ranunculus acris, Achillea millefolium, Bellis perennis, Cirsium arvense* and *P. lanceolata.*

The following sections of this chapter describe the rationale underlying the choice of study sites used in the research, and then describe each study site according to previous survey data.

2.3 Study Sites

2.3.1 Rationale behind choice of study sites and site descriptions

The choice of site to be used in the work presented below was guided by the aims of the research which are presented in Chapter 1. In addition study sites were chosen to be used as a set of replicates, resulting in the choice of sites which were as similar as possible to each other, in terms of aspect, soil type, elevation, land use and size. In order to fulfill the aims of the research (involving the examination of re-created chalk grassland alongside established chalk grassland, as well as the edge effects of these communities and of adjacent arable land) each site contains areas of chalk downland, re-created chalk downland and arable land, adjacent to each other where possible. Each of the habitats was further divided into edge and middle areas for the purpose of some of the research; edge areas were the habitat area within 10m of a field boundary such as a hedge or fence and middle areas comprised all of the habitat area except for the 10m border around the edge.

These main habitat types are representative of the mixed farming regime that is the commonest practice within the SWD ESA; wheat, oilseed rape, linseed and maize are the main arable crops, while sheep and cattle are usual grazing animals. The sites are distributed throughout the SWD ESA, to avoid bias from concentrating research in one geographic area of the scheme.

These specific requirements led to a narrow range of sites to choose from, mainly because of the limited uptake of land into the chalk downland re-creation option of the scheme (only 3% or 887 ha of the area eligible for this option (ADAS 1997)) . In addition, some of the existing chalk downland was found to be relatively degraded (due to nutrient run-off and poor management) and was therefore not of suitable quality for use in a comparative study. Within the sites, the choice of transect routes incorporating edge and middle areas was guided by a need for the different habitat types to be adjacent where possible and at least 100m long. These requirements are explained further in Chapter 3.

The seven sites chosen for use in this project are described below and their geographic location is shown on Fig 2.3. Information gathered in the course of this study, on community type and soil nutrient status, is presented in subsequent chapters. In addition to the information presented in each site description, Table 2.2 summarises the basic information about each site and can be used with the site maps.

Table 2.2: Summary information about the seven study sites chosen. (DCGS = Dorset Chalk Grassland Survey, DCGI = Dorset Chalk Grassland Inventory, WGI = Wiltshire Grassland Inventory, NVC = National Vegetation Classification).

Site	Langford	Huish	Court	Throope Manor	Coombe Bisset	Peckons Hill	Lower Pertwood
Other survey information	DCGS 1983/4 DCGI 1998 ESA monitoring SSSI notification	DCGS 1983/4 DCGI 1998	DCGS 1983/4 DCGI 1998 SSSI notification ESA monitoring	DCGS 1983/4 SSSI notification	SSSI notification, Wiltshire Wildlife Trust surveys WGI 1995	WGI 1995	WGI 1995 SSSI notification
NVC chalk communities	CG2c CG6	CG2aii CG2c	CG2aii CG2b CG2c	CG2 CG3b CG3d	CG2b	CG2b	CG2b
Notable plant sp.	*Gentianella amarella*	*G. amarella*, *G. anglica*	*Polygala calcarea*, *Anthyllis vulneraria*	*Thesium humifusum*, *Orchis ustulata*, *Carex humilis*	*T.humifusum*, *C.humilis*, *Blackstonia perfoliata*, *O.ustulata*		*Spiranthes spirales*
Notable Lepidoptera sp.	*Eurodryas aurinia*, *Hamearis lucina*		*Lysandra coridon* *Parasemia plantagenis*	*L. bellargus*	*L. bellargus*, *L.coridon*		
Grazing	Mainly sheep. Some cattle and horse	Sheep	Cattle	Sheep	Sheep	Cattle	Cattle and sheep
Downland re-created when ?	1994	1994	1993	1995	1994	1993	1994
Seed mix and rate.	Commercial downland mix, at 20kg/ha	Mix no.2, at 20kg/ha	Mix no.1 at 20kg/ha	Mix no.2, at 20kg/ha	Mix no.1, at 15kg/ha	Mix no.2, at 20kg/ha	Tailored mix – see site description.

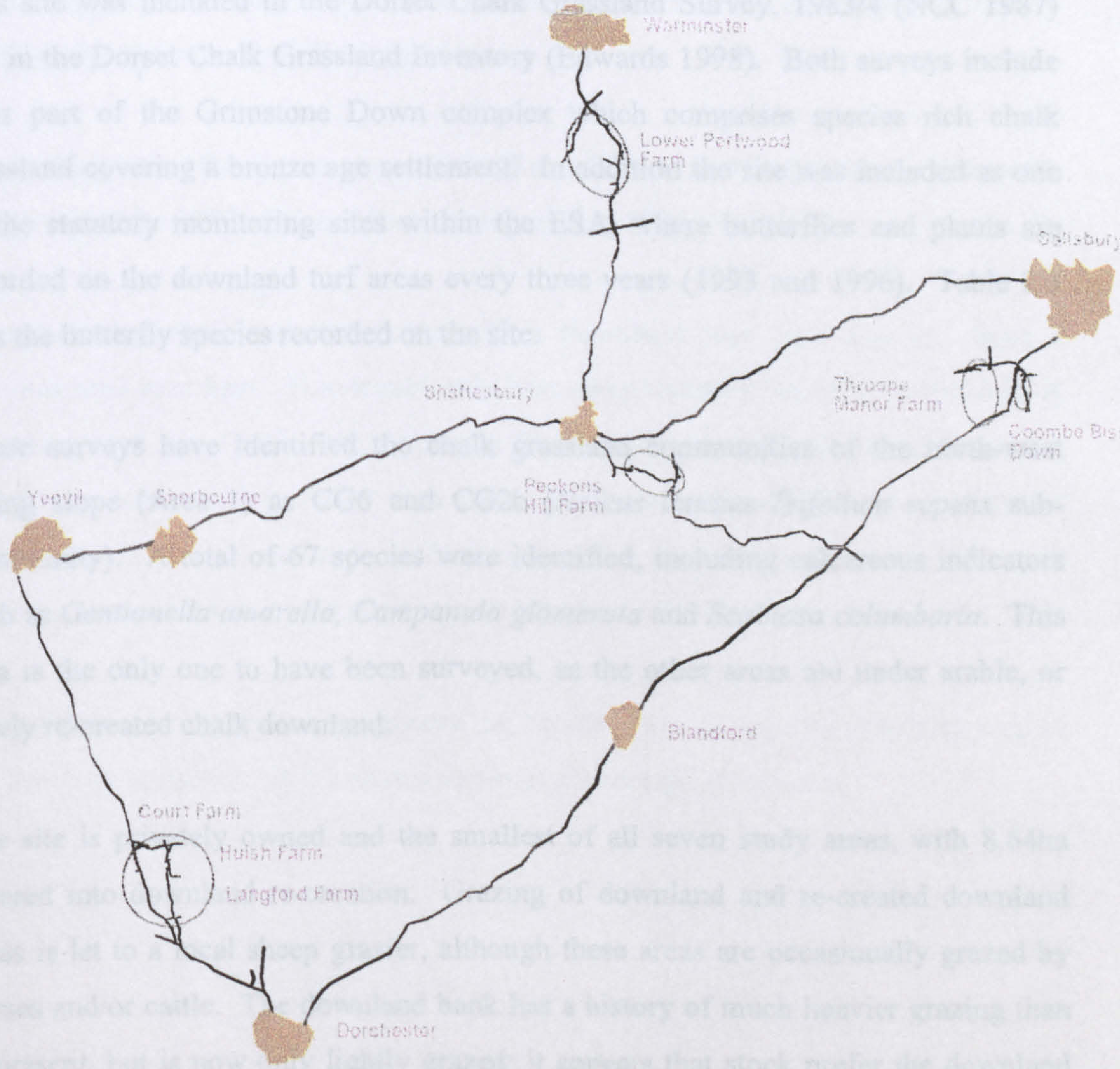


Fig 2.3: The geographic location of the seven sites used in this study. Black lines are major roads, solid shapes are towns and green elipses are study site locations, with the site name adjacent.

2.3.2: Site 1 - Langford Farm, Sydling St Nicholas, Dorset

Grid Ref.: SY 6495

Soil associations: Andover 1, Carstens.

Figs 2.4 & 2.5

This site was included in the Dorset Chalk Grassland Survey, 1983/4 (NCC 1987) and in the Dorset Chalk Grassland Inventory (Edwards 1998). Both surveys include it as part of the Grimstone Down complex which comprises species rich chalk grassland covering a bronze age settlement. In addition the site was included as one of the statutory monitoring sites within the ESA, where butterflies and plants are recorded on the downland turf areas every three years (1993 and 1996). Table 2.3 lists the butterfly species recorded on the site.

These surveys have identified the chalk grassland communities of the north-west facing slope (Area 1) as CG6 and CG2c (*Holcus lanatus-Trifolium repens* sub-community). A total of 67 species were identified, including calcareous indicators such as *Gentianella amarella, Campanula glomerata* and *Scabiosa columbaria*. This area is the only one to have been surveyed, as the other areas are under arable, or newly re-created chalk downland.

The site is privately owned and the smallest of all seven study areas, with 8.64ha entered into downland re-creation. Grazing of downland and re-created downland areas is let to a local sheep grazier, although these areas are occasionally grazed by horses and/or cattle. The downland bank has a history of much heavier grazing than at present, but is now only lightly grazed; it appears that stock prefer the downland re-creation of the valley bottom. The main influence on the downland turf appears to be rabbit grazing from two large warrens in the adjacent scrub. This has led to a predominance of those butterfly species which use longer downland turf, as can be seen from Table 2.3. *Eurodryas aurinia* (Marsh Fritillary) is also an occasional visitor to the site, although there is no breeding colony.

During the period of the study the re-created downland was topped in 1998 to control spread of *Bromus hordeaceus*. *Senecio jacobea* is hand pulled each year on the downland and re-created downland, as well as being controlled to some extent by the sheep grazing. Grazing tends to be intermittent from early summer to late autumn as the sheep are alternated between this site and a neighbouring farm, and this low level of grazing probably favours the small *Hamearis lucina* (Duke of Burgundy) colony found to the eastern end of the downland.

The arable area of the farm was sprayed off and left in 1996, before being sown with winter wheat for 1997. Oilseed Rape was grown in 1998.

The re-created downland was sown with a downland seed mix acquired from a regional seed merchant. This would only have approximated the recommended ESA reversion seed mix (no.2 - see Appendix 2) and contains agricultural cultivars and non-native seed varieties rather than native seed, as well as higher proportions of some legumes and grasses such as *Trifolium repens* and *Lolium perenne*. The seed mix was sown at the recommended rate of 20kg/ha in the autumn of 1994.

Fig 2.4 presents site details and shows the habitat areas used in this study as well as the butterfly transect. Fig 2.5 shows an aerial photograph of the site.

Table 2.3: Occurrence of butterfly species at Langford Farm, as recorded by SWD ESA statutory monitoring in 1993 and 1996 (R.Belding *pers.comm.*)

Common Name	***Latin Name***	**1993**	**1996**
Small Skipper	*Thymelicus sylvestris*	✓	✓
Large Skipper	*Ochlodes venata*	✓	✓
Dingy Skipper	*Erynnis tages*		✓
Grizzled Skipper	*Pyrgus malvae*		✓
Brimstone	*Gonepteryx rhamni*	✓	✓
Large White	*Pieris brassicae*	✓	
Small White	*Pieris rapae*	✓	✓
Green-veined White	*Pieris napi*	✓	✓
Green Hairstreak	*Callophrys rubi*	✓	
Small Copper	*Lycaena phlaeas*	✓	✓
Small Blue	*Cupido minimus*	✓	
Common Blue	*Polyommatus icarus*	✓	✓
Duke of Burgundy	*Hamearis lucina*	✓	✓
Painted Lady	*Cynthia cardui*		✓
Small Tortoiseshell	*Aglais urticae*	✓	✓
Red Admiral	*Vanessa atalanta*		✓
Peacock	*Inachis io*	✓	✓
Wall	*Lasiommata megera*	✓	
Gatekeeper	*Pyronia tithonus*	✓	✓
Meadow Brown	*Maniola jurtina*	✓	✓
Marbled White	*Melanargia galathea*	✓	✓
Ringlet	*Aphantopus hyperantus*	✓	✓
Small Heath	*Coenonympha pamphilus*	✓	✓

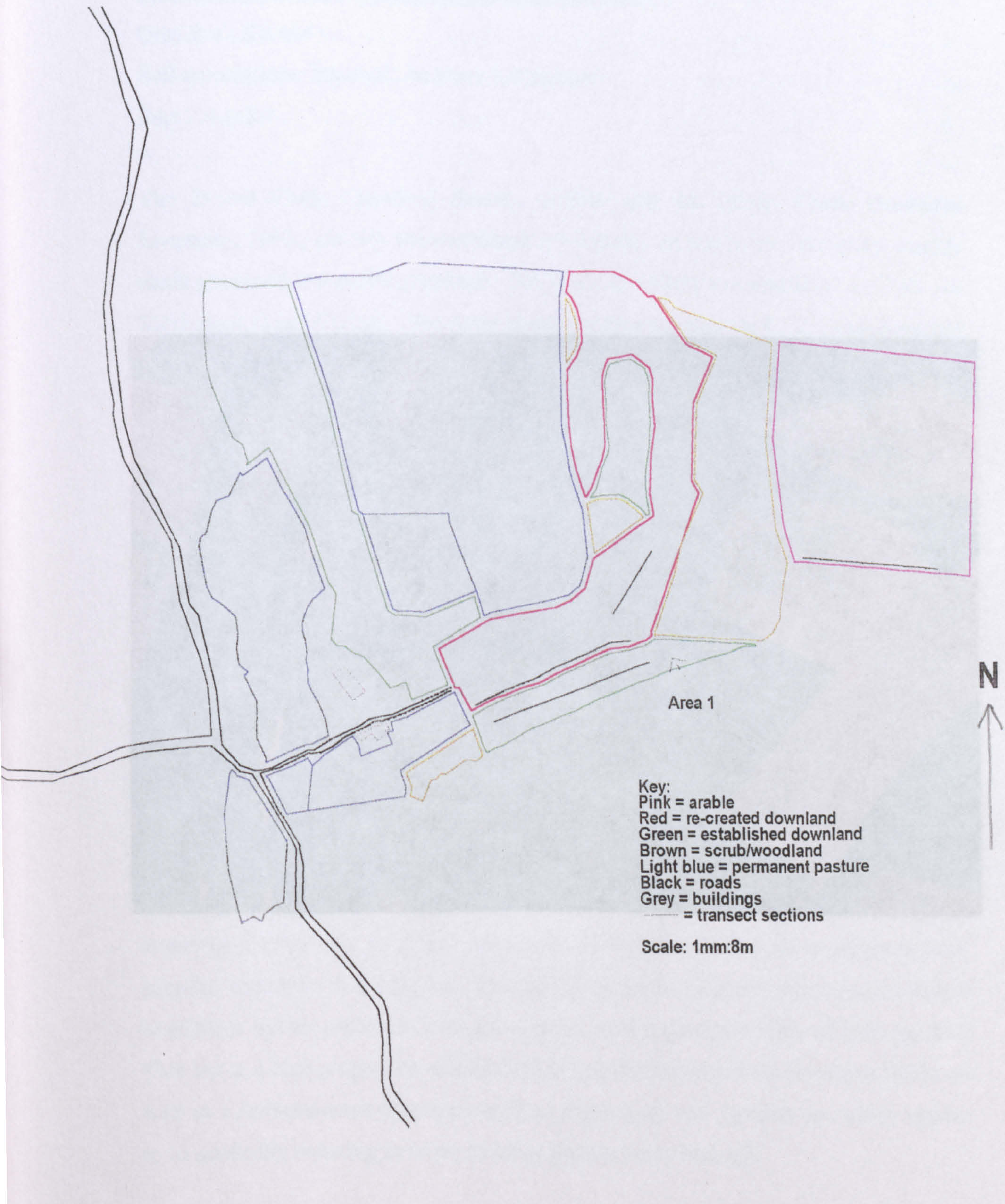


Fig 2.4: Map of Langford Farm.

Fig 2.5: Aerial photograph of Langford Farm (1996).

2.3.3: Site 2 - Huish Farm, Sydling St Nicholas, Dorset

Grid Ref.: SY 6597

Soil associations: Icknield, Andover 1, Carstens.

Figs 2.6 & 2.7

The Dorset Chalk Grassland Survey, 1983/4 and the Dorset Chalk Grassland Inventory, 1998, identify the downland of this site as a mix of very good quality chalk grassland and arable grassland. The chalk grassland was classified as CG2c (of SSSI quality) and CG2aii. This latter grassland type denotes the CG2 *Cirsium acaule - Asperula cynanchica* subcommunity, with 'ii' being the typical variant of this (Rodwell 1998). The 1983/4 survey recorded 73 downland species including chalk downland indicator species such as *A. cynanchica*, *Gentianella amarella* and *Helianthemum nummularium*.

The site is privately owned and consists of arable fields on the flatter areas and remnant chalk grassland or improved grassland on the steeper slopes and along the narrow valley bottom. The best chalk grassland (Area 1) is on a west facing slope, the bottom of which was ploughed and then allowed to revert back, perhaps around the end of World War II. It has been sheep grazed for many years.

As Fig 2.6 shows, the part of the site used in this study extends to cover an arable (rye grass ley) field to the east of the chalk downland and an ex-arable field to the north which was put into chalk downland re-creation in early May, 1994. A seed mix resembling ESA mix no.2 (see Appendix 2) was acquired from a regional farm supplier and sown at a 20kg/ha. The timing of the sowing and subsequent weather conditions led to problems with germination and a predominance of bare ground. This led to a high proportion of moss and lichen developing in the reversion fields, as well as a predominance of grasses such as *Festuca* sp. and *Agrostis* sp. which appear to be gradually reducing in cover as other species come through.

Subsequent to re-seeding, the downland re-creation areas have been topped to control thistles each year and sheep grazed in the spring and late summer. A walk over survey of these fields in 1997 identified 27 species in the re-creation field used in this study, including *Leontodon hispidus, Lotus corniculatus* and *Sanguisorba minor* (R.Belding, *pers. comm.*), although the latter two species are probable agricultural cultivars. The downland is grazed by sheep in the summer as part of a grazing compartment including the rest of the valley bottom, and the arable field is grazed in late summer and/or cut for silage.

Fig 2.6 shows the study site in detail and includes the transect route walked on this site. Fig 2.7 shows an aerial photograph of the site.

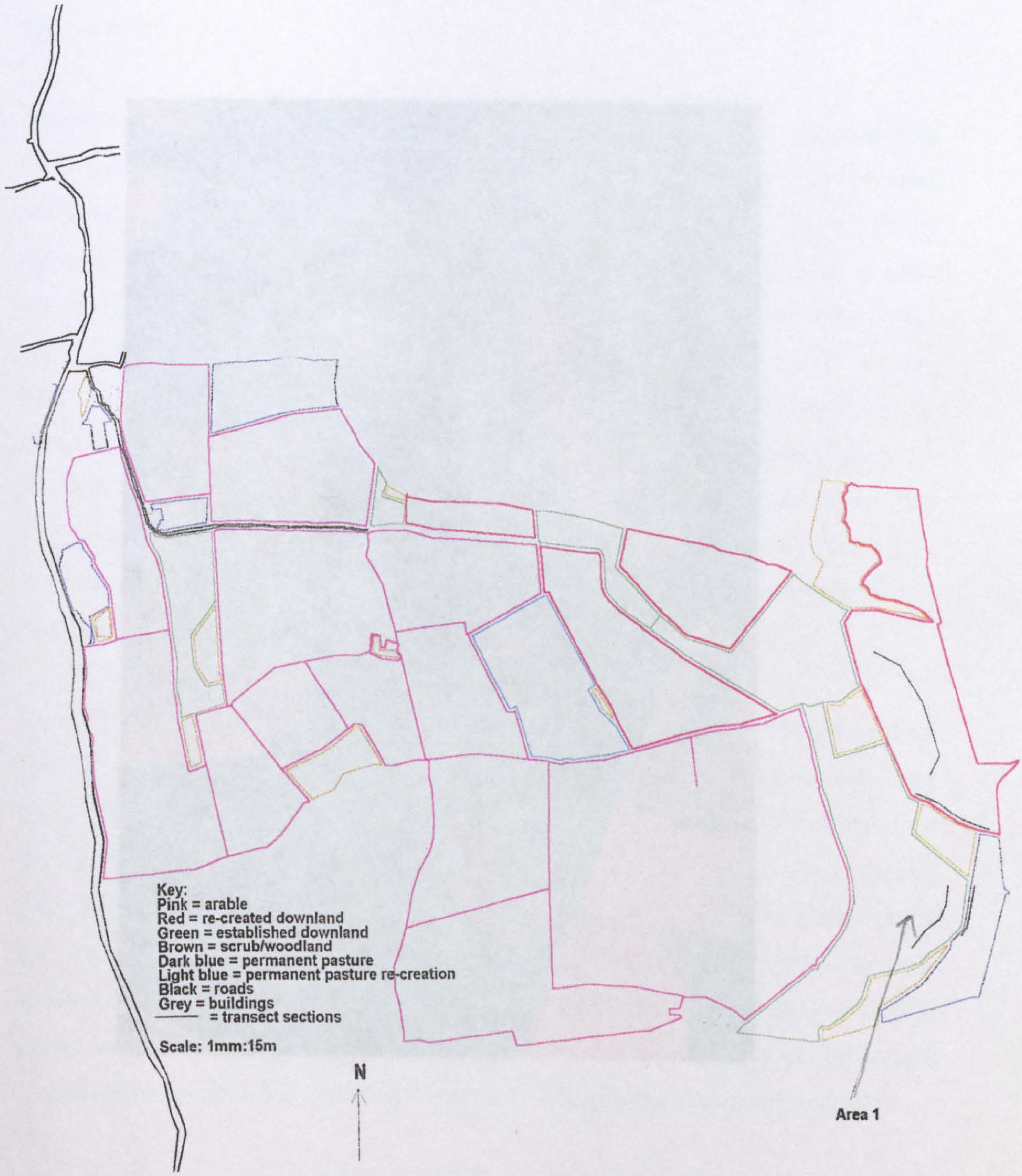


Fig 2.6: Map of Huish Farm.

Fig 2.7: Aerial photograph of Huish Farm (1996).

2.3.4: Site 3 - Court Farm, Sydling St Nicholas, Dorset

Grid Ref.: SY 6298

Soil associations: Icknield, Andover 1, Blewbury, Batcombe.

Fig 2.8 & 2.9

Previous surveys (1983/4 and 1988) showed that this site contains some good quality CG2 grassland including several of the sub-communities (CG2aii, CG2b (*Succisa pratensis-Leucanthemum vulgare*) and CG2c) perhaps indicating the range of topography and aspect contained within the farm. It was notified as a SSSI in 1987 for its 'varied plant communities characteristic of west/central Dorset and a rich assemblage of associated invertebrates' (SSSI Site Citation, NCC, 1987). At that time the site held good populations of *Lysandra coridon* (Chalkhill Blue), *Cupido minimus* and *Eurodryas aurinia*, as well as the Wood Tiger moth, *Parasemia plantagenis*. However, ESA statutory monitoring on the site has shown that *E.aurinia* is no longer present and *C. minimus* was last seen in 1993 (R.Belding *pers. comm.*). The flora includes nationally scarce plants such as *Polygala calcarea* as well as Dorset notables such as *Anthyllis vulneraria* and *Conopodium majus*.

Court Farm lies in a bowl shaped coombe, which faces east across the river valley. The hill tops and coombe bottom have all been ploughed, but the semi-circular slope of the coombe still retains it's downland and a sizeable ancient field system. In September/October 1993 the top fields were reverted to a mix of permanent pasture (Tier 2(2)) and downland re-creation (Tier 2(1)). ESA mix no.1 was used throughout for the downland re-creation (36ha in total) as all the fields are adjacent to good quality chalk downland. A 1972 survey of the Dorset chalk grassland (Jones 1973) shows area 1 as downland turf, and the relatively herb-rich nature of the present sward reinforces the conclusion that it has only been ploughed relatively recently.

The farm is managed as a mixed unit of arable and beef, with a large suckler herd grazing the downland, permanent pasture and re-created downland. The downland is divided into 3 grazing units and the area used in this study is grazed intermittently throughout the summer, until late September, in rotation with the other downland, pasture and re-created downland units. In addition, weeds such as thistles and nettles are controlled by topping in the re-creation fields and spot herbicide application along the edge of the downland.

The arable areas of the site are managed separately to the permanent grassland. During the course of this study oilseed rape, winter wheat and spring barley were harvested in rotation.

Fig 2.8 shows the site in detail and includes the transect route used in this study. Fig 2.9 shows an aerial photograph of the site.

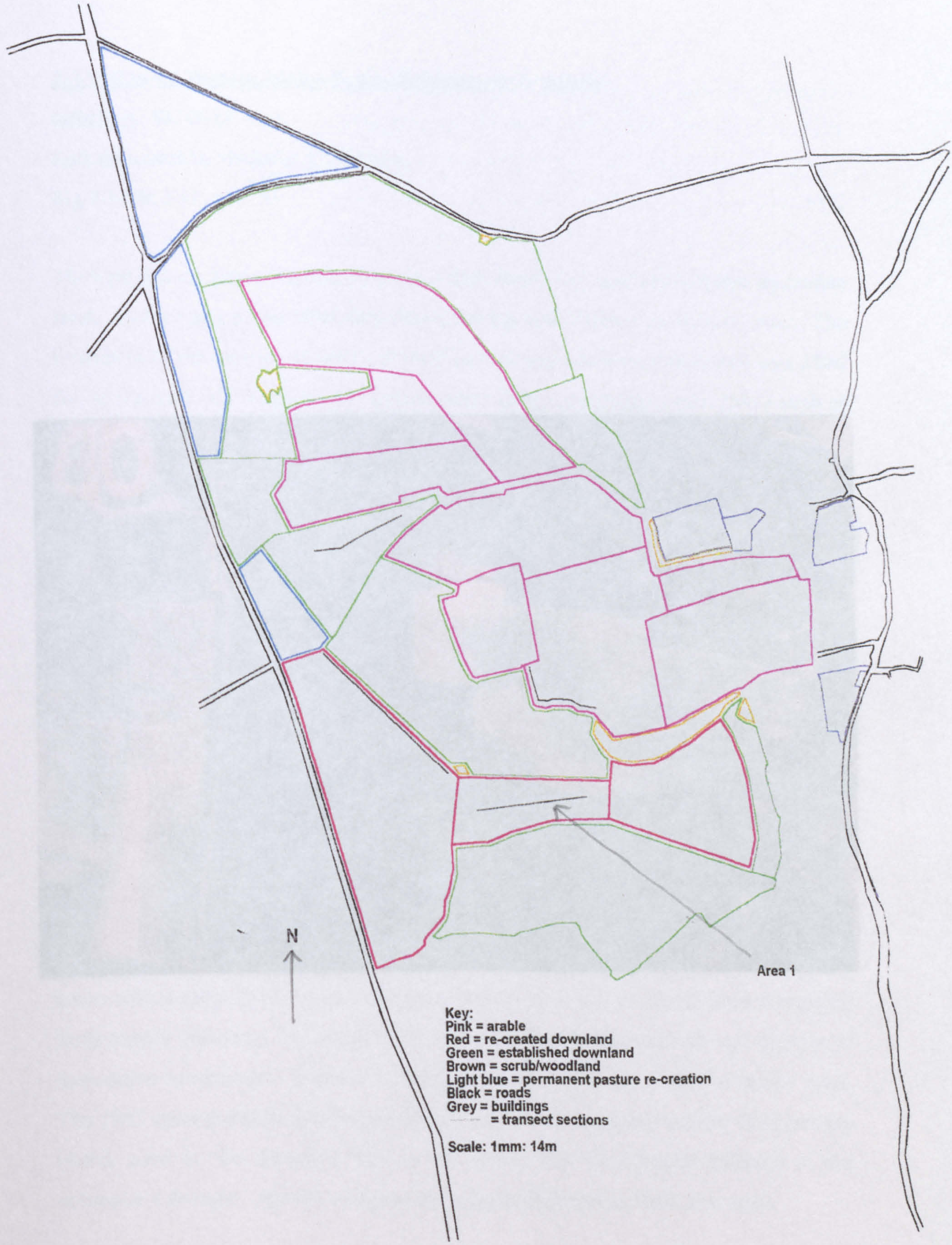


Fig 2.8: Map of Court Farm.

Fig 2.9: Aerial photograph of Court Farm (1996).

2.3.5: Site 4 - Throope Manor Farm, Bishopstone, Wiltshire

Grid Ref.: SU 0824

Soil associations: Andover 1, Carstens.

Fig 2.10 & 2.11

Throope Manor Farm consists of steep sided chalk coombes surrounded by arable land. As for many of the other sites the valley top and bottoms are mesotrophic. The downland of the coombe slopes is of good quality and has been designated as a SSSI due to the herb rich chalk sward. This contains many nationally scarce plants such as *Carex humilis*, *Orchis ustulata* and *Thesium humifusum*, as well as the butterflies *Lysandra bellargus* (Adonis Blue) and *Cupido minimus*. *Eurodryas aurinia* has been recorded in the past but is now no longer resident at the site.

The 1993/4 survey identified most of the chalk grassland as CG3 *Bromus erecta* grassland, containing sub communities CG3b (*Centaurea nigra*) and CG3d (*Festuca rubra – F. arundinacea*), although when first notified it was predominantly *F. ovina-Helictotrichon pratensis* grassland (CG2). This probably indicates a change in grazing practice since 1971 when the site was notified.

48.4ha of the farm have been entered into Tier 2(1), chalk downland re-creation, over a two year period (1993 and 95), and these have been sown with a relatively complex mosaic of seed mixes. ESA mix no.1 was used in a 50m buffer strip around all fields adjoining SSSI grassland and the rest of the field area inside the buffer zone was then sown with a more diverse mix. However, all the seed was obtained from a regional farm supply company, and consists of agricultural cultivars or forbs and grasses of non-native provenance. In areas 1 and 2 mix no.2 was used inside the buffer zone. The 1993 sowing was in the autumn and establishment was good but the 1995 sowing (fields used in this research) was in the spring and germination suffered in the subsequent drought. Species composition is quite different in these two areas.

The grassland component of the farm (approximately 210ha) is grazed by 600 ewes which are moved between two large grazing compartments. These are sold at market and the next group brought to the farm in late September each year. There is also a large rabbit warren at the northern end of the downland area used in this study. The arable area of the farm is relatively small (63ha) and all fields have conservation headlands sown with a rye grass and clover mix. In the three years of this study the arable field used to collect data from was sown with winter wheat each year. As can be seen from the transect route on Fig 2.10 the arable/downland edge of this transect runs along the crop edge of the conservation headland.

Fig 2.10 shows the transect route at this site. Fig 2.11 shows an aerial photograph of the site.

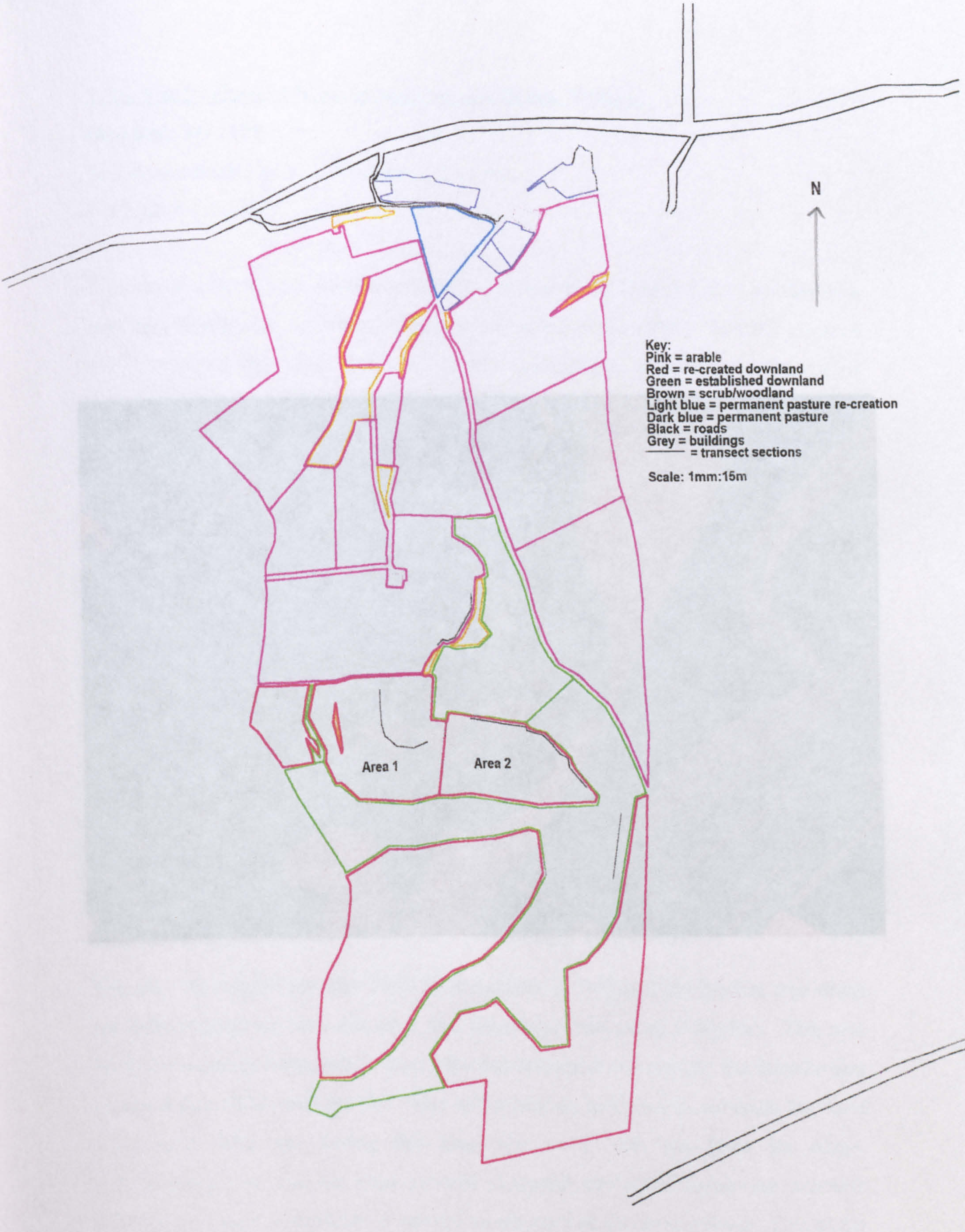


Fig 2.10: Map of Throope Manor Farm.

Fig 2.11: Aerial photograph of Throope Manor Farm (1996).

2.3.6: Site 5 - Coombe Bisset Down, Coombe Bisset, Wiltshire

Grid Ref.: SU 1125

Soil associations: Upton 1, Andover 2, Carstens.

Fig 2.12 & 2.13

This site was designated a SSSI in 1971 for its 'several animal and plant species of a restricted distribution in Britain' (SSSI Site Citation, NCC, 1988). In 1982 the area was described by EN staff as mostly consisting of 'very unimpressive grassland...semi-improved with *Lolium perenne* abundant' (EN *pers. comm.*). Since then changes in management have occurred and there has been a recurrence of much of the original fauna and flora.

Owned by the Wiltshire Wildlife Trust since 1995, this study site consists of a north-south running coombe which has been cultivated in the valley bottom and along lynchets on both slopes. However, the remaining 7.5ha of chalk downland between lynchets and on the steepest slopes is of very good quality, containing well grazed CG2b and more mesotrophic, ranker MG5 / MG6 communities on the lower, less steep slopes. The downland sections of the transect on this site ran through CG2b grassland but some of the subsequent botanical and larval work included MG6 communities as well. The sward is notable for nationally scarce flora such as *Blackstonia perfoliata*, *Thesium humifusum*, *Carex humilis* and *Orchis ustulata* and for the Lepidoptera; *Lysandra bellargus, Lysandra coridon* and *Cupido minimus*.

The site was entered into the SWD ESA scheme in 1993 and the lynchet tops sown the following spring with mix no.1 at a lower rate than usual (15kg/ha). This was done to encourage colonisation from adjacent downland and prevent the introduction of non-native forbs onto the site. The valley bottom had been in set-aside for three years until 1996 and during this time was sown with rye grass for silage. Subsequently, this area has been allowed to tumble down and recolonise naturally although it is topped regularly to control weeds such as *Cirsium arvense*. Due to the lack of a suitable arable field elsewhere on the site, this field was used as the arable section of the transect and in other work requiring data from arable habitat.

Grazing at Coombe Bisset Down has involved around 20 sheep, moved over the whole site during the summer, followed by a larger flock of around 100 sheep grazing throughout the winter. However, the Wiltshire Wildlife Trust have introduced grazing compartments and are reviewing the grazing in the light of the management requirements of the various scarce species on the site.

The site is shown in detail on Fig 2.12. Fig 2.13 shows an aerial photograph of the site.

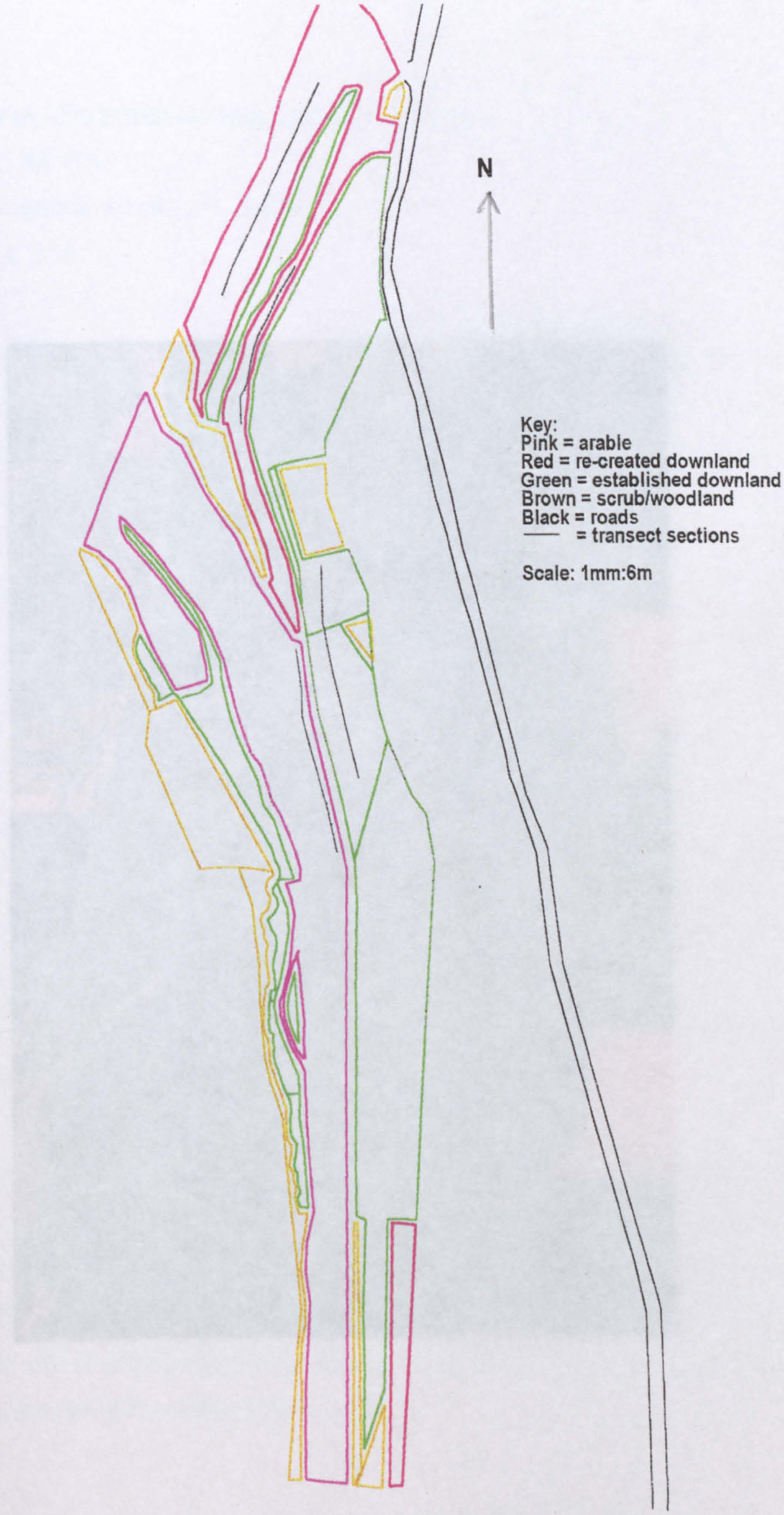


Fig 2.12: Map of Coombe Bisset Down.

Fig 2.13: Aerial photograph of Coombe Bisset Down (1996).

2.3.7: Site 6 - Peckons Hill Farm, Ludwell, Wiltshire

Grid Ref.: ST 9020

Soil associations: Icknield, Andover 1.

Fig 2.14 & 2.15

As Fig 2.3 shows, this site is situated along the scarp edge of the chalk as it drops away to the south-east of Shaftesbury. Gently sloping permanent pasture and arable at the top of the scarp grades into steep, folded slopes which have been cattle grazed, leading to narrow terraces along the contour lines and some poaching. The farm is contiguous with Zig Zag Hill to the west; a large chalk downland site containing significant populations of scarce downland plants and invertebrates.

The downland component of Peckons Hill Farm is mainly CG2b but where the butterfly transect follows the slope contour along to the west this becomes MG5 as the soils deepen, leading to a larger grass component and fewer calcicolous forbs. The downland section of the transect is directly above a small wood and it is likely that deer grazing is a significant influence at this site. Rabbits, in contrast, are only present in low numbers. At the top of the slope the turf has been improved, leading to a predominance of *Lolium perenne* and other grasses, and this area is entered into Tier 2 (Option 4) of the ESA, permanent grassland enhancement. It is managed by extensive grazing and cutting with minimal fertiliser application.

The whole farm was entered into the ESA in 1993 and contains 38ha of downland re-creation. This was all sown with mix no.2 in October except for the large field at the south of the site. A hay crop was cut for the first two years and the re-creation field used in this study is part of the farm's western grazing unit. A herd of around 40 cattle and calves graze periodically throughout the year and *Senecio jacobea* is hand pulled at the end of the summer from all areas.

The arable section of this study site is west of Peckons Hill Farm, adjacent to a track running parallel to the road. Wheat was grown in 1996, followed by barley in 1997 and linseed in 1998.

Fig 2.14 shows the transect route. Fig 2.15 shows an aerial photograph of the site.

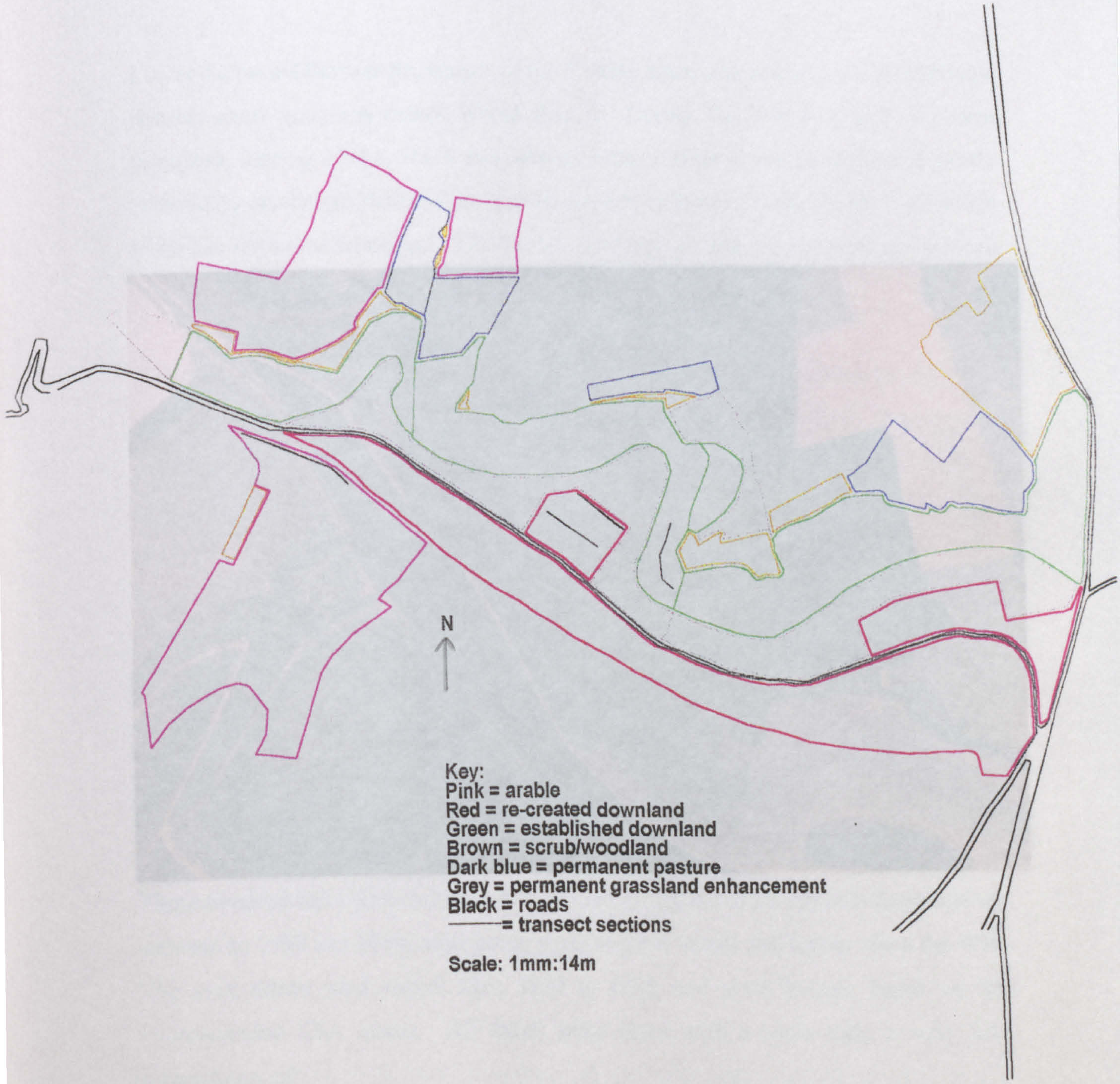


Fig 2.14: Map of Peckons Hill Farm.

Fig 2.15: Aerial photograph of Peckons Hill Farm (1996).

2.3.8: Site 7 - Lower Pertwood Farm, Hindon, Wiltshire

Grid Ref.: ST 8737

Soil associations: Icknield, Upton 1, Carstens.

Fig 2.16 & 2.17

Lower Pertwood Farm is the largest of the 7 study sites, and would have been almost entirely chalk grassland before World War II. During the War over half of it was ploughed, leaving 136ha which still remain today. This area of the farm is partly covered by an ancient field system and bisected by a Roman road, the route of which is visible across the downland. The farm is now organic and a proportion of the work is carried out using traditional methods.

The chalk grassland used in this study (Area 1) runs along a north-west facing slope which is mesotrophic (with MG5 communities) at the top and bottom. In-between, on the steepest part of the slope, is a narrow band of CG2b sub-community which is predominantly cattle grazed. The richest parts were identified in the Grassland Inventory for Wiltshire (English Nature 1995) and included the long barrow at the north-east end of the slope, although the survey found a general predominance of grasses and mosses on the site and a small patch of *Cirsium arvense* has been topped each year. A single spike of *Coeloglossum viride* (Frog orchid) was found in 1989. During the period of this study the area was grazed by a herd of around 30-80 cattle for periods of the year and occasionally by the large flock of sheep, although these were mainly used on other areas of downland.

Three hundred and eighteen hectares of former downland were put into downland re-creation in 1993 and 1994, after being used to grow wheat and barley since the War. The seed mixes used varied from field to field, and were loosely based on the recommended ESA mixes. All fields were sown with a basic mix, in very low proportions, of:

Trifolium repens

T. pratense

Trisetum flavescens

Koeleria macrantha

Briza media

Anthoxanthum odoratum

In addition to this mix, selected forbs were also sown at higher than usual rates to increase the palatability of the resulting sward for livestock. Fox Field (to the north of the existing downland) was sown with the following additions in September 1994;

7kg *Festuca ovina*

4kg *Cynosurus cristatus*

1kg *Agrostis capillaris*

3kg *Festuca rubra* L.subsp. *commutata*

1kg *Lotus corniculatus*

5kg *Medicago lupulina*

Waterloo (the downland re-creation field to the south of the existing downland) was sown with the following additions in June 1994;

8kg *Festuca ovina*

4kg *Cynosurus cristatus*

1kg *Agrostis capillaris*

2kg *F. rubra* L.subsp. *commutata*

1kg *Lotus corniculatus*

5kg *Medicago lupulina*

Both of these areas have been grazed by sheep and/or cattle and cut for hay in all years of this study.

The arable field used in this study was sown with a green manure in 1996 and, after this was ploughed in, the field was then sown with winter barley. In 1997 this was harvested and the field was re-sown with wheat. However, it should be noted that the arable fields at Lower Pertwood Farm were extremely rich in arable weeds and other calcicolous forbs, leading to less contrast between habitats than at other sites.

In 1998 the farm came to the end of the first five year period of the ESA agreement and was withdrawn from the scheme. As a result, the downland re-creation fields were ploughed and some data collection was affected.

Fig 2.16 details the study. Fig 2.17 shows an aerial photograph of the site.

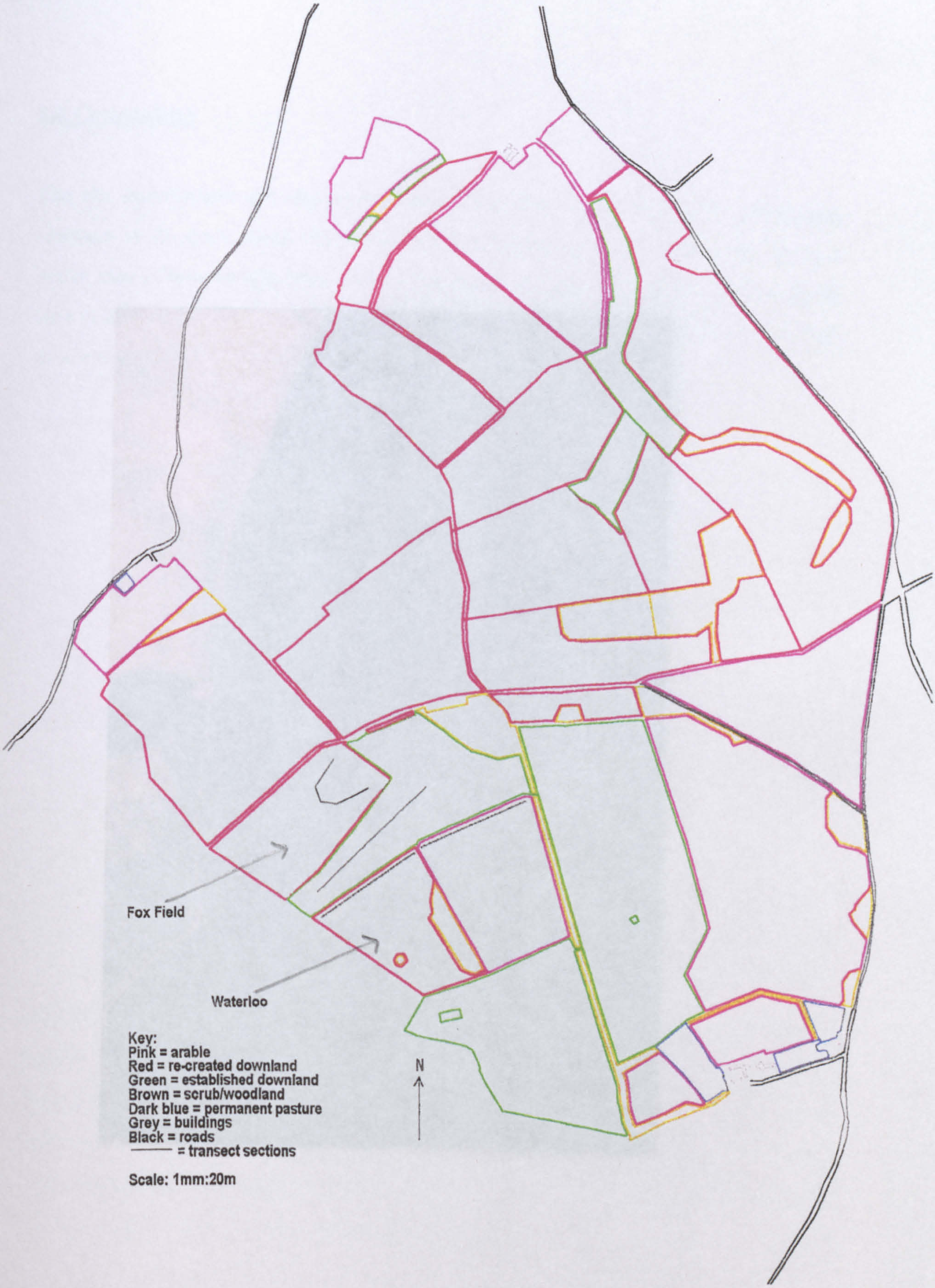


Fig 2.16: Map of Lower Pertwood Farm.

Fig 2.17: Aerial photograph of Lower Pertwood Farm (1996).

2.4 Conclusions

The site descriptions and maps presented in this chapter will be used in subsequent chapters to illustrate areas where research was carried out and to give the reader a better idea of how results from sites fit together. The background information given here is intended to be used in conjunction with results presented in this thesis and also as a summary of the available information on the seven study sites.

Chapter 3 - Methods

3.1 Introduction

Following on from Chapter 2, in which the background to the study sites was presented, this chapter describes the methodology of the experimental work carried out at each site. The sections are in the same order as the chapters in which the results are presented, and are grouped under the results chapter headings. It will be noted that none of the experiments involved the use of a time series and this was because it was felt that three years would not provide a meaningful series of data. It was not possible to find sites in different areas representing a longer time series as there was too much variation in methodology of re-creation and basic site parameters.

The first section describes methods used to evaluate the botanical species richness of existing and re-created downland. This was seen as a logical first step, given that subsequent invertebrate species richness depends largely on the availability of nectar and food plants (Porter et al. 1992) in addition to overriding factors such as climate.

The second section examines habitat quality, in relation to invertebrate species richness. This takes the evaluation of food and nectar plant availability from the previous chapter further by looking at the nutrient status of the soil on which plants are growing and comparing all three habitat areas used in the course of this study; arable, existing downland and re-created downland. The section also describes experiments designed to evaluate the effect of *Lotus corniculatus* (Bird-foot Trefoil) varieties on larvae of the Common Blue butterfly, *Polyommatus icarus*. This work was designed to illuminate the potential effect of the widespread use of non-native seed and agricultural varieties within the SWD ESA.

The third section (relating to the third results chapter) describes the methods of experiments which investigated the presence of invertebrate species (Hemiptera and

Lepidoptera) on ESA habitats. Part 1 describes presence/absence work, and Part 2 describes work looking at how each habitat is used (by the Lepidoptera only).

3.2 Methods

3.2.1 Botanical Species Richness on Existing and Re-created Downland

i) Measurement of Slope and Aspect

Aspect was recorded on each site by using a Silva, Type 3 compass measuring degrees (eg 50° north-east or 203° south-west). In each instance, one reading was taken representing the overall aspect of a particular site habitat section (see section 3.2.3.1 for an explanation of the habitats used). For most site sections, the aspect did not vary along the length of the section, but where the section was curved the reading was taken in the centre of the curve, to obtain an 'average' site aspect. Readings were taken by standing at the vertical middle of the section and reading from the compass when it was pointed at a perpendicular angle to the length of habitat (on straight sections) or bisecting the angle of the curve (on curved sections) in the horizontal plane.

Slope was recorded by using a standard Abney Level, to obtain readings from each section at each site, in degrees. These readings were taken along the route of the transect at each site (see site maps in Chapter 2 for transect routes). At most site sections three readings of slope were taken; one at each end of the section and one in the centre, but only a single reading was necessary when the transect section followed the slope. Measurements were taken by standing at the top or bottom of the slope, viewing the opposite end of the slope through the eye-piece of the instrument and moving the level until the small bubble was visible. The angle of difference between the eye piece and the level represents the slope of the area in question.

ii) Turf height/% cover

Turf height and % cover of vegetation were recorded each year at each site, along the transect route within each habitat section. Turf height was recorded using a standard drop disk, 30cm in diameter, cut from 3mm thick hardboard (weighing about 200gms) and dropped from a height of 1m along a dowling pole of 1cm diameter (Butterflies Under Threat Team 1986). The pole was marked with the height in 5cm increments. Although smaller discs have been used to measure turf height in autecological studies (Butterflies Under Threat Team 1986), this size is the most widely used and was decided on as the best diameter to measure turf height accurately in all the habitats in this study.

Measurements were taken on the following habitat sections;

- Existing downland (middle area)
- Re-created downland (edge area), adjacent to existing downland
- Re-created downland (middle area).

No readings were taken from the arable habitat due to problems with measuring stands of wheat, barley, oilseed rape or fields of stubble. In addition, the measurements would not have been particularly useful due to the changeable nature of arable fields throughout the year. The method used for gathering turf height data is described in Butterflies Under Threat Team (1986) and is also used by the SWD ESA project officer to evaluate turf height and avoid under or over-grazing (R.Belding, *pers. comm.*). This involves walking through the relevant area (a transect route habitat section in this study) and taking a measurement every ten paces. The methods were further modified in this study to account for edge and middle areas of habitat and the measurements in middle areas of habitat were not taken until the recorder was at least 10m from the edge of a habitat (see section 2.21 for an explanation of these habitat distinctions).

Vegetation cover was estimated by using a $0.5m^2$ quadrat which was dropped one pace ahead of each turf height measurement in order to avoid any unconscious site selection by the recorder. The quadrat was divided into $10cm^2$ sections and these were used to estimate % cover to the nearest 5%. This method was chosen to be consistent with that used by the Game Conservancy Trust when recording % cover on other restoration studies (A.Wakeham-Dawson, *pers. comm.*).

Thirty measurements per habitat type were taken for turf height and % cover. At some study sites the area being examined was less than 300 paces (30 measurements) long. If this was the case then the recorder only measured as many turf height/% cover readings as would fit into the area. Measurements were taken at the same time each year.

iii) Vegetation Quadrats

NVC methodology recommends the use of five $2m^2$ quadrats in short herbaceous vegetation (Evans 1989) but this risks losing some of the detailed distribution data within a site, due to the limited number of quadrats. An alternative approach would be to use $1m^2$ quadrats and accumulate the number of species recorded in each one until this number becomes relatively stable (ie most species present have been recorded) (Greenwood 1996). This would then be the correct number of quadrats to use in that habitat.

The approach adopted in this study reflects the amount of vegetation work to be carried out, and the relatively detailed information required. Within each habitat sub-division 20 x $1m^2$ quadrats (divided into $10cm^2$ squares) were placed randomly within the area. It was expected that this number would pick up most species present and give enough replications to enable conclusions to be drawn about species abundance and cover, as well as allowing enough time to study each habitat sub-division within each study site. The habitat sub-divisions used to evaluate plant species richness were;

- Existing downland turf (middle area)
- Existing downland turf (edge area)

- Re-created downland turf (middle area)
- Re-created downland turf (edge area)

Within each quadrat the presence/absence of all species (excepting mosses, lichens and fungi) and the % bare ground was recorded. In addition the % cover of certain key species was recorded, in order to be able to evaluate their abundance. These key species were; *L.corniculatus*, *Medicago lupulina* and *Trifolium dubium* which are all food plants of *P.icarus*, the butterfly used to evaluate habitat and food plant quality in this work. It was decided to record % cover rather than DOMIN values as statistical analysis would be easier to perform on the raw data rather than DOMIN scores which have already been converted from the raw data. Abundance and % bare ground were calculated by counting the number of whole $10cm^2$ squares occupied by a species/bare ground and summing them. If a section of a square contained a key species/bare ground then it was included only if more than half the square was occupied by a key species/bare ground.

The quadrats were placed randomly within each site by using a grid to overlay each habitat and generating random numbers to use as co-ordinates.

Plant species were identified using Fitter and Fitter (1995), Hayward (1995), Hubbard (1992) and Rose (1981) with nomenclature from Stace (1997).

The quadrat data set was analysed to examine sources of variation in the data and link these with environmental and habitat variables. This was carried out by performing different analyses:

- a detrended correspondence analysis (Hill 1979). This extracts the dominant pattern of variation in community composition from the data and displays it as axes of variation, which can be thought of as hypothetical environmental gradients. The eigenvalue of each axis corresponds to the separation of the data along that axis and the variance corresponds to the amount of variation in the data set explained by that axis (ter Braak 1986). This analysis was also used to evaluate the homogeneity of the downland used in the study. NVC community species constants (Rodwell 1998) were superimposed onto the plot, and the environmental variables were superimposed onto the quadrat scores plot in an attempt to explain the division of sites along the y-axis. The technique is explained further in section 4.1.

- a detrended canonical correspondence analysis (ter Braak 1988; ter Braak 1990). This is known as a 'direct gradient analysis' (Jongman et al. 1995) because it includes measured environmental variables. These are included in the analysis so that the amount of variation explained along each axis of the ordination is linked to a particular environmental variable. The variables must be measured within the vegetation recording unit and this meant that the only ones included in the DCCA were;

    - Downland/not downland habitat
    - Edge/not edge area
    - Bare ground/no bare ground

The other environmental variables which had been measured in the course of the study were analysed in the following way:

- Soil variables (pH, total nitrogen, nitrate, potassium, magnesium, sulphate and chloride and % organic matter), slope, aspect, turf height and bare ground (both from the 1998 drop disk and $50cm^2$ quadrat data) were correlated with species richness using the Spearman rank correlation coefficient calculation. This process ranks the data in each variable and then compares the ranks by calculating the 'sum of differences' between each variable using the following formula:

$$r_s = 1 - \left[\frac{6\sum d^2}{n^3 - n}\right]$$

where: r_s is the correlation coefficient

n is the number of units in each variable

d is the difference between the ranks of two variables.

- The total species richness and indicator species richness of each habitat was also compared and this analysis is explained in detail in section 4.1.

3.2.2 ESA Habitat Quality for Insects

i) Soil nutrient status of each site.

In the first year of the study (1996) soil samples were collected from each habitat type at each study site. The habitats were;

- Arable
- Existing downland
- Re-created downland

The soil was collected with a fork and trowel and multiple samples were taken from each field. These were located by using a standard soil sampling methodology described in Rowell (1994) and which is also used for the ESA statutory monitoring.

This involves laying an imaginary series of lines, in the shape of a W, over the whole area of each field. Samples are collected from each point of the 'W' (down to a depth of 15cm) and are then amalgamated into a representative sample from the field.

After being collected all the samples were placed in labelled clear plastic bags and refrigerated at 4°C. pH was measured as soon as possible, to prevent any alteration of this due to change in the soil condition. All the soils were subsequently analysed for potassium, magnesium, nitrate, phosphate, chloride and sulphate. Loss on ignition was also calculated to give a measure of the % soil organic matter content. Although there are limitations to this method; very chalky soils can give higher loss on ignition results than other soils due to partial combustion of the chalk component, it was thought that the process would yield useful information.

Soil nitrogen content was calculated from the nitrate component by multiplying the nitrate concentration (mg/kg) by the proportion of nitrogen in nitrate (22.58), calculated from relative atomic and molecular masses, and then dividing by 100. This gave a measure of mineral (available) nitrogen which would be less than the actual mineral nitrogen because it did not include data for nitrogen held as ammonium. However, it was assumed that this would not constitute a significant error because the mineral nitrogen component of downland soils is mostly made up of nitrate (Rowell 1994).

Methodologies are described below and all follow standard analysis techniques described in texts such as MAFF (1986) and Rowell (1994). Results were analysed to look for significant differences between the soils. This was carried out by using the non-parametric test (Kruskal-Wallis) which compares the median of each group of samples.

Analysis of pH

Around 50 grammes of each soil was placed in a foil dish and oven dried for 24 hours at 120°C, following which it was sieved through a 1mm sieve. Then, 30g of each soil was placed into a 250ml beaker and 75ml of distilled water was added using a 25ml measuring cylinder. Each mixture was stirred for 2 minutes and then left for 1 hour. A pH meter (Hanna HI.9025C) was calibrated using buffer solutions of pH 4 and pH 7, made up in 100ml volumetric flasks. The electrode of the pH meter was placed in each soil solution in turn, avoiding the settled soil at the bottom of the beaker, and the pH was read from the meter. In between measuring the pH of each solution the pH meter was rinsed with distilled water and also stored in distilled water if left for any length of time.

Analysis of nitrate, phosphate, chloride and sulphate

Concentrations of these soil nutrients were analysed by using an ion chromatograph machine (DIONEX auto-analyser) after some initial preparation. The air dried soils were put through a 2mm sieve, after which three 1g samples of each soil was weighed to an accuracy of 2 decimal places. The samples were placed in lidded bottles which had first been rinsed with distilled water, and 25ml of distilled water was added to each using a measuring cylinder. The bottles were placed in an orbital shaker for 10 minutes and the contents of each was filtered through filter paper (Whatman's No.42 grade), discarding the first few drops of filtrate. The filtrate was collected in the tubes used by the Dionex auto-sampler and these were then refrigerated until they could be put through the machine. The machine was calibrated using standards of the following composition, and every ten samples the calibration was checked again by re-running the standards. The standards were;

- 1 part per million (ppm) nitrate, phosphate, chloride and sulphate
- 10 ppm nitrate, phosphate, chloride and sulphate

- 30 ppm nitrate, phosphate, chloride and sulphate

Analysis of potassium and magnesium

The potassium and magnesium content of each soil was obtained by using flame spectrometry (using a UNICAM 939 machine). The air dried soils were put through a 2mm sieve, after which four 5g samples of each soil was weighed to an accuracy of 2 decimal places. The samples were placed in lidded bottles which had first been rinsed with ammonium nitrate, and 25ml of 1 molar ammonium nitrate was added to each using a 50ml pipette. The exact quantity of ammonium nitrate used was not important as long as it was present in excess in the solution. The bottles were placed in an orbital shaker for 30 minutes and the contents of each was filtered through filter paper (Whatman's No.42 grade) into a suitable bottle, discarding the first few drops of filtrate. These were then refrigerated until they could be put through the machine.

The analysis process for the two elements was slightly different, due to the way in which the spectrometry works. Magnesium is analysed using flame *absorption* spectrometry, measuring the concentration of the element by the amount of absorption occurring within the light spectrum (consisting of three lines of different resonance wavelengths) from a magnesium hollow cathode lamp when the sample is flame-atomised through it. This decrease in light intensity can be converted to an absorbance value, which is directly proportional to the magnesium concentration of the sample (although at high concentrations interference with other compounds may occur and a releasing agent may have to be used to prevent distortion of this relationship). All the samples put through this analysis had 5ml of strontium nitrate added to them to prevent inteference and the 'second line' of the magnesium spectrum (202.6nm) was used to calculate the magnesium concentration, as it is slightly less sensitive than the 'first line' which is mainly used for samples with a very low magnesium concentration.

Potassium can be more simply determined by using flame *emission* spectrometry. During this process the solution containing potassium is flame atomised and the intensity of light emitted at 766.4nm or 769.9nm (the wavelengths of the potassium spectrum) is proportional to the concentration of potassium in solution. The samples were analysed for potassium by using the second of these wavelengths, the 'second line', and this is because there was a relatively large amount of the element in the samples.

Standards are needed to calibrate the machines for both these processes and the ones used in the work for this thesis are presented below.

Magnesium standards	Potassium standards
20 ppm magnesium	30 ppm potassium
30 ppm magnesium	50 ppm potassium
50 ppm magnesium	100 ppm potassium

Analysis of % organic matter

After putting the oven dried soil samples from each site through a 2mm sieve, three 2g samples of each soil were placed in pre-weighed crucibles. These were placed in a furnace at 450°C overnight and weighed after cooling the next day. It was important not to leave the interval between ignition and re-weighing too long or water absorption by the samples would alter the results. The % organic matter was calculated by using the following formula of weights in grammes, all measured to two decimal places;

$$\text{\% organic matter} = \frac{(crucible + soil, unignited) - (crucible + soil, ignited)}{(crucible + soil, unignited) - crucible} x100$$

The results from the above procedures were analysed to look for trends in the nutrient status of the soils on different habitats at different sites after initially looking at similarity in the results between sites.

ii) The effect of soil type on three varieties of Lotus corniculatus.

Three varieties of *Lotus corniculatus* were grown on three different soils, to investigate their response to different nutritional conditions. The varieties were Leo and Oberhausteder (agricultural cultivars) and Fontmell (native, collected from Fontmell Down, Dorset). They were grown on arable soil, downland soil and peat based compost, after being germinated in seed compost and potted (see section iii for pot sizes) into the relevant soils after the first week. The field collected soils were taken from all study sites, in small samples which were then amalgamated to create representative downland and arable soils. These soils were sieved to achieve a uniform consistency before use. The seedlings in their soils were labelled and arranged in a random block design in a glasshouse and weeded and watered regularly.

After four months the area of each plant was recorded by using a transparent 1cm grid laid over the plant. Squares which were more than half filled by vegetation were included and those less than half filled were discounted, giving a plant area measured to the nearest square centimetre. The data was analysed by ANOVA to detect significant differences in the mean area of each variety.

iii) Polyommatus icarus larvae grown on different varieties of Lotus corniculatus.

In the first year of this study a trial was run to examine the differences in the weight and development time of *P.icarus* larvae fed non-native varieties or agricultural cultivars of *L.corniculatus*. The trial was conducted in a laboratory where temperature was kept as constant as possible (±2°C) throughout the development period of the larvae.

Three different varieties of *L.corniculatus* were grown by a commercial nursery. These were;

- Leo (a non-native agricultural cultivar)
- Maitland (a non-native agricultural cultivar)
- Lewisham (a native variety, collected from remnant chalk grassland near Lewisham, Greater London).

The seeds were sown on 15 February 1996, and pricked out into plug trays on 28 March, after which they were brought to the site of the experiment. During this growth period they were kept on a heated underblanket at 65-70°C, grown in a peat based compost and watered daily without the addition of any fertiliser. For the duration of the experiment the plants were potted into 7x7x8cm square (0.38L volume) pots and kept under plastic, in a 'poly-tunnel', on a bed of coarse gravel where they were less likely to be exposed to pest attack. They were watered twice a day with tap water.

The *P.icarus* larvae were ordered from a livestock specialist who captured a fertilised female of the species in Hampshire and reared the larvae through to the end of their first instar. Once the larvae arrived they were placed *in situ* in the laboratory. The experiment was designed as a randomised block. Silver foil trays, 20cm in diameter were placed within a grid on a laboratory bench and each was allocated a variety of *L.corniculatus* by generating pairs of random numbers which were used as co-ordinates. Each tray was labelled and then covered with a square of black entomological netting held in place with an elastic band, to avoid predation or parasitism. The experiment was run in a laboratory, rather than outside, for this same reason.

Larvae were placed in trays in order of variety, the first, fourth and seventh larvae were placed in trays of variety 1, the second, fifth and eighth larvae were placed in trays of variety 2 and the third, sixth and ninth larvae were placed in trays of variety 3, and so on. Trays which were not allocated larvae were used as controls. Each tray had an amount of plant material of the correct variety placed in it every two days. This amount was usually a 10-15cm length of *L.corniculatus*, harvested from the growing plants, and sufficient to feed the larvae for two days. Before the plant material was placed in the trays it was weighed to three decimal places on a balance, and all the larvae were weighed individually. At the same time, one sample of plant material from each variety, of known weight, was placed in an oven at 60°C for two days.

After two days had elapsed the old plant material and any feces were removed from each tray and re-weighed, as were the larvae. The plant material was removed from the oven and re-weighed, to give a wet/dry weight ratio and fresh, weighed plant material was put into the oven for the next two days. Then, fresh plant material of each variety was weighed, placed in the appropriate trays and the larvae returned to feed for two more days. Each foil tray was lined with paper to provide a more stable microclimate, and this was also replaced every two days. The room temperature was recorded on a max-min thermometer every four days, and controlled by thermostatic radiators in the laboratory.

Once the larvae had pupated the pupae were weighed and then left to emerge. The time this took was recorded. As imago's appeared they were placed into one of three flight cages, according to the variety of *L.corniculatus* that they had been reared on. They were supplied with nectar, both from flowers and from shallow dishes of sugar water. Potted plants of the variety of *L.corniculatus* which they had been bred on were placed in each of the cages. The imagos were left in the cages until all the females had mated and oviposited on the food plants.

Once these eggs had hatched the larvae were transferred to the foil trays and the experiment was run for a second time. This differed from the first run of the experiment only in that the larvae were not randomly allocated to varieties of *L.corniculatus* but were instead put in trays containing the variety of plant material which their parents had been bred on. As before, when these larvae had pupated, the pupae were kept until emergence and the pupation time and emergence success were recorded.

Data from the second run of the experiment was not used, due to the low number of larvae in each group which meant poor replication was achieved. There was also a high mortality, possibly due to the inbreeding which had occurred when the first generation were mated.

Data from this experiment was analysed in a number of ways.

- The amount of plant material ingested by each larva was calculated by using regressions (the procedure is detailed in section 5.2.2.2).

- Significant variation between samples was examined by one-way ANOVA or Kruskal-Wallis tests, depending whether the data was parametric (the variance of the different sample groups was homogeneous) or non-parametric (sample variances were non-homogeneous). The ANOVA test compares the mean of each sample group and Kruskal-Wallis tests compare the median of each sample group if the sample variance is too great to use the mean confidently.

- Where sample means were significantly different a Tukey test was performed to examine the data further and determine where the difference lay. This test uses a computed test statistic which is compared to the sample means to distinguish those which are significantly different.

- If sample sizes were not identical (eg 5,5,7) (preventing the use of the Tukey test) then 95% confidence limits were calculated and applied to the data on a bar chart.

The significant difference lies between those samples whose confidence limits do not overlap.

- To test for independence within a data set, Chi-squared tests were used. These compare observed data with calculated expected data and test for significant discrepancy between the two.

- Linear regression was used to identify the relationship between sets of data.

- To test for homogeneity of variance the Fmax test was used. This produces a ratio from the largest and smallest sample variances which is then compared to a tabulated value determined from the number of samples and the degrees of freedom.

A nutritional index was calculated (modified from Rausher (1981) and Stoyenoff (1994)), to further examine the nutritional quality of the three different *L.corniculatus* varieties;

Relative Consumption Rate (wet food basis):

$$\text{RCR} = \frac{\text{wet weight of food eaten}}{\text{(insect wet weight at beginning of trial)(time)}}$$

The index was calculated from the first two day feeding period only, because after this the data was not always comparable. Two other indices, Efficiency of Conversion of Digested Food and Approximate Digestibility are commonly used to gain information in experiments of this kind, but could not be used here as they require dry weights and would be invalid if based on wet weights.

All statistical procedures are described in Fowler (1994).

3.2.3 Use of ESA habitats by invertebrates

3.2.3.1 Presence of indicator species

i) Homoptera

As a quick method of evaluating the presence of a group of invertebrates other than the Lepidoptera, a joint project with the Game Conservancy Trust was planned. This involved sampling the Homopteran (leafhopper) fauna on re-created and established downland at each of the farms used in this study.

Samples were collected by using a motorised suction trap/D-Vac (Fig 3.1) (Dietrick 1961). The efficiency of the D-Vac as a sampling tool is discussed in Morris (1990). The methodology used in this work was guided by work carried out on the Park Grass area at Rothamstead (Morris 1992) and closely followed other GCT experiments using the D-Vac to collect invertebrates (A.Wakeham-Dawson, *pers. comm.*). Five samples were collected at each habitat in August, 1996. Each sample consisted of a cluster of five, 3 second sucks from the D-Vac which were then amalgamated into one labelled, clear plastic bag. This gave 5 composite samples per habitat and 10 samples per site.

Once collected the samples were frozen immediately (within 3 hours of collection) to prevent predation of sample material within each bag. The samples were defrosted and dried during the winter, when the Homopteran component was sorted into sample tubes, using one labelled tube per sample. The Homoptera were dry stored, as opposed to being preserved in ethanol because this method preserves the colour of individuals which can aid the identification of some species of leafhopper. Samples were identified down to species where possible, or genus if no male specimens were present (the diagnostic characteristic of many species is the male adeagus), using the

Fig 3.1: The D-Vac apparatus used for leafhopper collection.

standard Hemiptera keys (LeQuesne 1960; LeQuesne 1965; LeQuesne 1969; LeQuesne and Payne 1981) and a reference collection of Hemiptera held at the Institute of Terrestrial Ecology in Dorset. The resulting species counts and lists were analysed for significant differences in species richness between the two habitats at all sites. In addition, some species are known to be indicators of chalk downland or early successional stages in habitat development, and these were noted in all the samples.

ii) Lepidoptera

Butterfly transects were carried out at all sites for the first year (1996) of this study (one per site), following methodology described in Pollard (1977). This was adapted in the following ways to allow comparison between different habitats at each site and also to allow comparison of different areas of habitat (edge and middle areas) at each site.

Each transect covered four habitat areas;

- Existing downland turf (middle area)
- Re-created downland turf (middle area)
- Re-created downland turf (edge area) adjoining existing downland turf
- Arable field (edge area) adjoining existing downland turf.

Each transect was walked once every two weeks (between April and September), and all seven were walked in the same order to ensure that they were evenly distributed within the two week period. However, the guidelines for walking transects identify certain weather conditions when a transect cannot be walked (Hall 1981), and this meant that it was not always possible to walk every transect at exactly a two week interval.

Within each of the above habitat sections, a 100m section was marked, within which any butterflies seen were counted separately from those on the rest of the section. This standard length of transect was designed to allow direct comparison of butterfly abundance and species richness between sites. At all times, butterflies were only recorded if they flew through an imaginary box of $5m^2$, held in front of the transect walker, although notes were kept of any butterflies seen on site away from the transect route. In addition to the above information shade temperature (using a digital thermometer), wind speed (in metres/second using an anomometer) and weather conditions (S=sun, C=cloud) were recorded on each transect.

Results were analysed by using one-way Analysis of Variance (ANOVA) to look for variation in species richness and number of individuals found between habitats at all sites. The butterfly species richness was divided into total species and selective/non-mobile species in order to examine whether there was a difference between the species distribution of more selective species when compared to all species. The selective species chosen were those which live in closed populations (Thomas 1989).

<u>*3.2.3.2 Habitat use by indicator species*</u>

i) Emergence traps

Having established which butterfly species were present by carrying out butterfly transects, emergence traps were used at one site to investigate whether these species actually bred on the site and whether use of the established and re-created downland habitats differed. Emergence traps were set at Langford Farm during the summer of the second year of research. The traps were designed especially for the experiment (Fig 3.2) and used less entomological netting than a $1m^3$ emergence trap but covered four times the area (ie $4m^3$). Ten traps were erected on 25th April; five on the re-created downland (middle area) and five on the re-created downland (edge area). They were randomly allocated by using the same grid system described in section

3.2.1, and pairs of random numbers were generated as co-ordinates for each emergence trap.

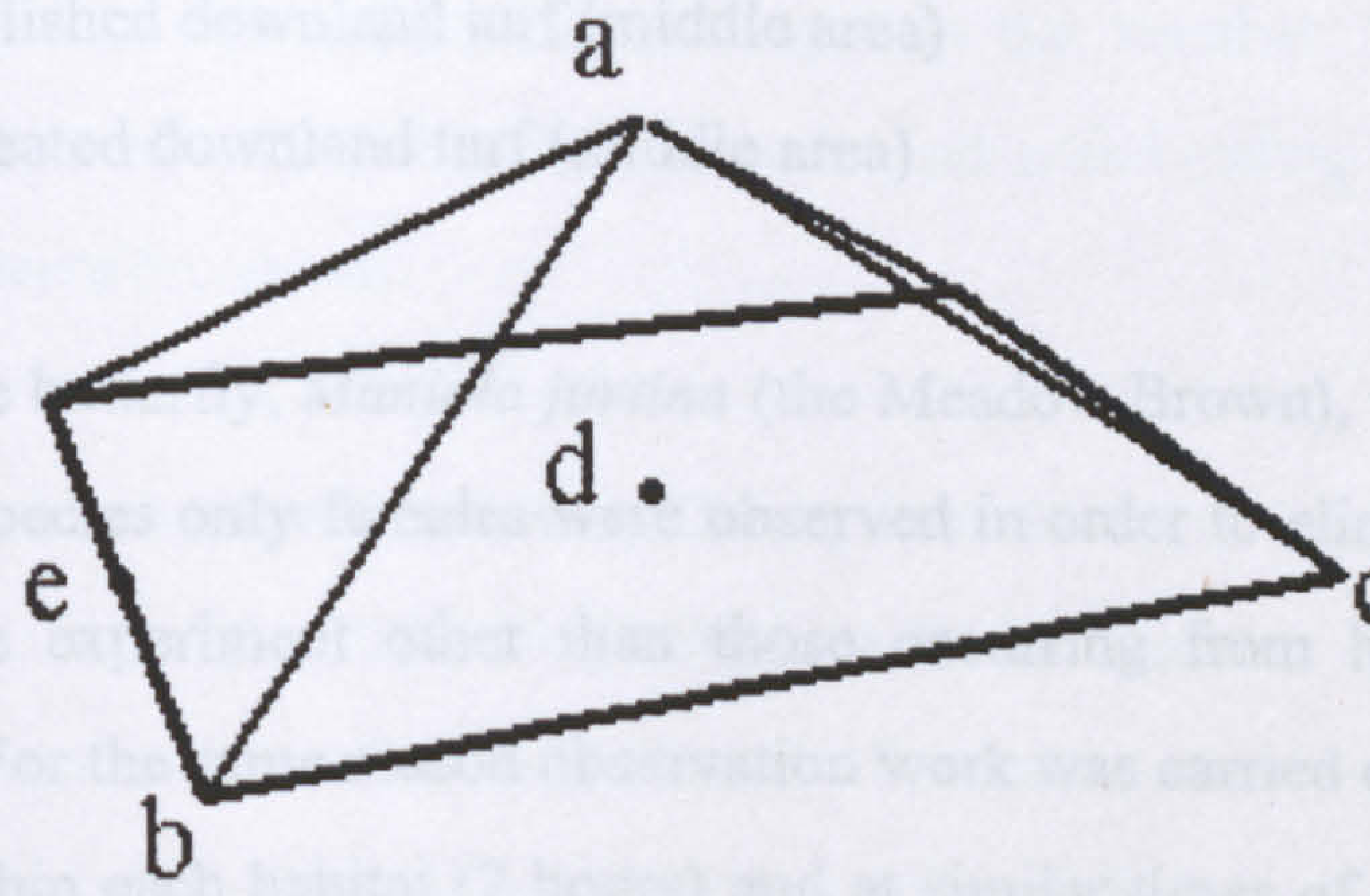
Once in place the traps were checked every two days and thorough searches were made through the netting for any emerged Lepidoptera, and of the vegetation inside. Any emergences were recorded and the adults released, and the trap was left for another two days. Lack of grazing pressure inside the emergence traps caused a rapid growth of vegetation and this, coupled with the fact that once in place the traps prevented oviposition in this area, meant that they were moved approximately every four weeks to a new location. The new position of each trap was recorded to ensure that the exact position of every emergence was known.

No emergences were recorded on the re-created downland middle area so these traps were moved to the established downland and both sets of traps were repositioned approximately a month after first being erected. In June an additional 5 traps were erected on each habitat to increase the sample size and all traps were repositioned again in July, with a final search being carried out on 17th September.

Results were analysed by calculating the number of butterflies and species emerging per $40m^2$, per hectare and per actual area of each habitat. This data was then compared to the number of butterflies recorded via transect methodology at this site.

ii) Observation work

Observation work was carried out at all sites to determine whether there were differences in how re-created and established downland was used by butterflies. This technique has been used before (Dover 1989) to record butterfly behaviour but was developed here to examine differences in behaviour on different habitats. The habitats used for this work were:



Dimensions: a-d = 0.5m
b-c = 2m
a-e = 1.12m
e-b/d = 1m

A zip is inserted along a-e on one side of the pyramid.

Fig 3.2: Emergence trap design and the traps in situ at Langford Farm.

- established downland turf (middle area)
- re-created downland turf (middle area)

Only one butterfly, *Maniola jurtina* (the Meadow Brown), was used for this work and of this species only females were observed in order to eliminate sources of variation from the experiment other than those occurring from habitat variation (Wiklund 1978). For the same reason observation work was carried out for a standard length of time within each habitat (2 hours) and at similar times of day, although this was not always possible due to variation in the weather. The period during which observation work was carried out was well within the *M.jurtina* flight period (Emmet and Heath 1990).

Butterflies were located by starting to walk in a random direction from a chosen point in the field. Both direction and start point were chosen randomly using the method detailed in section 3.2.1. The first female *M.jurtina* to be seen was followed until it was either lost from sight, had passed out of the habitat, was within 10m of the habitat edge or was eaten/caught/trapped by a predator. The behaviour of each individual was divided into categories and the time spent on each behaviour was recorded (in seconds) with a stopwatch.

The behavioural categories were:

- flying
- resting
- basking
- feeding (nectar source was noted)
- ovipositing
- mating
- encountering others (species and sex (if possible) was noted)

In addition to this information changes in the weather (those lasting more than a minute) as well as the temperature and wind speed (using the scale described in Hall (1981)) were recorded.

Results were analysed by using Chi-squared tests comparing the minutes spent on a particular activity within each habitat with the minutes spent on all other activities within each habitat. Seconds, instead of minutes, were used for the Chi-squared test analysing the time spent encountering others. This is because the amount of time spent on this activity was less than five minutes and the test cannot be used on frequencies of less than five.

iii) Egg searches

Searches for the eggs of *P.icarus* were carried out at Coombe Bisset Down as a third method of evaluating the differences in use of two different habitats, re-created downland turf (edge and middle areas) and established downland turf (edge and middle areas). Egg searches were made within twenty random quadrats placed in each area. Whether these were found or not, the height of any *L.corniculatus* plants were recorded as was the total % cover of these plants and the % bare ground in each quadrat. If nectar sources were present these were counted and recorded species by species. At each egg position the following were recorded; number of eggs per leaf; height of each from the ground; and distance of each from the edge of the patch of foodplant.

The analysis of this data is described in Chapter 6.

iv) How butterfly distribution relates to environmental factors.

Data sets collected from the experiments described above were also used in several Spearman rank correlations to investigate the relatedness of environmental factors and butterfly species richness/distribution within the downland and re-created downland habitats. It was hoped that these would determine which environmental characteristics determine butterfly distribution on the different habitats and that information about the quality of re-created downland as a habitat for invertebrates would be gained. These correlations are described in greater detail in Chapter 6 and it should be noted that the habitats used were restricted to downland and re-created downland middle because these were the only habitats included in all data sets.

Subsequent chapters present the results of the experiments described here. Chapter 4 presents results from the first set of experiments described in this chapter, and investigates the botanical species richness of re-created downland when compared to existing downland.

Chapter 4 - The botanical species richness of re-created and established downland.

4.1 Introduction

This chapter presents the results of work comparing the species richness of established and re-created downland within the South Wessex Downs Environmentally Sensitive Area. In addition the vegetation data is linked (by Spearman Rank Correlation) with other site parameters such as soil nutrient status, turf height and bare ground to evaluate the effect of each on plant community composition (measured as species richness) and habitat type. The variation in habitat botanical composition due to field edge effect is also examined.

The results are presented in two sections. The first section examines differences between habitats, and includes a detrended correspondence analysis (DCA) which extracts the dominant pattern of variation in community composition from the data set and species richness/indicator species work which examines variation in the vegetation quality of the different habitats. The second section attempts to determine which environmental factors affect vegetation composition, and includes a detrended canonical correspondence analysis (DCCA), as well as the results of a series of correlations of environmental factors with the quadrat data. The DCA species and quadrat scores plots are used to evaluate the variation in vegetation composition within the downland quadrats.

The final section of this chapter discusses the results of the analyses described above and looks at the limitations and possibilities for further study in the work.

Before presenting these results, some of the terms used in this chapter must be explained. The phrase **indicator species** is used, when referring to those plants which are indicative of either species rich chalk downland or of a diverse plant community. There are several available lists of calcicolous indicator species (for example Rodwell (1998)) and the plant species used as indicators in this work belong to a list devised for the Dorset Chalk Grassland Inventory (Edwards 1998). This list was used because it represents plants which are indicative of the chalk downland distinctive to the Dorset area (and the South-Wiltshire area used in this study (B.Edwards, *pers.comm.*)) as well as including plants of local importance and national scarcity, and plants indicative of a diverse community. Given the low species richness of the downland re-creation fields it was thought best to use a list of indicator species with slightly broader specifications than just the strict calcicoles. Table 4.1 lists the plant species used as indicators and shows which classification category they have been given.

Table 4.1: The species used as 'calcicolous' indicators in the analysis of vegetation work (taken from Edwards (1998)). Key: a=nationally rare (Red Data Book species), b=nationally scarce, c=Dorset/Wiltshire rare, d=strict calcicoles (restricted to chalk and limestone), e=diverse community indicators.

Species	**Classification**	**Species**	**Classification**
Anacamptis pyramidalis	d	*Anthyllis vulneraria*	d
Arabis hirsuta	d	*Asperula cynanchica*	d
Blackstonia perfoliata	e	*Briza media*	e
Calamintha ascendens	d	*Campanula glomerata*	d
Campanula rotundifolia	e	*Carex humilis*	b
Carlina vulgaris	d	*Centaurium pulchellum*	e
Cerastium arvense	d	*Cirsium acaule*	d
Cirsium eriophorum	d	*Cirsium tuberosum*	a
Clinopodium acinos	d	*Coeloglossum viride*	d
Cynoglossum officinale	d	*Danthonia decumbens*	e
Filipendula vulgaris	d	*Galium verum*	e
Gentianella amarella	d	*Genianella anglica*	b
Gymnadenia conopsea	d	*Helianthemum nummularium*	d
Herminium monorchis	c	*Hippocrepis commosa*	d
Hypericum montanum	d	*Iberis amara*	d
Inula conyza	d	*Juniperis communis*	c
Koeleria macrantha	d	*Leontodon hispidus*	e
Marrubium vulgare	b	*Onobrychis viciifolia*	d
Ophrys apifera	e	*Orchis ustulata*	c
Orobanche elatior	d	*Phyteuma tenerum*	b
Picris hieracioides	d	*Pilosella officinarum*	e
Pilosella peleteriana	a	*Pimpinella saxifraga*	e
Plantago media	d	*Polygala calcarea*	d
Primula veris	e	*Rosa agrestis*	a
Salvia verbenaca	d	*Sanguisorba minor*	d
Saxifraga granulata	e	*Scabiosa columbaria*	d
Serratula tinctoria	e	*Silene nutans*	b
Spiranthes spiralis	d	*Stachys officinalis*	e
Succisa pratensis	e	*Tephroseris integrifolia*	b
Thesium humifusum	b	*Thymus polytrichus*	e
Thymus pulegioides	d	*Viola hirta*	d

Quadrat data were analysed for total species richness (by counting the total species present in each quadrat) and also for the number of indicator species present, to give a better idea of habitat quality. The indicator species were taken from the list in Table 4.1 and, on the re-created downland were divided into three categories:

- total indicator species (all indicator species found in each quadrat)
- sown indicator species (those indicator species known to have been introduced via the seed mix - all of these are assumed to be non-native)
- native indicator species (those indicator species which have occurred naturally within the habitat area).

These three categories gave a more detailed picture of how species richness on the re-created downland was related to that of the established downland and in section 4.3 the results are linked with other studies which examine edge affect in arable areas and the affect of agrochemical drift on different sward types.

This chapter also presents the results of two types of ordination; detrended correspondence analysis (DCA) and detrended canonical correspondance analysis (DCCA) which were performed on the quadrat data. DCA (Hill 1979) is performed on a matrix of quadrat/species data and extracts (via ordination) the dominant patterns of variation along a series of axes. Eigenvalues (from 0-1) are calculated for each axis and are taken as a measure of how much of the variation in the data (related to differing species composition) is explained by each axis (Jongman et al. 1995). An axis can be thought of as an hypothetical environmental gradient, such as temperature (Vasseur and Potvin 1998) or soil nitrogen (Mitchell et al. 1997), and the nature of the gradient is not always obvious from the ordination results (ter Braak 1986; Kent and Coker 1992).

DCCA (ter Braak 1986; ter Braak 1988a) combines ordination with regression to test whether species data is related to measured environmental variables. It is performed by analysing the variance between all possible combinations of the data set and ninety-nine Monte Carlo permutations (ter Braak 1990) were used in this analysis. It follows from this that if an environmental variable relates strongly to an ordination axis (given by a correlation coefficient) then a large part of the variation in the species data is 'accounted for' by that environmental variable (ter Braak 1988b).

The DCCA environmental variables in the analysis presented below were limited to the data collected from each quadrat. This led to three variables being defined:

- downland/not downland
- edge/not edge
- bare ground/not bare ground,

and the amount of variation within the species data accounted for by each is described.

4.2 Results

The quadrat data used in this chapter can be found in Appendix 5 (on floppy disk), and a summary is presented in Table 4.2.

4.2.1. The difference between established and re-created chalk downland.

i) The DCA quadrat scores plot

The DCA quadrat scores plot can be used to evaluate the homogeneity of the habitats used in this study and these results are presented below. The eigenvalues generated for each axis (Table 4.8) are the same as those for the species scores plot although the environmental gradients represented are not necessarily the same. It should be noted that second and third axes are used because the first axis was entirely accounted for by the presence/absence of *Urtica dioica* (see section 4.2.2.1 for explanation).

The quadrat scores plot (Fig 4.1) shows that established downland quadrats are grouped towards the origin of the x-axis while re-created downland quadrats are grouped towards the positive end. This difference was explored by calculating the mean quadrat score for each habitat and then identifying significant differences in the data by using a Kruskal-Wallis test (variances of the site scores for individual habitats were not found to be homogeneous). The quadrat score represents the optimum placing of that habitat along the axis in question, calculated by reducing all the habitat eigenvectors to a single eigenvalue. For example, if the environmental gradient represented by the second axis was aspect then the eigenvalue for each habitat would indicate the optimum aspect at which that habitat occurs. Results are presented in Table 4.3.

	Downland habitat type:			
Site:	**Established middle**	**Established edge**	**Re-created middle**	**Re-created edge**
Langford Farm	19.65±0.58	16.65±1.04	16.60±0.59	19.00±0.70
Huish Farm	33.50±0.85	26.45±1.02	11.35±0.73	14.85±0.78
Court Farm	22.45±0.79	17.35±0.44	18.05±0.43	16.85±0.49
Throope Manor Farm	31.15±0.82	23.75±1.40	14.70±0.68	17.45±0.61
Coombe Bisset Down	34.35±0.59	32.00±0.74	16.70±0.64	19.95±0.81
Peckons Hill Farm	30.25±1.17	30.00±0.99	15.15±0.52	16.50±0.38

Table 4.2: A summary of the quadrat data presenting mean number of species found per habitat at each site (with standard errors).

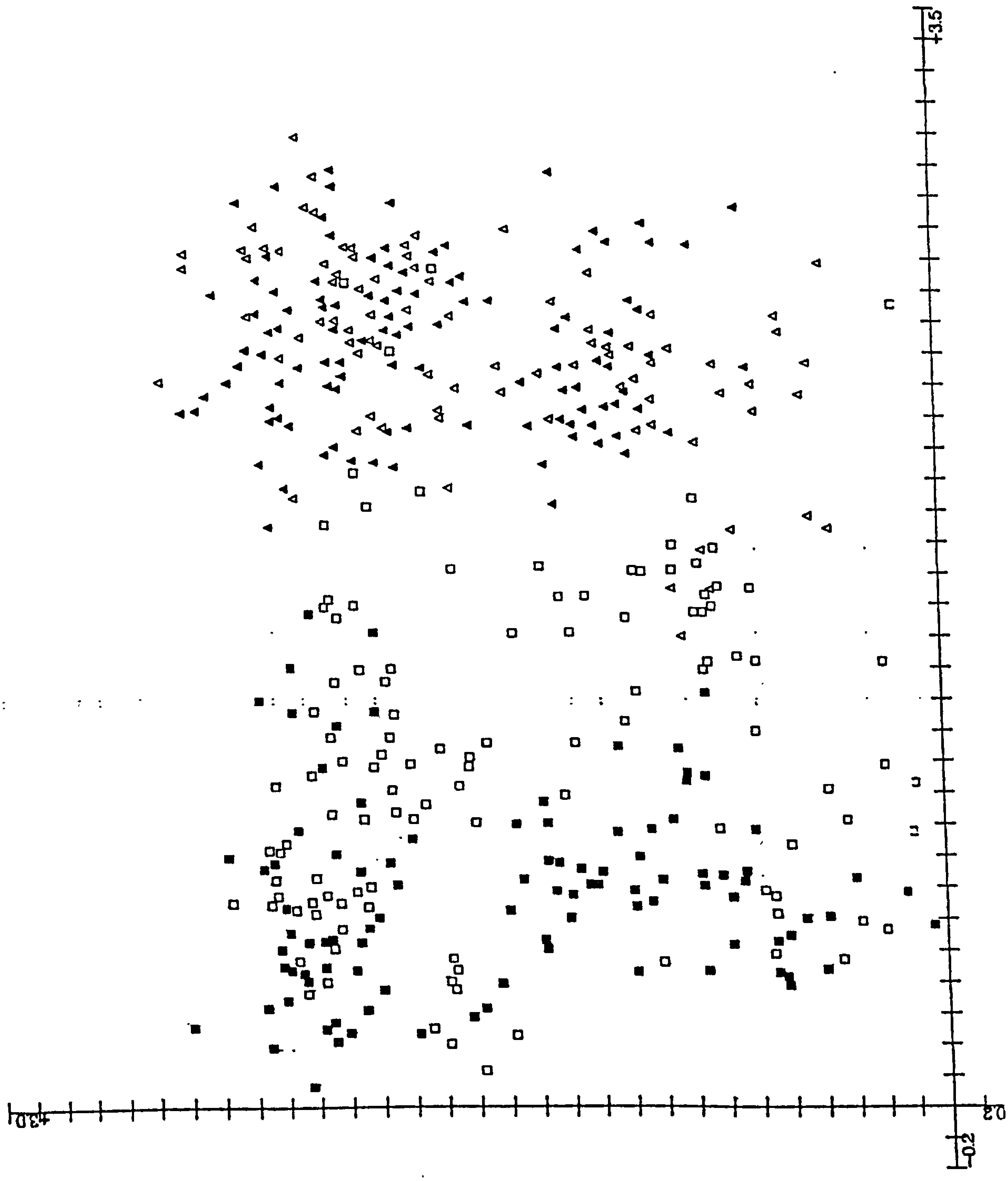


Fig 4.1: The DCA quadrat scores plot showing how established and re-created downland sites are separated along the axes. (Squares represent established downland quadrats and triangles represent re-created downland quadrats; empty = edge area, filled = middle area).

Table 4.3: Mean DCA x-axis (second axis) quadrat scores for each habitat type, with results of the Kruskal-Wallis test identifying whether they are significantly different.

Habitat	**Downland middle**	**Downland edge**	**Re-creation middle**	**Recreation edge**
Mean quadrat score (from all sites)	0.61	1.09	2.40	2.45
Standard deviation	0.30	0.54	0.34	0.38
Mean rank (Kruskall-Wallis test)	87.34	160.02	350.28	364.35
Test statistics:	Chi-square= 357.536	df = 3	p<0.001	n=120 within each habitat.

The table shows that there is a significant difference (at 99.9% confidence limits) in the mean quadrat scores of downland middle and re-creation edge (at opposite ends of the axis), and that this is probably also true for the downland and re-creation habitats which are closest on the axis (downland edge and re-creation middle) and for downland middle and edge habitats. It is not possible to state this with certainty because the Kruskal-Wallis test is not powerful enough to distinguish between any variables except those with the highest and lowest mean rank.

To clarify the results, the mean quadrat score from all sites can be shown graphically, with 95% confidence limits (Fig 4.2). Habitats where the confidence limits do not overlap are significantly different (at $p<0.05$) and it can be seen that downland edge and middle habitats are different, as are downland edge and re-created downland middle and edge. It can also be seen that the edge and middle of the re-created downland are not significantly different.

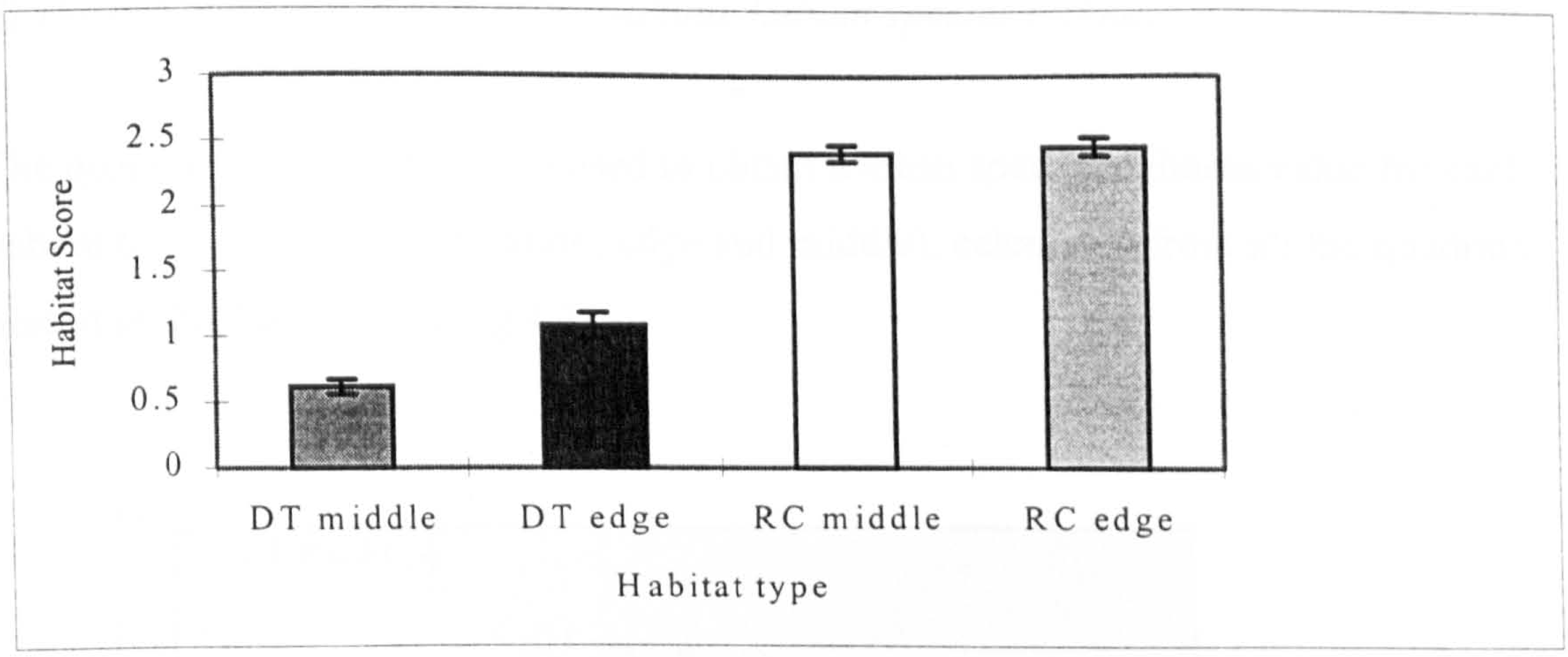


Fig 4.2: The mean ordination quadrat score within each habitat, including 95% confidence limits (DT = established downland, RC = re-created downland).

Although no environmental factors are included in the analysis it seems that the second axis of the ordination (the x-axis) is explained by a combination of habitat species richness and the type of species present. The ordination analysis weights individual quadrats by their species richness, as well as by where those species lie in the species scores plot. This means that quadrats containing species towards the positive end of the species scores plot x-axis will tend to lie at the same end of the x-axis on the quadrat scores plot. They will also tend to be towards one end of the axis or the other on the quadrat scores plot depending upon whether they contain many or few species (Jongman et al. 1995).

There is not as much separation along the x-axis within the quadrats from the re-created downland edge and middle habitats. This is perhaps because the difference in species richness between these two habitats is not as great as the species richness between downland edge and middle, as is shown in the next section.

ii) The use of indicator species to evaluate habitat species richness

The quadrat data collected were used to obtain a mean species richness value for each habitat (downland and re-creation, edge and middle), calculated from all the quadrats placed in that habitat (see Fig 4.3).

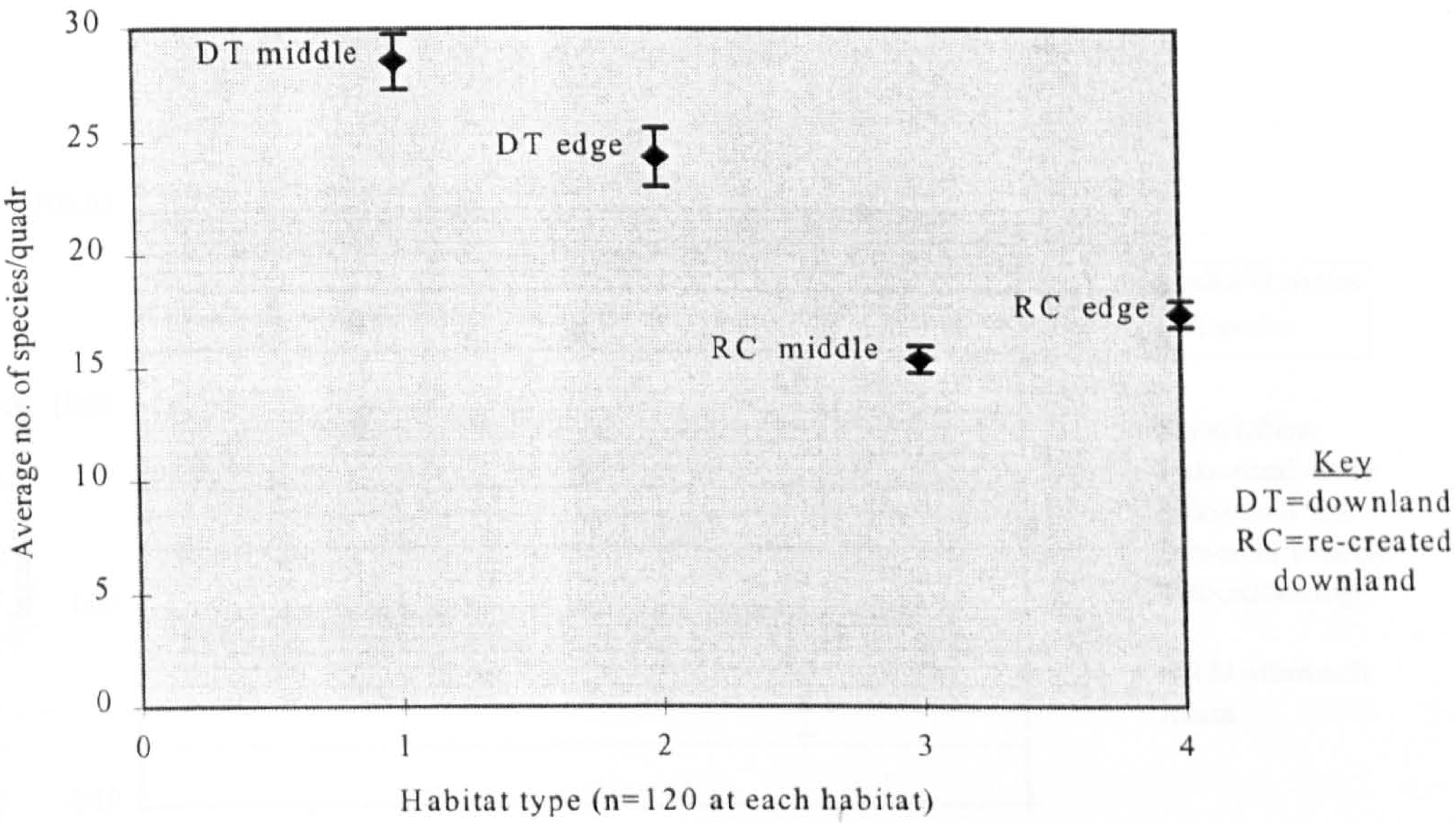


Fig 4.3: Average species richness within each habitat type, with 95% confidence limits.

Fig 4.3 shows that downland habitat has a higher species richness than re-created downland habitat (both middle and edge), and that fewer species are found at the edge of the downland than in the middle. This situation is reversed on the re-created downland habitat where more species were found growing at the edge.

A Kruskal-Wallis test showed that there was a significant difference in the median species richness of the habitats (χ^2_3 = 234.99, p<0.001). Calculated 95% confidence limits suggest that habitat species richness is significantly different between all habitats, and the most significant difference is between established downland middle and re-created downland middle habitat.

Species richness is not necessarily the best indicator of habitat quality given that it does not differentiate between ruderal and calcicolous species. Therefore, a new data set was constructed, consisting only of the calcicolous indicator species found in each quadrat (the criteria used to determine these is explained in section 4.1). This sub-set of the original quadrat data showed the same trends as the species richness data but (see Fig 4.4) there was a larger separation in species richness between the downland and re-created downland.

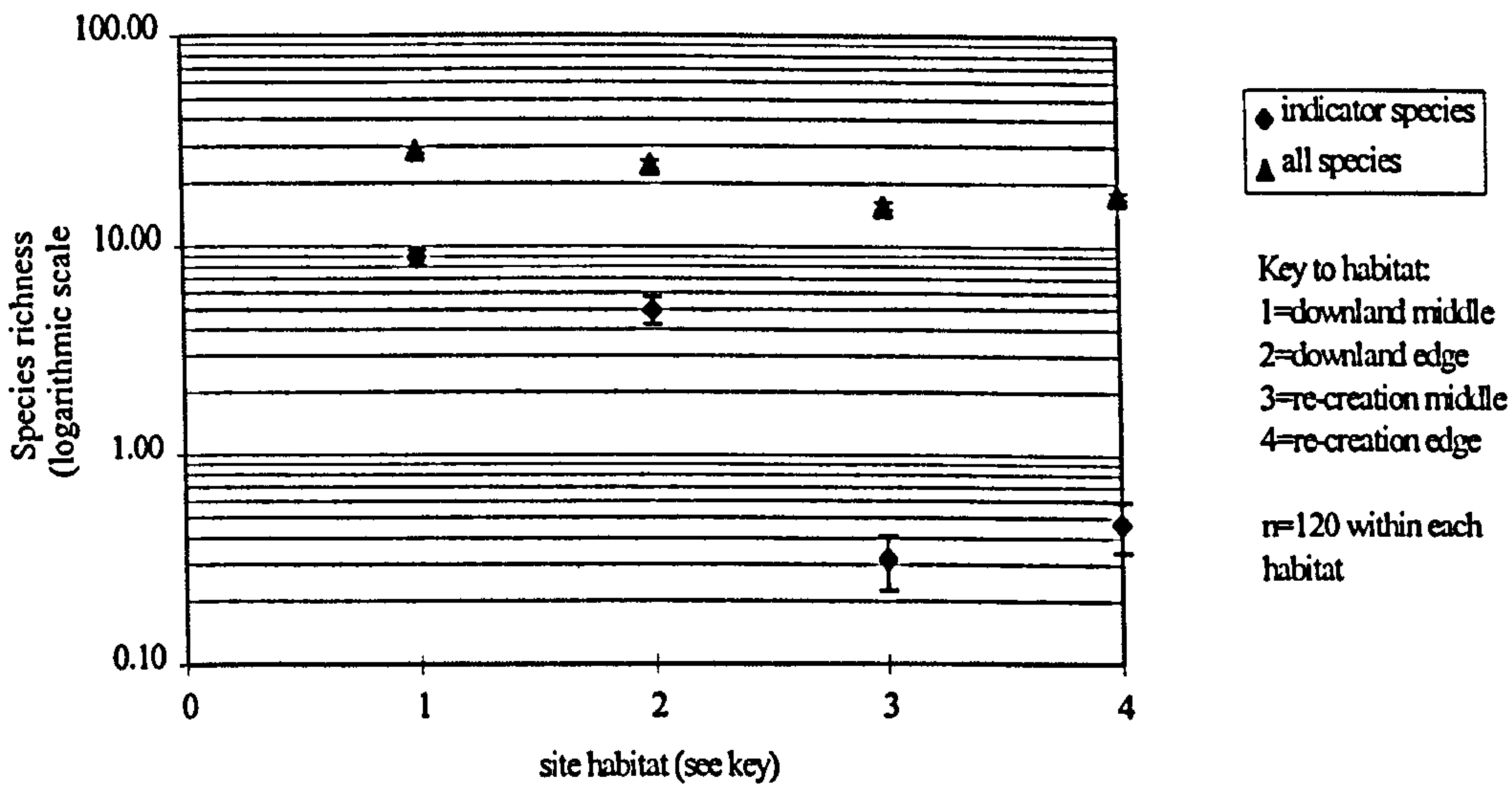


Fig 4.4: A comparison of total species richness and number of indicator species within each habitat.

When the number of indicator species is expressed as a proportion of the total species within each habitat (Table 4.4) it can be seen that the edge of the downland is less species rich than the middle of the downland and that it also contains proportionately fewer indicator species. This illustrates the erosion in quality of chalk downland edge habitat. Reasons for the trend shown here are discussed in section 4.3.

Table 4.4: The proportion of species richness accounted for by indicator species in each habitat. Data represents mean number of species per quadrat.

	Downland middle	**Downland edge**	**Re-creation middle**	**Re-creation edge**
Total indicator species	8.88	4.94	0.32	0.47
Total species richness	28.56	24.37	15.43	17.43
Proportion of indicator species	31%	20.30%	2.07%	2.70%

There is no significant difference in the number of indicator species found on the re-created downland edge and middle areas, and this is perhaps a reflection of the artificial nature of this sown sward. The downland re-creation indicator species richness is a combination of sown and naturally colonised species, with the predominant influence from the sown species. As the composition of the seed mix was known at each downland re-creation site the naturally colonised indicator species can be separated from the sown indicator species. For simplicity these sown species are still classed as indicators although it must be accepted that they are not functioning as such.

Fig 4.5 shows the quadrat data, separating sown and naturally colonised (native) 'indicator' species on the re-created chalk downland. The difference in sown and native indicator species present on the re-creation middle habitat is significant at 95% confidence limits ($\chi^2_1 = 3.88$ based on the data in Table 4.5). This shows that there are fewer naturally colonised indicator species than sown indicators on this habitat.

On the re-created downland edge habitat there is no signicant difference between the number of sown and native indicator species (using the same test results above), although it can be seen that the number of native species is actually slightly higher than the number of sown 'indicator' species, suggesting species spread is occurring from adjacent downland. This is also shown by comparing the native indicator species on re-created downland edge and middle; it appears from the 95% confidence limits that this difference is significant and species spread from existing downland to re-created downland is occurring at the edge of the re-created downland. The fact that this is shown from the indicator species data, implies that species with specific habitat requirements (such as *Cirsium acaule* and *Hippocrepis commosa*) are colonising re-created downland, as well as those species with more general habitat requirements.

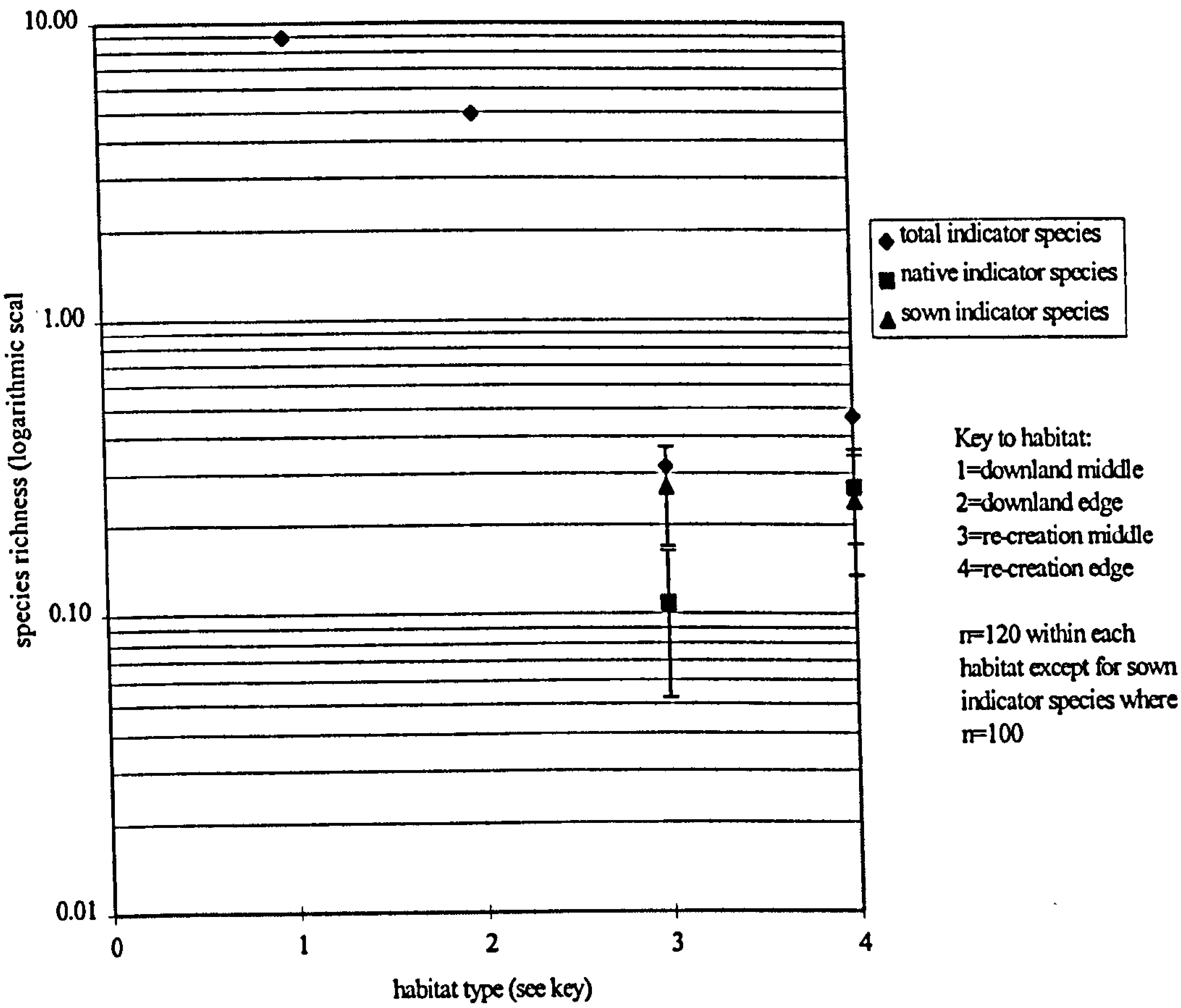


Fig 4.5: The division of total indicator species richness between naturally occurring and sown indicator species on re-created downland habitat.

The number of sown and naturally occurring indicator species found within each re-created downland habitat can be expressed as proportions (Table 4.5). It should be noted that total indicator species richness was calculated from a sample size of 120 and the sown indicator species richness was calculated from a sample size of 100.

Table 4.5: The sown and naturally occurring indicator species richness within re-created downland edge and middle habitat expressed as a proportion of the total indicator species richness.

Habitat	**Origin of seed**	**Indicator species richness**	**Total 'indicator' species richness**	**Expressed as a proportion of total 'indicator' species richness.**
Re-created downland middle	sown	0.27	0.32	0.84
Re-created downland middle	naturally occurring	0.11	0.32	0.34
Re-created downland edge	sown	0.24	0.47	0.51
Re-created downland edge	naturally occurring	0.27	0.47	0.58

This table expresses the conclusions drawn from the graph – and shows that in the middle of the re-created downland a large proportion of the indicator species richness is made up from sown species such as *Koeleria macrantha* and *Medicago lupulina*, whereas at the edge of the re-created downland the number of sown and naturally occurring indicator species is about the same. This demonstrates that there are more naturally occurring indicator species here than in the middle of the re-created downland. It is interesting to note that the number of sown indicator species in each re-created downland habitat is very similar (an average of 0.24 and 0.27 per quadrat).

The results of this work on sown and naturally occurring indicator species richness should be considered when interpreting the ordination data presented earlier in this section. An ordination plot of *Lotus corniculatus* presence/absence within the quadrats (Fig 4.6) appears to show that the species occurs in many of the re-created downland habitats, perhaps leading to the assumption that some native downland species can be found on the re-created downland at high abundances. However, this

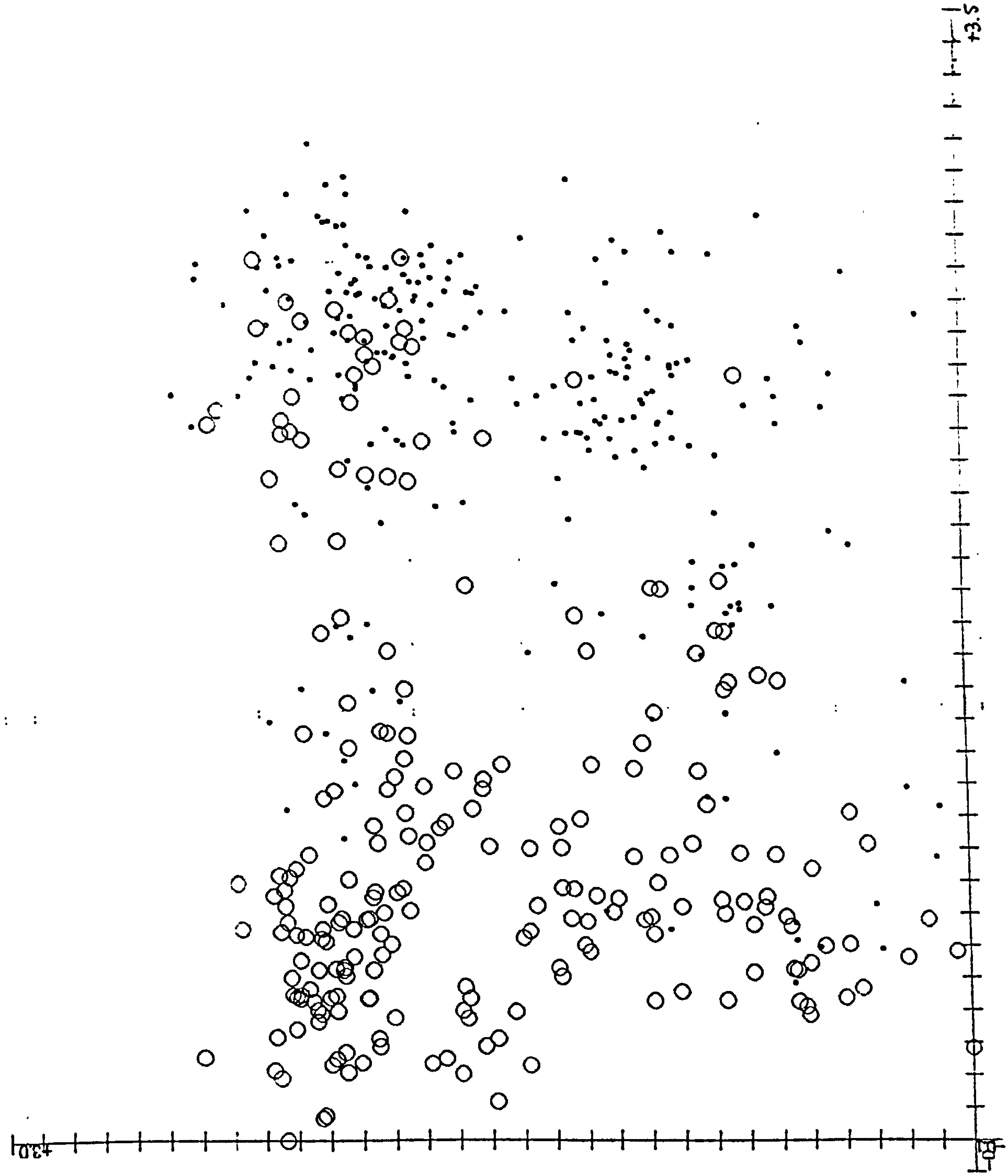


Fig 4.6: An ordination plot of *L.corniculatus* presence/absence, drawn from the quadrat data. (Large circles = presence, small circles = absence).

species was included in most of the re-created downland seed mixes and it is therefore probable that the *L.corniculatus* occurring on the re-created downland is almost all non-native, rather than naturally colonised. The interpretation of the ordination plot with respect to the occurrence of native *L.corniculatus* is quite different to how the ordination plot appears from the quadrat data.

Similarly, the placing of some of the chalk downland species (those included in downland re-creation seed mixes) on the species scores plot will not be representative of their true placing within a downland community, because they will be 'pulled' away from that position by their sown abundance in the re-seeded communities.

4.2.2 Variation in the vegetation composition of established and re-created chalk downland

4.2.2.1 - The effect of environmental variables on vegetation composition.

The causes of variation in species composition within and between habitat were investigated by using the DCA species scores plot and Spearman rank correlations. Before this, the results of the DCC analysis are presented, showing which main factors underly the variance in the quadrat data.

i) Detrended canonical correspondence analysis (DCCA) of three environmental variables.

A detrended canonical correspondence analysis was performed on the quadrat data and included three environmental variables which were applied to each quadrat;

- downland/not downland
- edge area/not edge area
- bare ground/not bare ground

As expected the analysis found that most of the variation in the data set was accounted for by whether a quadrat was placed within downland habitat or not, or within an edge area or not. These findings were significant at the highest possible level ($p<0.01$ due to only 99 permutations being performed) and reflect the significant differences in mean quadrat score presented in section 4.2.1. The presence of bare ground was not found to account for a significant amount of the variation in the data set (see Table 4.6).

Table 4.6: The results of DCC analysis combining species data with three environmental variables (Variable 1 = downland/not downland, Variable 2 = edge/not edge, Variable 3 = bare ground/not bare ground)

	Variance	**F-ratio**	**Significance**
Variance explained by all variables	0.43		
Variance explained by variable 1	0.38	30.58	$p<0.01$
Variance explained by variable 2	0.04	3.32	$p<0.01$
Variance explained by variable 3	0.01	1.05	$p<0.27$

The total variance explained by all the variables was 0.43 (theoretical total explained variance = 1). This implies that much of the variance in the data set is not accounted for by the environmental variables included in the DCCA and leads to the next results section where other influences on the variation in the vegetation data are examined. The species scores plot is examined and several environmental variables are correlated with species richness and habitat to determine which have the greatest influence on vegetation composition.

ii) The DCA species scores plot

Detrended correspondence analysis of the variation within the vegetation data showed that the first axis was entirely accounted for by the presence or absence of *U. dioica*. This finding is partly an artefact of the random quadrat sampling which included one quadrat where *U.dioica* and *Dipsacus fullonum* (Teasel) were the only species present. The correspondence analysis would interpret this as a significant variation within the data set as the detrended technique does not distinguish between significant variation from environmental variables and significant variation from unusual occurrences in the vegetation.

Table 4.7 shows the corresponding eigenvalues for each axis and it can be seen that the value for the first axis is quite low, indicating that there is not a good dispersion of the species scores along the ordination axis and that the first axis is perhaps masking the variation shown in subsequent axes. Axis variance corresponds to the amount of variation in the data set accounted for by each axis and this shows that 7.8% of the variance in the data set was accounted for by the presence or absence of *U.dioica* in each quadrat.

Table 4.7: Eigenvalues and corresponding variances from the DC analysis on the whole data set.

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigenvalues	0.526	0.405	0.216	0.161	6.734
Cumulative percentage variance of species data	7.8	13.8	17	19.4	
Variance accounted for by each axis	7.8	6.0	3.2	2.4	

The DCA was re-run after constraining the data set so that *U.dioica* was weighted at zero. This meant that the species was still present in the ordination plot but that it had no effect on the data. The re-calculated eigenvalues show this (Table 4.8) - the first axis has a value of 1, due to the dispersion being entirely accounted for by the unweighted *U.dioica*, but the second and third axes have higher eigenvalues, indicating that there is a much better dispersion of the data set along these axes. It can also be seen that the corresponding cumulative percentage variances are larger; 25.3% of the total variance in the data set is explained by the four calculated eigenvalues, rather than 19.4% of the total variance being explained when the influence of *U.dioica* was included.

Table 4.8: Eigenvalues and corresponding variances from the DC analysis on the data set when *U.dioica* was unweighted.

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigenvalues	1	0.458	0.218	0.144	7.185
Cumulative percentage variance of species data	13.9	20.3	23.3	25.3	
Variance accounted for by each axis	13.9	6.4	3.0	2.0	

When the total inertia (the total amount of dispersion capable of being explained by all available axes) of the two analyses are compared it can be seen that by removing *U.dioica* from the analyses more information is available from the data set.

Fig 4.7 shows the species scores plot obtained from the second DC analysis (using second and third axes). Dispersion along the x-axis appears to be linked to habitat age or stage of succession. At the far end of the axis are ruderal species such as *Viola arvensis, Trifolium campestre* and *Sherardia arvensis*, many of which are annuals (Stace 1997) and therefore indicative of early successional habitats. Within the data set, they were exclusively found on the re-created downland habitat. At the negative end of the axis (corresponding to the opposite extreme of the environmental variable) species such as *Carex humilis, Polygala calcarea* and *Gentianella amarella* are to be found. As well as being mostly biennial species, these are indicative of chalk grassland (Ratcliffe 1977; Edwards 1998) and have specific habitat requirements. They are all species found as part of the chalk downland plagioclimax (Hope-Simpson 1940).

The y-axis (third axis) appears to separate the data set on the basis of vegetation structure. Species characteristic of ranker, closed vegetation such as *Listera ovata,* *Viola riviniana* and *Luzula campestris* are found clustered towards the negative extreme whereas those species more often found in dry, open turf (*Hypericum perfoliata, V. arvensis* and *Arenaria serpyllifolia*) occur at the extreme positive end of the axis. It is possible there is a link with grazing intensity on this axis - sward structure is a result of several factors including grazing and those species characteristic of grazed and ungrazed swards (for example *Asperula cynanchica* and *Prunus spinosa*) appear to be separated. However, this axis only explains 3% of the variation in the data (Table 4.8).

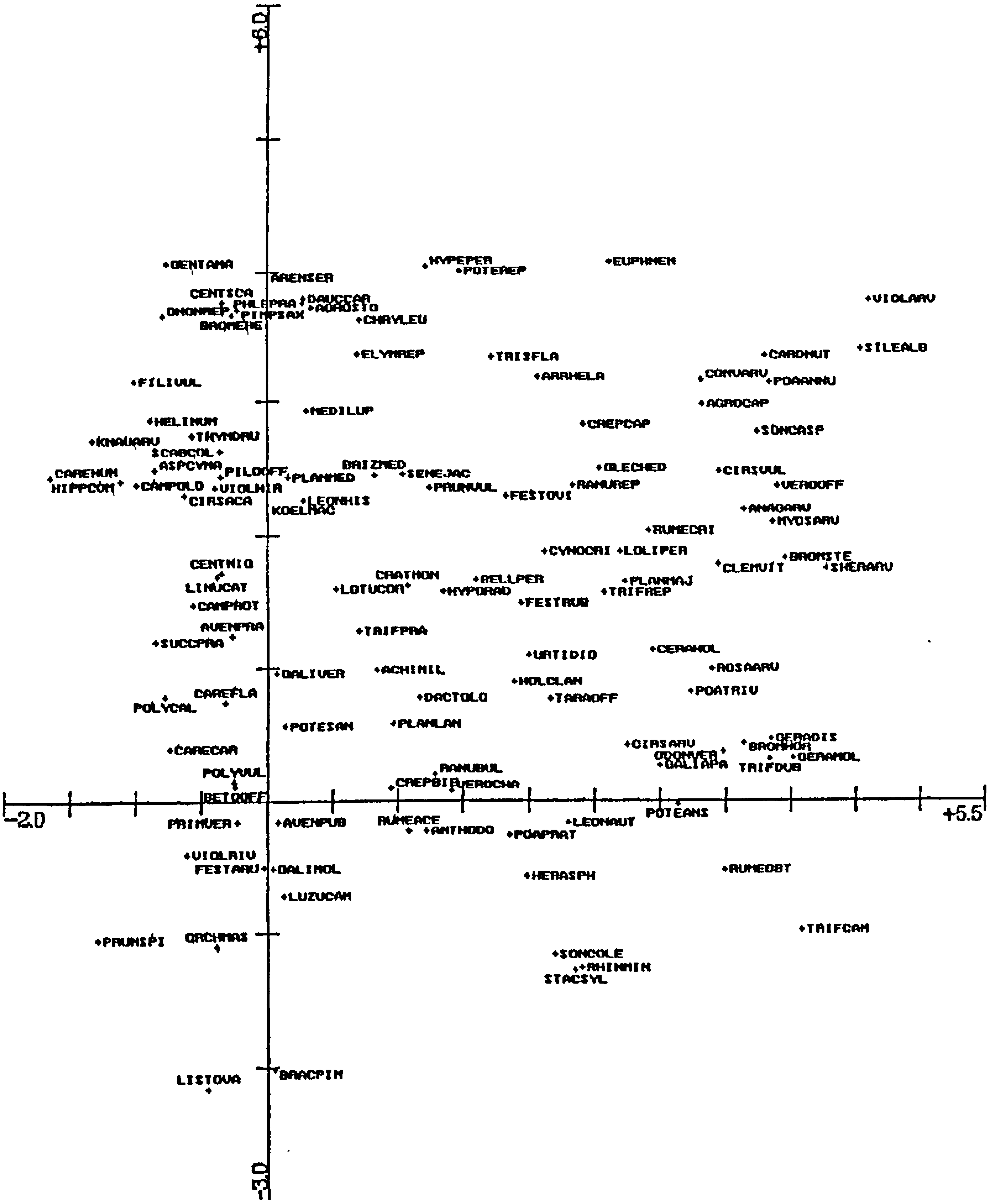


Fig 4.7: The DCA species scores plot, showing separation of species along the ordination axes. Species abbreviations are explained in Table 4.9.

Table 4.9: Key to the plant species names on DCA species scores plot.

Abbreviation	Species name and name used elsewhere in text if different	Abbreviation	Species name and name used elsewhere in text if different
ACHIMIL	*Achillea millefolium*	LEONAUT	*Leontodon autumnalis*
AGRIEUP	*Agrimonia eupatoria*	LEONHIS	*Leontodon hispidus*
AGROCAP	*Agrostis capillaris*	LINAVUL	*Linaria vulgaris*
AGROSTO	*Agrostis stolonifera*	LINUCAT	*Linum catharticum*
ANAGARV	*Anagallis arvensis*	LISTOVA	*Listera ovata*
ANTHODO	*Anthoxanthum odoratum*	LOLIPER	*Lolium perenne*
ANTHVUL	*Anthyllis vulneraria*	LOTUCOR	*Lotus corniculatus*
ARCTMIN	*Arctium minus*	LUZUCAM	*Luzula campestris*
ARENSER	*Arenaria serpyllifolia*	LYCHF-C	*Lychnis flos-cuculi*
ARRHELA	*Arrhenatherum elatius*	MATRMAT	*Matricaria matricarioides*
ARTVULG	*Artemisia vulgaris*	MEDILUP	*Medicago lupulina*
ASPCYNA	*Asperula cynanchica*	MYOSARV	*Myosotis arvensis*
AVENPRA	*Avenula pratensis (Helictotrichon pratensis)*	MYOSCAE	*Myosotis caespitosa*
AVENPUB	*Avenula pubescens (Helictotrichon pubescens)*	ODONVER	*Odontites verna*
BELLPER	*Bellis perennis*	ONONREP	*Ononis repens*
BETOOFF	*Betonica officinalis (Stachys officinalis)*	ORCHMAS	*Orchis mascula*
BLACPER	*Blackstonia perfoliata*	ORCHUST	*Orchis ustulata*
BRACPIN	*Brachypodium pinnatum*	OROBMIN	*Orobanche minor*
BRACSYL	*Brachypodium sylvaticum*	PAPARHO	*Papaver rhoeas*
BRIZMED	*Briza media*	PHLEPRA	*Phleum pratense*
BROMERE	*Bromopsis erecta*	PICRHIE	*Picris hieracioides*
BROMHOR	*Bromus hordeaceus*	PILOOFF	*Pilosella officinarum*
BROMSTE	*Bromus sterilis (Anisantha sterilis)*	PIMPSAX	*Pimpinella saxifraga*
BRYODIO	*Bryonica dioica*	PLANLAN	*Plantago lanceolata*
CAMPGLO	*Campanula glomerata*	PLANMAJ	*Plantago major*
CAMPROT	*Campanula rotundifolia*	PLANMED	*Plantago media*
CARDACA	*Carduus acanthoides*	POAANNU	*Poa annua*
CARDNUT	*Carduus nutans*	POAPRAT	*Poa pratensis*
CARECAR	*Carex caryophyllea*	POATRIV	*Poa trivialis*
CAREFLA	*Carex flacca*	POLYCAL	*Polygala calcarea*
CAREHUM	*Carex humilis*	POLYVUL	*Polygala vulgaris*
CARLVUL	*Carlina vulgaris*	POLYAVI	*Polygonum aviculare*
CENTNIG	*Centaurea nigra*	POTEANS	*Potentilla anserina*
CENTSCA	*Centaurea scabiosa*	POTEREP	*Potentilla reptans*
CERAHOL	*Cerastium holosteoides*	POTESAN	*Poterium sanguisorba (Sanguisorba minor ssp. minor)*
CHAETEM	*Chaerophyllum temulentum*	PRIMVER	*Primula veris*
CHRYLEU	*Chrysanthemum leucanthemum (Leucanthemum vulgare)*	PRUNVUL	*Prunella vulgaris*
CIRSACA	*Cirsium acaule*	PRUNSPI	*Prunus spinosa*
CIRSARV	*Cirsium arvense*	RANUBUL	*Ranunculus bulbosus*
CIRSVUL	*Cirsium vulgare*	RANUFIC	*Ranunculus ficaria*
CLEMVIT	*Clematis vitalba*	RANUREP	*Ranunculus repens*
CONOMAJ	*Conopodium majus*	RHINMIN	*Rhinanthus minor*
CONVARV	*Convolvulus arvensis*	ROSAARV	*Rosa arvensis*
CORYAVE	*Corylus avelana*	ROSA SP	*Rosa sp.*
CRATMON	*Crataegus monogyna*	RUBUFRU	*Rubus fruticosus agg.*

CREPBIE	*Crepis biennis*	RUMEACE	*Rumex acetosa*
CREPCAP	*Crepis capillaris*	RUMECRI	*Rumex crispus*
CYNOCRI	*Cynosurus cristatus*	RUMEOBT	*Rumex obtusifolius*
DACTGLO	*Dactylis glomerata*	SCABCOL	*Scabiosa columbaria*
DACTFUC	*Dactylorhiza fuchsii*	SCRONOD	*Scrophularia nodosa*
DANTDEC	*Danthonia decumbens*	SENEJAC	*Senecio jacobaea*
DAUCCAR	*Daucus carota*	SENEVUL	*Senecio vulgaris*
DIPSFUL	*Dipsacus fullonum*	SHERARV	*Sherardia arvensis*
ELYMREP	*Elymus repens (Elytrigia repens ssp. repens)*	SILEALB	*Silene alba*
EPIL SP	*Epilobium sp.*	SILEDIO	*Silene dioica*
EUPHEXI	*Euphorbia exigua*	SONCARV	*Sonchus arvensis*
EUPH SP	*Euphorbia sp.*	SONCASP	*Sonchus asper*
EUPHNEM	*Euphrasia nemorosa*	SONCOLE	*Sonchus oleraceus*
FESTARU	*Festuca arundinacea*	STACSYL	*Stachys sylvatica*
FESTOVI	*Festuca ovina agg.*	SUCCPRA	*Succisa pratensis*
FESTRUB	*Festuca rubra*	TARAOFF	*Taraxacum officinale agg.*
FILIVUL	*Filipendula vulgaris*	THESHUM	*Thesium humifusum*
GALIAPA	*Galium aparine*	THYMDRU	*Thymus drucei (Thymus polytrichus)*
GALIMOL	*Galium mollugo*	TORIJAP	*Torilis japonica*
GALIVER	*Galium verum*	TRAGPRA	*Tragopogon pratensis agg.*
GENTAMA	*Gentianella amarella*	TRIFCAM	*Trifolium campestre*
GENTANG	*Gentianella anglica*	TRIFDUB	*Trifolium dubium*
GERADIS	*Geranium dissectum*	TRIFPRA	*Trifolium pratense*
GERAMOL	*Geranium molle*	TRIFREP	*Trifolium repens*
GERAROB	*Geranium robertianum*	TRISFLA	*Trisetum flavescens*
GLECHED	*Glechoma hederacea*	TRITAES	*Triticum aestivum*
GYNMCON	*Gymnadenia conopsea*	ULEXEUR	*Ulex europaeus*
HELINUM	*Helianthemum nummularium*	URTIDIO	*Urtica dioica*
HERASPH	*Heracleum sphondylium*	VERBTHA	*Verbascum thapsus*
HIPPCOM	*Hippocrepis comosa*	VEROCHA	*Veronica chamaedrys*
HOLCLAN	*Holcus lanatus*	VEROOFF	*Veronica officinalis*
HYPEPER	*Hypericum perforatum*	VICICRA	*Vicia cracca*
HYPOGLA	*Hypochoeris glabra*	VICISAT	*Vicia sativa*
HYPORAD	*Hypochoeris radicata*	VIOLARV	*Viola arvensis*
KNAUARV	*Knautia arvensis*	VIOLHIR	*Viola hirta*
KOELMAC	*Koeleria macrantha*	VIOLRIV	*Viola riviniana*
LAPSCOM	*Lapsana communis*		
LATHPRA	*Lathyrus pratensis*		

As well as the dispersion along the main axes there are some noticeable clusters of species within the ordination. These represent groups of species which are often found in association within the quadrats and can be interpreted as clusters of species which prefer similar conditions. One cluster comprises *Scabiosa columbaria, Asperula cynanchica, Pilosella officinarum, Viola hirta, Cirsium acaule, Campanula glomerata, Plantago media, Thymus polytrichus* (shown as *T.drucei* on the plot) and *Koeleria macrantha*, while another cluster is *Centaurea scabiosa, Phleum pratense, Daucus carota, Agrostis stolonifera, Leucanthemum vulgare* (shown as *Chrysanthemum leucanthemum* on the plot) and *Ononis repens*. Potential factors causing the differences in habitat requirement within these groups are examined in the next section.

iii) The influence of environmental factors on plant species distribution

Detrended canonical correspondence analysis can only be performed on data collected from within the same sampling points (Kent and Coker 1992). Because of this, the qualitative environmental data (Table 4.10) collected from each main habitat type (downland and re-created downland) was compared with the quadrat data by calculating Spearman rank correlation coefficients. These were performed in two ways;

- using habitat (represented by species richness) as a variable to investigate differences in vegetation between habitats,
- within each habitat to investigate which environmental variables effect the vegetation of a particular habitat.

Table 4.10: Data used in the calculation of Spearman rank correlations (r_s) linking environmental variables with species richness and habitat.
(DT = Downland turf, RC = Re-created downland, Sp.R = naturally occurring indicator species richness per site per habitat, Slp = slope (degrees), BrGnd = Mean % bare ground, Trf Ht = Turf height (cm), NO_3 = nitrate (mg/kg), N = total nitrogen (mg/kg), Mg = magnesium (mg/kh), K = potassium (mg/kg), OM = % soil organic matter, Cl = Chloride (mg/kg), SO_4 = sulphate (mg/kg)).

Habitat	Sp.R	aspect	Slp	BrGnd	Trf Ht	NO_3	N	Mg	K	pH	OM	Cl	SO_4
DT	5.75	344.0	22.3	0.67	9.87	106.2	24.0	188.1	142.2	6.91	33.7	51.9	59.8
DT	10.25	307.0	23.0	0.17	4.83	74.5	16.8	130.9	87.3	6.58	24.6	95.4	49.2
DT	4.45	354.0	24.3	3.17	7.33	206.2	46.6	147.7	52.9	7.31	36.2	75.5	45.8
DT	12.85	277.0	24.0	0.50	6.83	49.9	11.3	125.2	104.3	7.35	28.9	59.4	40.9
DT	12.50	235.0	25.0	0.00	8.23	45.0	10.2	149.5	67.6	7.28	36.0	38.3	43.1
DT	7.50	57.3	24.7	2.17	8.82	230.4	52.0	109.1	115.9	8.04	32.5	42.7	57.5
RC	0.05	344.0	4.8	0.00	6.57	94.8	21.4	70.2	203.9	7.24	23.5	48.3	45.5
RC	0.05	251.0	9.7	3.50	5.88	46.6	10.5	63.9	257.3	7.15	11.8	41.8	32.4
RC	0.00	112.0	4.0	0.17	9.28	30.7	6.9	85.1	256.8	6.11	9.90	59.6	36.7
RC	0.35	N/A	0.0	0.00	7.65	50.1	11.3	57.8	85.3	7.35	13.4	65.5	40.3
RC	0.15	270.0	6.0	0.00	9.63	31.1	7.0	44.1	147.1	7.43	14.7	28.0	32.8
RC	0.05	37.0	6.0	3.50	7.32	147.5	33.3	93.1	111.5	8.00	30.3	164.7	63.3

Correlations with habitat type.

The correlation of environmental parameter with habitat type used species richness to represent habitat type. This was possible because it was found that there was a significant difference ($U=0.000$, $p<0.01$, Mann-Whitney U-Test) between the species richness of downland and re-created downland (using the indicator species sub-set).

Table 4.11: Spearman rank correlation coefficients (r_s) of those variables found to be significantly correlated. (Significances: ** = $p<0.01$, * = $p<0.05$. $n=12$ for each environmental variable).

Environmental variable	Sp.R	Slope	N/NO_3	Mg	K
Slope	+0.769**				
Mg	+0.634*	+0.725**			
K	-0.655*				
OM	+0.613*	+0.778**	+0.615*	+0.811**	-0.650*
SO_4			+0.818**	+0.629*	

The analysis showed that species richness correlated with several of the variables (see Table 4.11), indicating that they can be used to distinguish between established and re-created downland. The high correlation of species richness with slope probably reflects the trend of agricultural intensification which has led to most of the machine accessible downland being ploughed for arable usage. This means that the downland fragments (high species richness) left are on the steepest slopes.

Magnesium and potassium also showed significant ($p<0.05$) correlations with species richness but these results must be interpreted with caution. Both of these soil nutrients also correlated with organic matter which in turn correlated with species richness. The correlation coefficient for magnesium and organic matter ($p<0.01$) was more significant than that of magnesium and species richness ($p<0.05$), but this does not necessarily reflect the strength of the relationship as the sample size was quite small and the data comes from two different sets (re-created and established downland). When plotted graphically the data show that organic matter and magnesium have a more obvious linear relationship (this is reflected in the higher R-squared value) than species richness and magnesium (Fig 4.8 and 4.9). It seems logical that there is a link between magnesium and organic matter because soil magnesium content is normally linked to % organic matter and is often deficient in arable soils due to their low levels of organic matter.

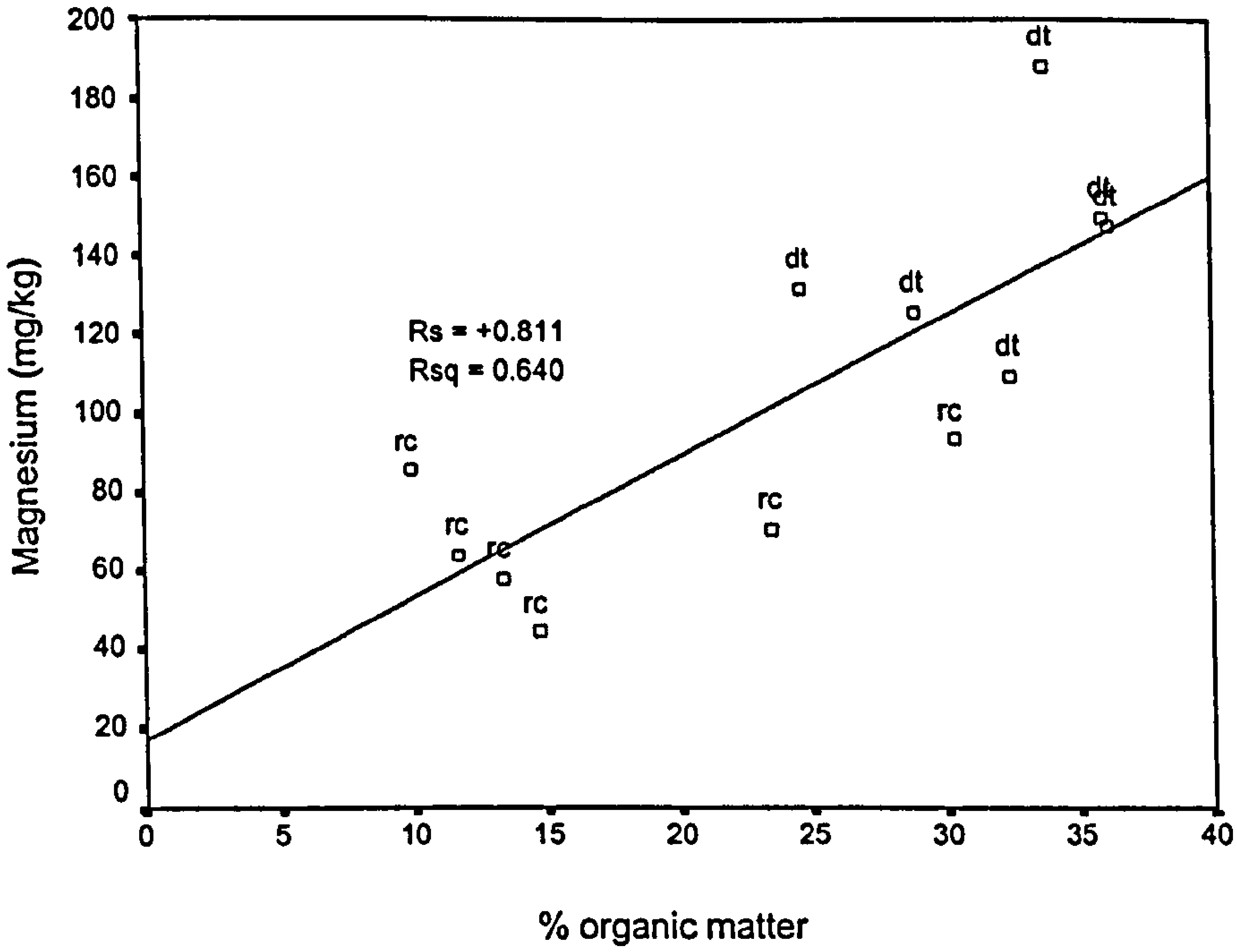


Fig 4.8: Scatter plot of soil magnesium against % soil organic matter, showing the Spearman rank correlation coefficient and the R-squared value. (rc = re-created downland, dt = downland turf)

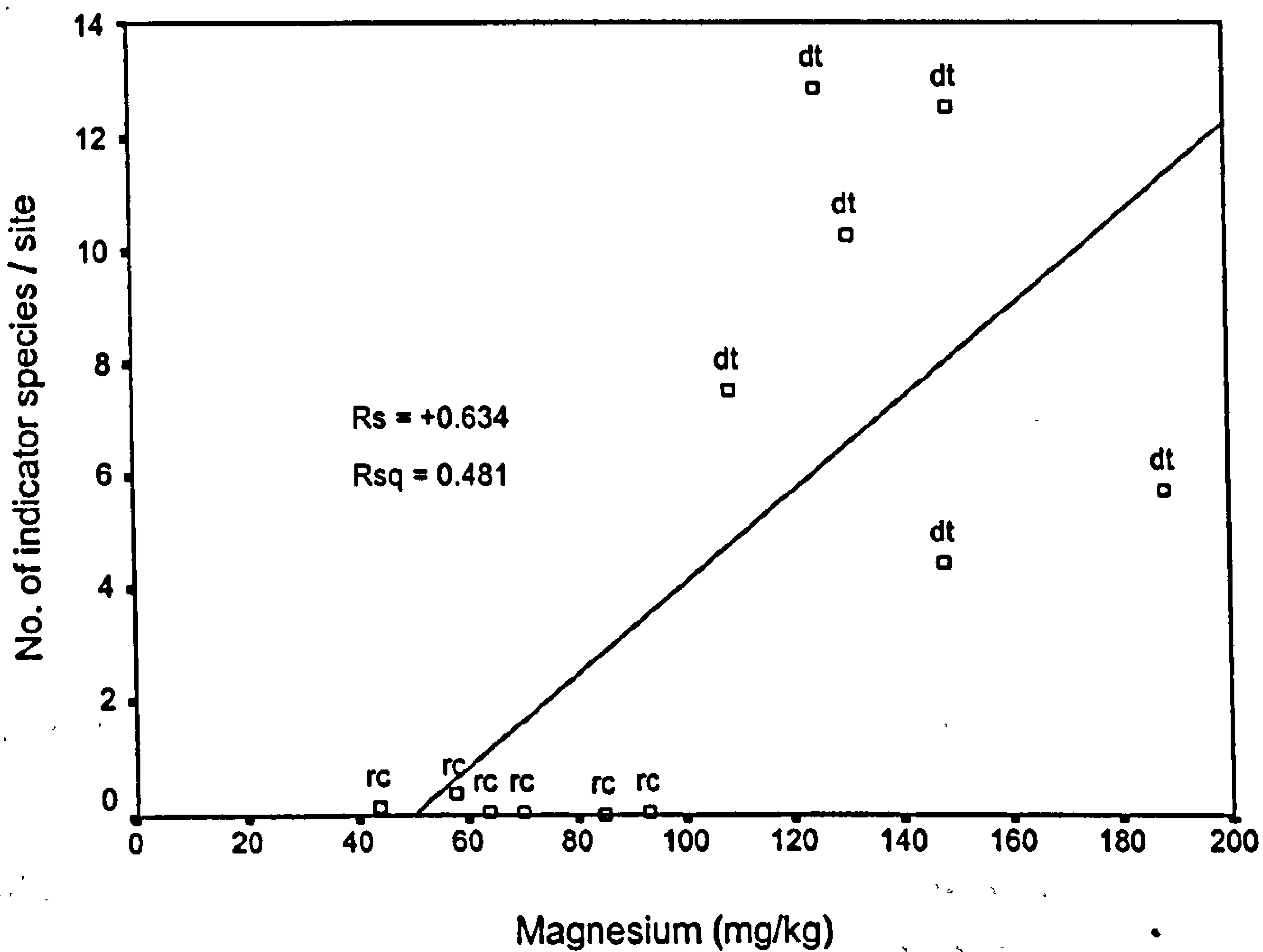


Fig 4.9: Scatter plot of soil magnesium against number of calcicolous indicator species, showing the Spearman rank correlation coefficient and the R-squared value. (rc = re-created downland, dt = downland turf)

Similarly, although the correlation coefficients of potassium with species richness and organic matter are very similar, it seems likely that potassium is related more to habitat type (represented by species richness) because this element is applied in relatively large quantities to arable habitat in agricultural fertiliser. This would be the predominant influence on levels of this soil nutrient, eclipsing differences in the natural level which might be linked to organic matter, and explains why the correlation is negative - less potassium is found on the habitat with more organic matter (downland).

There are other significant correlations which can be used to infer differences in habitat type, especially when looked at in conjunction with data from other chapters of this thesis. For example organic matter is correlated with nitrate and total nitrogen; probably due to the amount of organic matter in the soil leading to mineralisation or immobilisation of these nutrients (see Chapter 5). The significant correlation of sulphate with nitrogen and magnesium is perhaps surprising given that sulphate levels normally reflect atmospheric deposition rather than underlying soil processes (Brady 1990).

It can also be seen that organic matter and magnesium are correlated with slope. This is possibly because the slope is correlated with species richness (ie varies with habitat type), so the correlation with organic matter and magnesium with slope reflects the correlation of these two factors with habitat (assessed by species richness).

The processes underlying these results will be further discussed in section 4.3.

Correlation of environmental variables within downland habitat.

Within the established chalk downland habitat it was found that nitrogen/nitrate correlated negatively with species richness (Table 4.12, Fig 4.10), meaning that high species richness is associated with low soil nitrogen content. This result appears unusual at first when examined alongside the work in Chapter 5 which shows that nitrogen levels are linked to soil organic matter content and the process of mineralisation which releases nutrients into the soil for plant uptake. However, the correlation reflects the fact that downland flora are adapted to live on nutrient poor soils and therefore impoverished sites are often more species rich, as is shown by Pywell et al. (1997), Wells et al. (1976) and Wells et al. (1994). Those sites with more impoverished soils will have more chalk downland indicator species present than those with slightly richer soils. If the total species richness was examined then the correlation would probably be in the opposite direction.

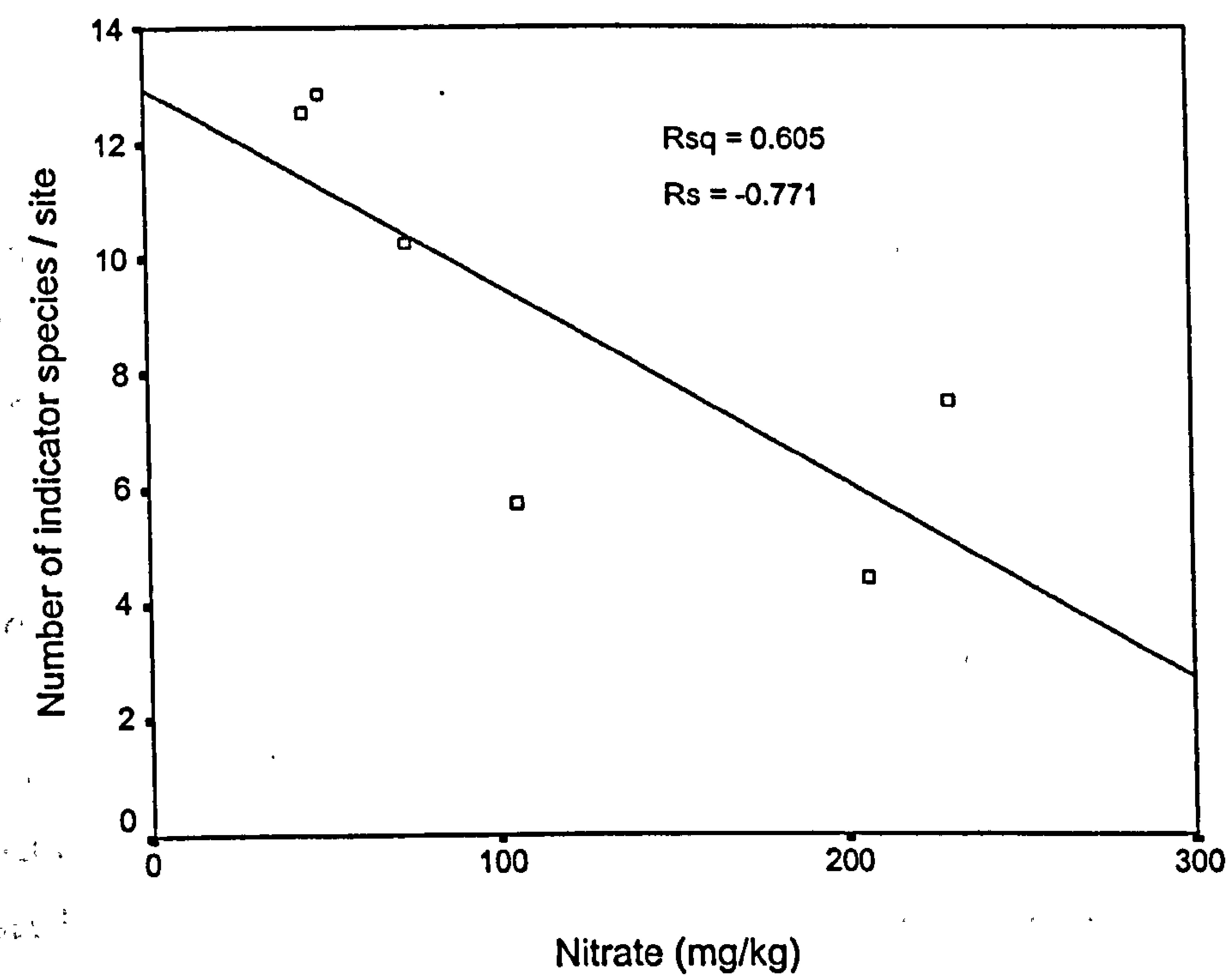


Fig 4.10: Scatter plot of nitrate and number of calcicolous indicator species on downland habitat: showing the Spearman rank correlation coefficient and the R-squared value.

The downland turf data also showed that bare ground correlated with species richness, as well as with nitrogen/nitrate. It is difficult to interpret these results without knowing more about the environmental conditions, but it could be that the bare ground is related to grazing - those sites with heavy grazing (more bare ground) are less indicator species rich because they are on soils with a higher nitrogen status, perhaps because of enrichment from the animal dung.

Table 4.12: Significant Spearman rank correlations (shown by correlation coefficient r_s) within established downland turf habitat. (Significances: * = p<0.05, ** = p<0.01).

Environmental variable	**Indicator species richness**	**% Bare ground**
% Bare ground	-0.771*	
Nitrate/nitrogen	-0.771*	+0.886**

Although there was no significant correlation between indicator species richness and habitat, it is worth noting that the correlation coefficient (r_s = -0.600) was negative. Aspect was measured in degrees from a compass and the lower numbers correspond to north and east facing aspects. This corresponds with the observation that the highest quality chalk grasslands are often restricted to south and west facing slopes where optimum conditions of heat and light are found (Smith 1980).

Correlation of environmental variables within re-created downland habitat.

The only correlation determined from within the re-created downland data set was that of nitrogen/nitrate with organic matter (r_s = +0.829, p<0.05). This relationship (see Fig 4.11) shows that high levels of soil organic matter are linked to high levels of nitrogen/nitrate, and should be examined in conjunction with the nitrate data in Chapter 5. It was shown (section 5.2.1) that re-creation soils had very low levels of nitrogen/nitrate and that this was linked to the lack of soil organic matter, which leads to immobilisation occurring within the soil. The correlation result appears to verify this by showing that within the re-created downland levels of organic matter are positively correlated with available nitrate (93% of the data on the graph fits the best fit line). On an ex-arable habitat such as re-created downland it is levels of nutrients such as nitrate which will help determine the success or failure of the sown sward and the fact that the only significant correlation was with nitrate/nitrogen (out of four other soil nutrients) shows that this is probably the most important one.

Although higher nitrate levels were linked with decreased indicator species richness within the downland habitat, the data in Chapter 5 shows that levels of nitrogen/nitrate in re-created downland are much lower than those in downland turf, and it is likely that the correlation within the downland represents a different scale of magnitude to the overall difference in nitrate/nitrogen between the two habitats.

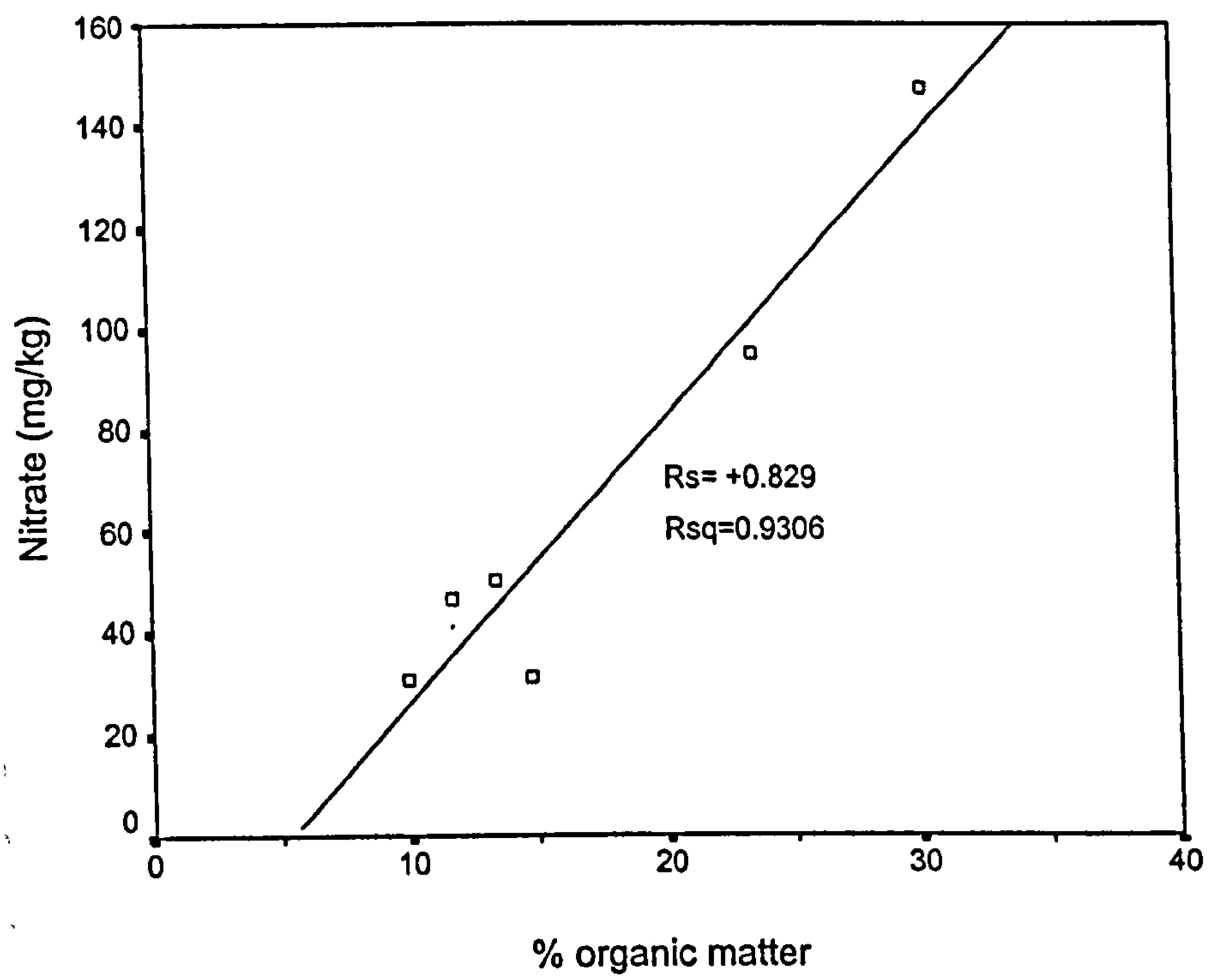


Fig 4.11: The relationship between nitrate and soil organic matter in re-created downland habitat (showing the r-squared value of the regression line and the Spearman rank correlation coefficient).

These correlations help to further explain the axes of the quadrat scores ordination plot (section 4.2.1). The environmental factors which correlate with habitat type (via the link between species richness and habitat) and with species richness within habitat can be used to help interpret the separation of habitats within the ordination. If further ordination axis had been calculated (instead of just using four) then these axis would probably have corresponded to the environmental variables which had significant correlations with species richness (and therefore habitat), such as slope, magnesium and organic matter. However, it must be remembered that the main sources of variation within the quadrat data set were from species richness (second axis), followed by precipitation (third axis) (see section 4.2.2.2).

4.2.2.2 The homogeneity of existing chalk downland

i) The DCA quadrat scores plot

The six study sites from which information on the floristic composition of chalk downland and re-created downland was gathered divided geographically into two groups;

- three sites north of Dorchester in the Sydling Valley, and
- three sites in Wiltshire; two in the Avon river catchment and one in the Stour catchment (see Chapter 2 and maps).

One of the assumptions made about these study sites was that they were homogeneous with respect to the baseline chalk grassland used in comparison with the re-created downland. This section addresses this assumption and evaluates the differences between sites, as shown by the DCA ordination plot.

The quadrat scores plot of second and third ordination axes (see section 4.2.2.1 for an explanation of why the first axis was not used) shows that there appears to be a separation between the sites along the y-axis (third axis). Broadly speaking, sites in Dorset are situated towards the origin (except for the re-creation area of Huish Farm) and sites in Wiltshire are situated towards the positive end of the y-axis (see Fig 4.12). The nature of the DCA analysis means that it is not possible to say what environmental variable is causing this (Kent and Coker 1992).

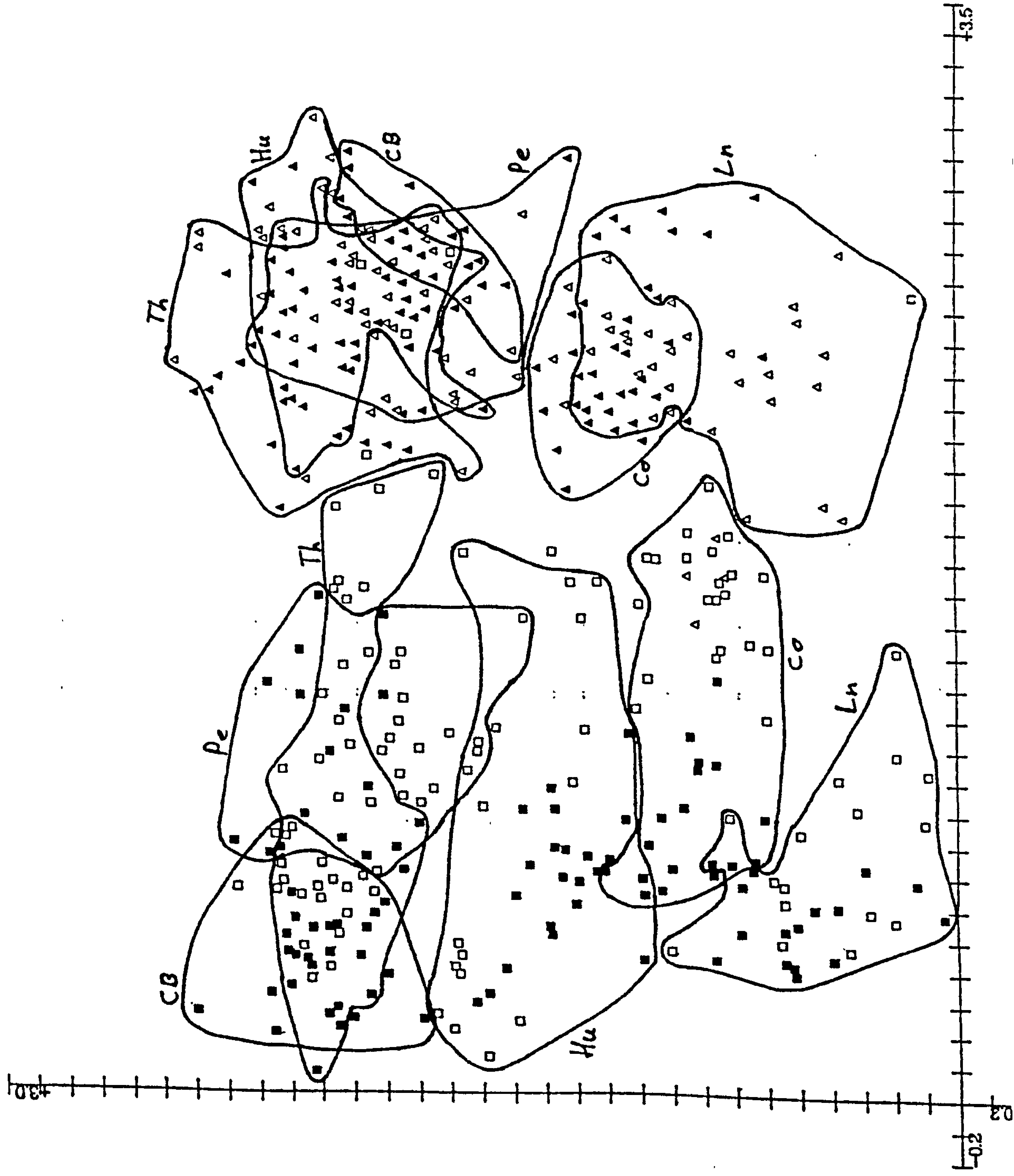


Fig 4.12: The quadrat scores plot from DCA, with the position of each study site superimposed. Symbols are the same as in Fig 4.1. Dorset sites: Ln = Langford Farm, Hu = Huish Farm, Co = Court Farm, Wiltshire sites: Th = Throope Manor Farm, CB = Coombe Bisset Down, Pe = Peckons Hill Farm.

However, by superimposing environmental variables over the ordination it is possible to determine which are linked to the separation along the axis. Site values for species richness, bare ground, nitrogen, organic matter, precipitation, type of grazing, aspect and height above sea level were examined.

The comparison of environmental parameters with site position on the ordination is presented in Table 4.13 which is arranged in the same way as the sites on the ordination plot - those sites above the division on the y-axis are at the top of the table and those sites below the division on the y-axis are at the bottom of the table. It can be seen that precipitation is the only factor which divides the sites on the ordination suggesting that the axis divides the vegetation data according to how the sites responded to different levels of rainfall. These results are discussed in section 4.3.

Table 4.13: Comparing environmental parameters with site position on the y-axis of the site scores ordination. (Ordination position: above = above the divide on the y-axis, below = below the divide on the y-axis. Parameter: SpR = Species richness, BG = bare ground (%), N = total nitrogen (mg/kg), OM = soil organic matter content (%), G = type of grazing, A = aspect (degrees), Ht = height above sea level (m), Pt = precipitation (mm); (Environment Agency, South Wessex Area, *pers.comm.*).

Site & habitat (DT=downland, RC=recreation	Ordination position (y-axis)	Parameter							
		SpR	BG	N	OM	G	A	Ht	Pt
Peckons DT	above	7.5	7	52	33	cattle	57	220	875
Throope DT	above	12.85	0	10	35	sheep	277	125	846
Coombe DT	above	12.5	0	11	29	sheep	235	125	846
Peckons RC	above	0.05	0	33	30	cattle	37	250	875
Throope RC	above	0.35	34	10	14	sheep	N/A	90	846
Coombe RC	above	0.15	0.5	7	13	sheep	270	85	846
Huish RC	above	0.05	25	11	11	sheep	251	190	1078
Court DT	below	4.45	0.5	46	36	cattle	354	165	1078
Huish DT	below	10.25	0	16	24	sheep	307	150	1078
Langford DT	below	5.75	0	23	33	sheep	344	110	1078
Court RC	below	0	0	6	9	cattle	112	180	1078
Langford RC	below	0.05	13.5	21	23	sheep	344	85	1078

ii) The DCA species scores plot.

The species scores plot can also be used to evaluate variation in habitat quality between different sites. This was carried out by looking at the groups of species which are indicative of a particular community type. These are referred to as constants (Rodwell 1998) and can be used to evaluate the ordination if superimposed on the species scores plot. The major grassland communities represented within the quadrats are:

- CG2 *Festuca ovina – Helictotrichon pratensis* grassland
- CG3 *Bromopsis erecta* grassland
- CG6 *H. pubescens* grassland
- MG5 *Cynosurus cristatus - Centaurea nigra* grassland
- MG6 *Lolium perenne - Cynosurus cristatus* grassland.

(communities identified from Edwards (1998) and NCC (1987))

Figs 4.13 and 4.14 show the species scores plot with the constants for calcareous and mesotrophic communities overlaid on each plot. Mesotrophic grassland (MG) communities appear to occupy a position further towards the positive end of the second axis and further towards the origin in the third axis than the calcareous grassland (CG) communities. This could be indicative of the slightly lusher appearance of these grasslands (such as ley pastures and semi-permanent grazing meadows) , and the fact that they often develop under conditions of slightly more intensive management than calcareous grasslands and on slightly richer soils (Rodwell 1998).

These results seem to show that there is a difference between the permanent downland found at different sites; at the very least the calcareous grassland communities are separated from the mesotrophic grassland communities. This variation between sites was also shown by the quadrat scores plot, which appeared to separate the sites on the basis of amount of precipitation. The variation in downland turf quality between sites is important because of its possible influence on the adjacent re-created turf. A regression (Fig 4.15) of the naturally occurring indicator species on the re-created downland at all sites against the indicator species on the downland turf at all sites appears to show that below a certain number of downland turf indicator species there is no spread of these significant species from existing downland to re-created downland. This shows that the quality of the downland turf does affect the quality of the re-created downland turf.

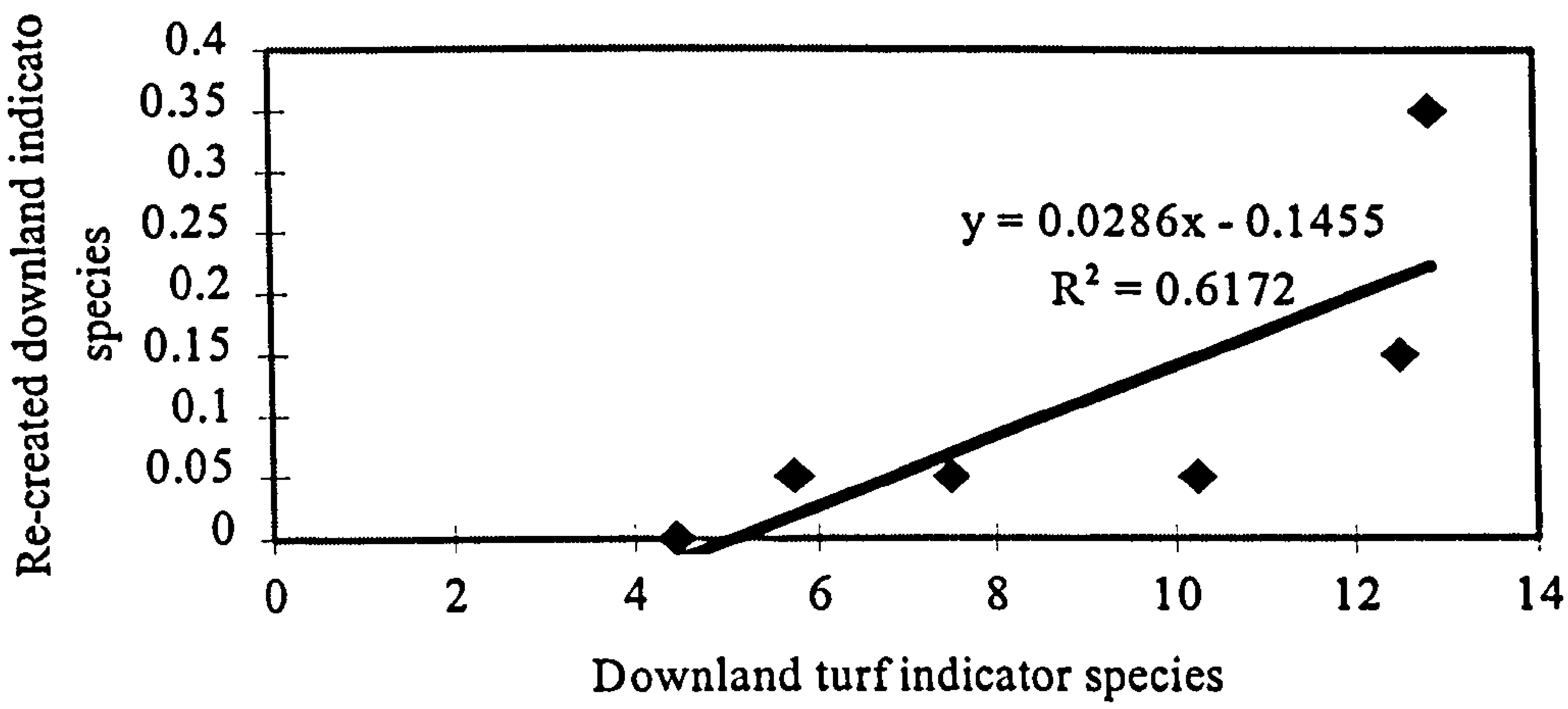


Fig 4.15: The relationship between established and re-created downland with respect to the spread of indicator species from established to re-created downland (including line of best fit).

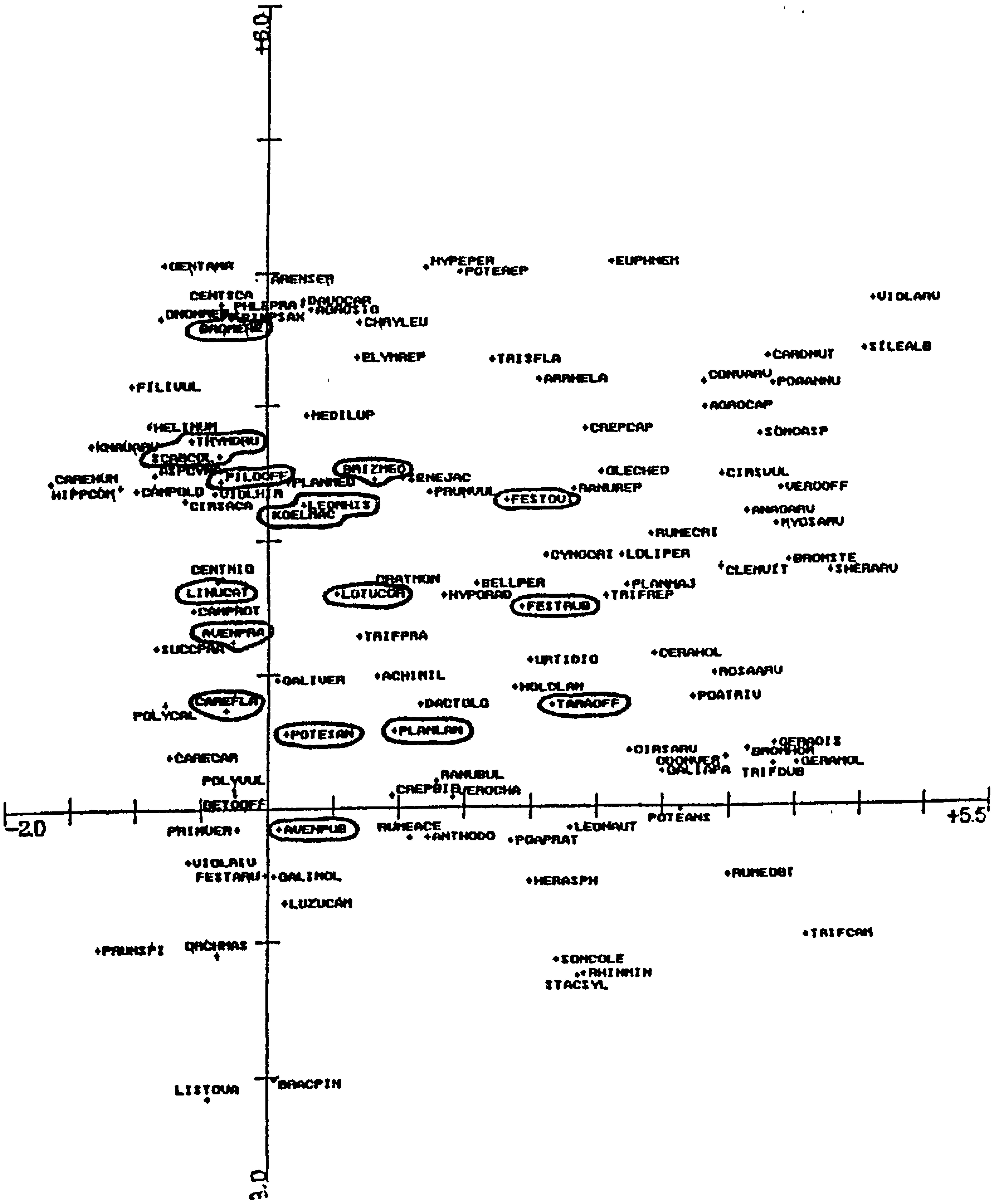


Fig 4.13: The DCA species score plot overlaid with CG2, CG3 and CG6 calcareous grassland community constants (Rodwell 1998). Species abbreviations are explained in Table 4.9.

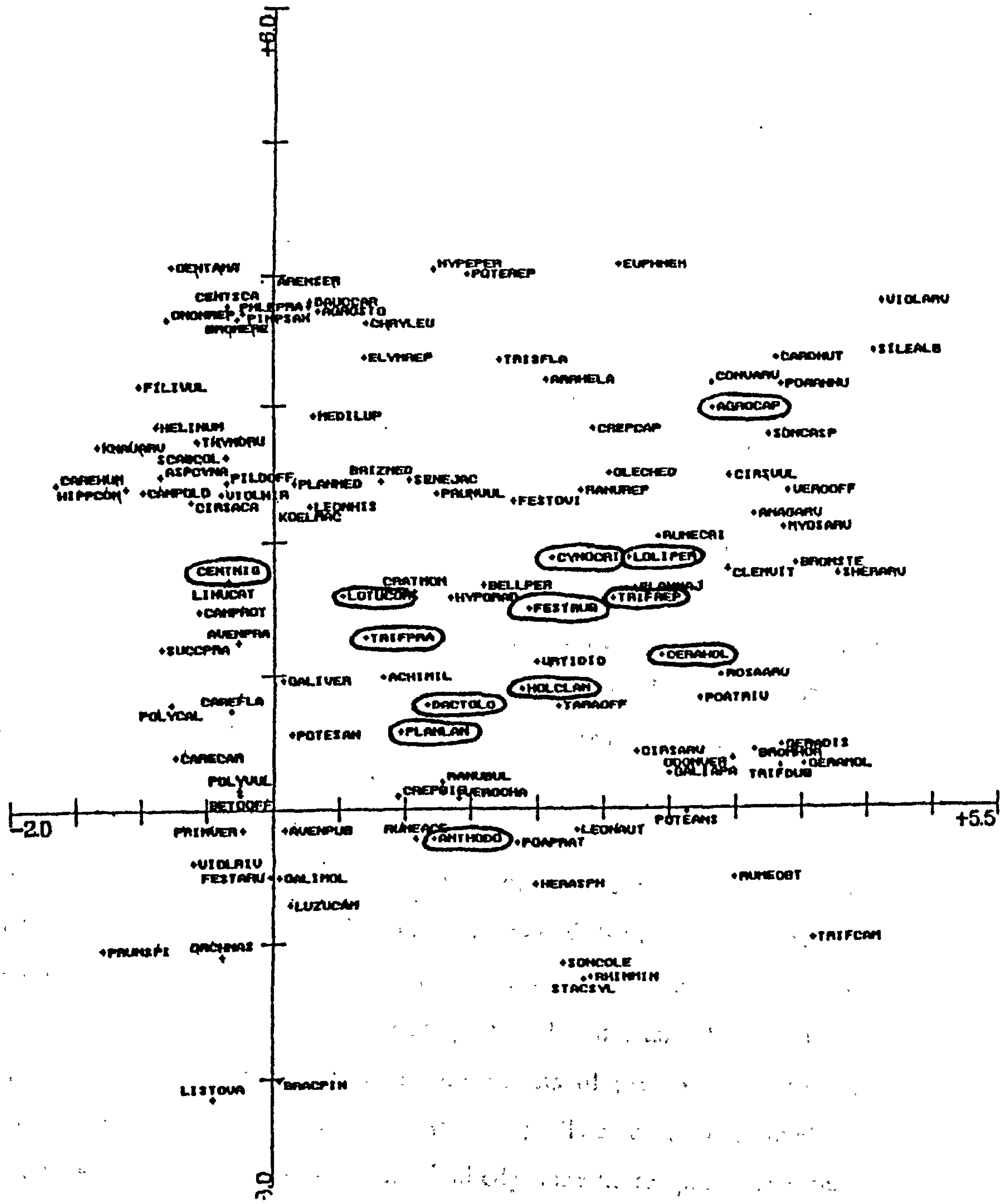


Fig 4.14: The DCA species score plot overlaid with MG5 and MG6 mesotrophic grassland community constants (Rodwell 1998). Species abbreviations are explained in Table 4.9.

4.3 Discussion

4.3.1 The difference between established and re-created chalk downland.

The largest difference in habitat shown on the DCA quadrat scores plot was between established downland middle and re-created downland middle area, and this is not surprising given that each of these areas is relatively isolated from the other habitat and has a completely different management history.

The within habitat differences are far more interesting, and the ordination and species richness data show that there are differences between edge and middle areas within each habitat. Total species richness and indicator species richness declines at the edge of the established downland, but on the edge of the re-created downland the total and indicator species richness increases. This effect is exaggerated when just the naturally occurring (as opposed to sown) indicator species are examined and results show that very few of these species occur in the middle of re-created downland compared to the number of sown indicator species. On the edge of this habitat the situation is reversed and there are more naturally occurring indicator species than sown ones (although this was not significant).

Previous studies demonstrate that the species richness of field edges is often greater than that in the middle of these areas (Marshall 1989; Wilson and Aebischer 1995). Although much of this work refers to arable habitat it is not unreasonable to assume many similarities between re-created chalk grassland and arable fields - both are sown swards and, in the first few years, the effects of previous applications of fertiliser are still evident in the soil (ADAS 1998). The results presented in this chapter do show that re-created downland field edges are more species rich than the middle areas but they also present evidence of species spread from the adjacent downland onto the new habitat. This shows that the re-created downland edges are not only species rich because they might have received lower fertiliser applications (allowing weed species to grow) while the field was under arable but also because there is cross-over of, specialised downland plant species (such as *Hippocrepis commosa*) from one habitat to the other.

The reverse of this effect is observed on the downland habitat where the number of indicator species is lower in the edge area. This is probably due to the years of agrochemical drift, both fertiliser and herbicide, from the adjacent arable fields. It has been shown that chemical drift does reduce the species richness of adjacent swards; for example Kleijn (1998) showed that herbicide application at a concentration comparative with that from chemical drift caused a decline in species richness of both grasses and forbs on fallow grass. The study also showed that the effects of fertiliser drift were far more severe and constant on species richness and individual species abundance than the effects of herbicide. This has implications for re-created downland within the South Wessex Downs ESA where a proposal is being considered to allow agreement holders to apply fertiliser to this habitat to increase it's productivity (R.Belding, *pers.comm.*), especially when one of the aims behind downland re-creation is to provide a buffer habitat to protect existing chalk downland (ADAS 1997).

It is also possible that the species richness of existing downland edge habitat is not just affected by agrochemical drift but by the lack of suitable seed sources. A study in America found that model simulations of edge habitat species richness related to habitat fragment size predicted certain 'edge sensitive' species which would decline exponentially once habitat size fell below a certain level (Laurance and Yensen 1991). Downland edge habitat is not surrounded by a constant source of material from which it can be re-colonised. It is recognised that most downland species persist by vegetative reproduction and tillering and that the closed nature of the sward means that not many species arrive by seed (Hutchings et al. 1989; Hutchings and Booth 1996). However, it might be that sward re-colonisation from the seed rain represents a small but crucial element of the sward stability. At the habitat edge, where the sward is not surrounded by sources of these species, re-colonisation from the seed rain will be reduced and may well have a subtle effect over time. Add to this the fertiliser effect, which encourages grasses and forbs such as *Anisantha sterilis*, and *Galium aparine* (Wilson and Aebischer 1995), and the fact that most of the downland in this study represented small fragments of formerly large areas, and it can be seen that there are significantly degrading forces in action.

This is the opposite to what has been found on heathland where habitat degradation has been linked with an increase in species richness and this rise in the number of species is used as a way of tracking the habitat quality (Webb and Rose 1994). However, research on the downland re-creation at Twyford Down in Hampshire found that the species richness of calcicoles (when measured from a checkerboard pattern superimposed over downland turf and adjoining bare ground) showed the same pattern of variance in species richness on edge and non-edge areas as was found in the present study (L.Ward, *pers.comm.*).

4.3.2 Variation in the vegetation composition of established and re-created chalk downland

Variation in habitat quality is shown to be linked to many different factors; environmental, edaphic and biotic (Smith 1980) and the eigenvalues of each axis of the DCA ordination demonstrate that this was true for the chalk grassland in this study. The cumulative variance of all calculated axes was 25.3%, indicating that only a quarter of the variance in the data was accounted for, and that many other axes would need to be calculated to account for the majority of the variance in the data. Each axis represents an environmental gradient (Kent and Coker 1992) and although the DCCA ordination demonstrated that the main sources of variation came from whether the data was collected on downland or within an edge or not, the Spearman rank correlations of habitat with environmental variable gave a more complete picture of the interactions between plant community and environment.

It was shown that nitrogen was closely linked to indicator species richness on re-created downland, and reasons for this are discussed in section 4.2. On established downland other soil nutrients were found to be important, highlighting the fact that soil nutrient status is an important factor to consider when managing or re-creating a habitat (Gilbert and Anderson 1998). Several previous studies have demonstrated the effectiveness of soil stripping as a way of reducing the nutrient status of arable habitats and the importance of providing a suitable seed bed (Marrs and Gough 1989; Gibson 1995). The work presented here sheds further light on which soil factors are important to consider when attempting to re-create chalk downland, such as nitrogen and soil organic matter.

It is also possible that the concentration of soil nitrogen is linked to the first axis of separation within the species scores plot. This was entirely accounted for by the presence/absence of *U. dioica*, a species which has been linked with conditions of high soil nitrate in the past (Olsen 1921). Olsen discusses a link with soil phosphate and it has since been discovered that presence or absence of *U. dioica* is also linked strongly with other environmental and soil conditions (Greig-Smith 1948). The species grows best on uncompacted soils with a fairly low clay content, and is not normally found above a pH of 7.5 (Fitter and Peat 1994). In addition to this the occurrence of seedlings is associated with sites that have been very wet and exposed to full sunlight (Greig-Smith 1948).

U.dioica was found more often on downland than on the re-created downland and this is probably linked to compaction of the soil, lower phosphate and nitrate and higher clay content in the ex-arable habitat. Within the downland it is to be expected that particular micro-climates - damp and sunny - will determine its distribution, as well as possible links with nitrate and phosphate. The fact that this species accounts for the largest single amount of variation in the data seems to indicate that it has very particular habitat requirements. The un-weighted position of *U.dioica* on the species scores plot is towards the origin on the y-axis and around the middle of the x-axis, indicating a preference for more moist sites and also that it is found in association with species characteristic of young and established habitat such as *Holcus lanatus* and *Festuca rubra*. The pH of both downland and re-created downland habitats was at the top end of the range for *U.dioica* (7.16 and 7.37) and it might also be that the separation of this species from the others reflects those quadrats where the pH was slightly lower.

The correlations were also interesting for the links which were not found to be significant and this includes that of aspect with species richness. Jones (1973) and Smith (1980) identified aspect as one of the factors determining the type of downland community which develops and Perring (1959) relates the distribution of some downland species to topography and aspect. For example:

> Species reaching their maximum cover on slopes between SE and N but found in small quantity on other slopes. Generally absent from flat and gentle slopes, this group includes *Scabiosa columbaria, Polygala calcarea, Asperula cynanchica, Linum catharticum* and *Euphrasia nemorosa*.

> Species which have their main centre of distribution on the flat top or open, shallow slopes between NW and E, including *Festuca rubra, Campanula rotundifolia, Prunella vulgaris* and *Leontodon hispidus*.

The correlation analysis presented in this chapter is not detailed enough to link particular species to downland slopes of a particular aspect, but it is interesting that although species richness was not significantly linked to aspect there was a slight correlation between the two within the downland habitat (see section 4.2). It may also be that the fragments of downland left do not represent an evenly distributed subset of the aspects of chalk downland before the war when most of the recent ploughing was carried out. Those areas which were ploughed represent areas with the best potential for arable use and would probably have included proportionately more south and west facing slopes. If this is the case then the fragments left could bias an analysis of aspect and species richness as there will not be as many of the (theoretically) best south/south-west facing sites left.

It might also have been expected that slope or aspect would correlate with some of the edaphic (soil) factors since these have been shown to effect each other (Jones 1973) but this was not the case and may have been because of the relatively small sample size or because of the time of year when the soil data was collected. A truly representative picture of the soil nutrient status would have required several sampling times throughout the year (see Chapter 5).

The correlation of slope with species richness/habitat (section 4.2) showed that downland was associated with the steepest slopes. This was also found in a survey of the Dorset chalk grassland in the 1970's (Table 4.14), indicating that the influence of agricultural intensification was apparent then and is probably more so now. However, it is difficult to state this with certainty from the sample of 6 study sites.

Table 4.14: The slope of 58 surveyed chalk grassland sites in Dorset (adapted from Jones (1973))

Slope (degrees)	5-14	15-24	25-35
Downland sites in Dorset	3	23	32

This table can be compared with the slope of the downland and re-created downland (ex-arable) sites used in this study (Table 4.15) and shows that the downland sites are of similar slope to many of those in the 1972 survey.

Table 4.15: The mean slope of downland and re-created downland at the sites used in this study.

Habitat	**Mean slope (degrees)**	**Sample size (n)**	**Standard Deviation**
Downland	23.9	6	1.03
Re-created downland	5.1	6	3.16

Slope is probably not the only variable whose range has been narrowed through man's activities on the downland. Ploughing of those sites most suitable for arable farming has removed most of the downland previously found on flatter areas; Salisbury Plain and Porton Down in Wiltshire are reminders of what large parts of the chalk lands would once have looked like. These areas would have had different levels of precipitation and maximum/minimum temperatures, and would probably have contained a subtly different plant community structure than the steeper areas of chalk downland, favouring species tolerant of a slightly different set of conditions. By fragmenting and reducing this habitat the range of these species would also be reduced and instead, species found on the drier, steeper areas will be favoured. It is also likely that those invertebrate species which can migrate from one fragment to another will be favoured; altering the invertebrate species composition found on downland over time. It would be interesting to study the long term consequences of man's influence on this habitat, and perhaps link it with similar studies on fragmentation in the tropical rainforests where similar selection processes would be expected to operate.

A possible source of error arises in the correlation data due to the fact that, for individual habitat correlations, only six pairs of data were available for each environmental factor. This is due to there only being six study sites and could lead to error as Fowler (1994) states that the number of paired observations in a Spearman rank correlation should be between seven and thirty, presumably to provide a large enough sample size for ranks to be used. Also, the species richness used in the correlation was taken from the most selective category used on the quadrat data; that of naturally occurring calcicolous species. If the total species richness of each habitat had been used the correlation results would have been different but it was felt that a more meaningful interpretation could be gained from using the naturally occurring species richness.

4.3.3 The homogeneity of existing chalk downland

Analysis showed that the study sites in Dorset receive more precipitation than those in south Wiltshire. This local variance in the vegetation accounted for by a climatological variable has been noted before (Wells 1975) but is difficult to document. It appears to be distinct from the community scale variance described by Rodwell (1998) which is used to classify (for example) the CG2 (*F. ovina-H. pratensis*) grasslands as distinct from other types of grassland found on the chalk. Local variation was found within the grassland communities studied here which is at too small a scale to be included in NVC classification but which determined the separation of the study sites along the y-axis of the quadrat scores plot. For instance *Carex caryophyllea* and *Stachys sylvatica* are found to occur at higher abundances in the CG2b subcommunity in Wiltshire than in Dorset (B.Edwards, *pers.comm.*).

The soil nutrient data presented in Chapter 5 also shows that there is variation between the sites (both downland and re-created downland habitat) and it has been shown that precipitation (as well as slope and aspect) can influence soil properties (Smith 1980). It would be interesting to use canonical correspondence analysis to link soil nutrient status with the species data and discover which part of the variation it accounts for.

These findings have implications for the interpretation of the rest of the work presented in this thesis, because a basic assumption was that the study sites were similar enough to regard as replicates. However, the data show that the differences between habitat type, including whether the sample is taken from habitat edge or middle, are far greater than the variation within habitat. Consequently, the sites are assumed to be a reasonable set of replicates.

4.4 Summary

The results presented in this chapter have shown that:

- There was significant degradation of habitat quality with respect to indicator plant species on the edge of the established downland. This may partly be due to fragmentation or past fertiliser/herbicide drift (Laurance and Yensen 1991; Kleijn and Snoeijing 1998) and will affect the natural colonisation of adjacent re-created downland (see section 4.2.2.2ii). These results imply that the decision to allow fertiliser applications on re-created downland within the SWD ESA should be reconsidered.

- Habitat enrichment by calcicolous indicator species was shown to occur within the first 10m of re-created downland adjacent to established downland. This habitat contained significantly more naturally occurring indicator species than the middle of the re-created downland. Species found included; *Leontodon hispidus, Succisa pratensis, Hippocrepis commosa, Plantago media, Primula veris* and *Galium verum.*

- Vegetation community type within this data set was distinguished by age and structure. Although organic matter and nitrogen were the most important factors distinguishing between re-created and established downland there were other edaphic and climatic factors such as rainfall, magnesium and slope which were important within the habitats.

- The study sites illustrate local variation in chalk downland botanical community structure and it was found that precipitation levels are a major influence on this. The downland sites also show the effect of agricultural intensification by nature of their being restricted to the steepest slopes when compared to the re-created downland sites.

This chapter has examined differences in vegetation community and structure between the re-created and established downland. Chapter 5 investigates the effect of non-native downland plant species (sown into the re-created downland sward) on the larval development of associated herbivores by examining one indicative plant-herbivore pair; the Common Blue butterfly (*Polyommatus icarus*) and it's main larval food plant Birds Foot Trefoil (*Lotus corniculatus*).

Chapter 5 - Re-created downland habitat quality for insects

5.1 Introduction

This chapter examines two particular aspects of the quality of re-created chalk downland as a habitat for insects; soil nutrient quality is evaluated in the context of it's influence on the associated vegetation; and results are presented on the effect of non-native provenance *Lotus corniculatus* on *Polyommatus icarus*.

5.2 Results

5.2.1 Soil nutrient status

The determination of established and re-created downland and arable soil nutrient parameters showed that soil affected by re-creation management represents an intermediate stage between downland and arable soil. The results of all soil nutrient analyses are presented in Table 5.1.

It was not possible to apply parametric statistics due to the considerable variance among the samples. Instead the median of each group of soils was compared (within each nutrient parameter) using Kruskal-Wallis tests to determine whether there were significant differences between different soils. These tests showed (Table 5.2) that only the soil organic matter (% loss on ignition) and magnesium concentration (mg/kg) differed significantly between the soils from each habitat.

Table 5.1: Summary results of soil analyses from all sites, presented as mean data with standard errors.

	Soil Type		
	Downland	**Reversion**	**Arable**
pH	7.16±0.19	7.37±0.27	7.51±0.28
% Organic Matter	34.23±2.75	17.28±2.74	14.18±1.49
Nitrate (mg/kg)	109.17±29.37	69.3±16.05	105.44±25.52
Nitrogen (N) (mg/kg)	24.65±6.63	15.65±3.62	23.81±5.76
Potassium (mg/kg)	97.69±11.58	176.23±25.43	160.19±35.45
Magnesium (mg/kg)	145.13±9.98	65.13±7.32	43.69±4.47
Phosphate (mg/kg)	Below detectable limits	Below detectable limits	Below detectable limits
Chloride (mg/kg)	59.99±7.46	63.17±17.64	34.86±5.59
Sulphate (mg/kg)	51.24±3.25	40.99±4.09	44.19±3.65

Table 5.2: Results of Kruskal-Wallis tests to determine where nutrient levels are significantly different in the three soils tested.

Nutrient parameter	Nitrogen	NO_3	PH	%OM	SO_4	K	Mg	Cl
K calculated	1.425	1.425	2.898	12.712	4.148	4.594	15.636	3.896
df	2	2	2	2	2	2	2	2
Significance (p)	.490	.490	.235	.002 **	.126	.101	.000 ***	.143

*** = significance of $p<0.001$

** = significance of $p<0.01$

Soil organic matter content and magnesium concentrations were greatest in the downland soil and did not differ significantly between reversion and arable soils. The potassium results were not found to be significantly different but did demonstrate an opposite trend to the magnesium results - the highest concentrations were found in reversion and arable soils and the lowest were found in downland soils (illustrated graphically in Fig 5.1).

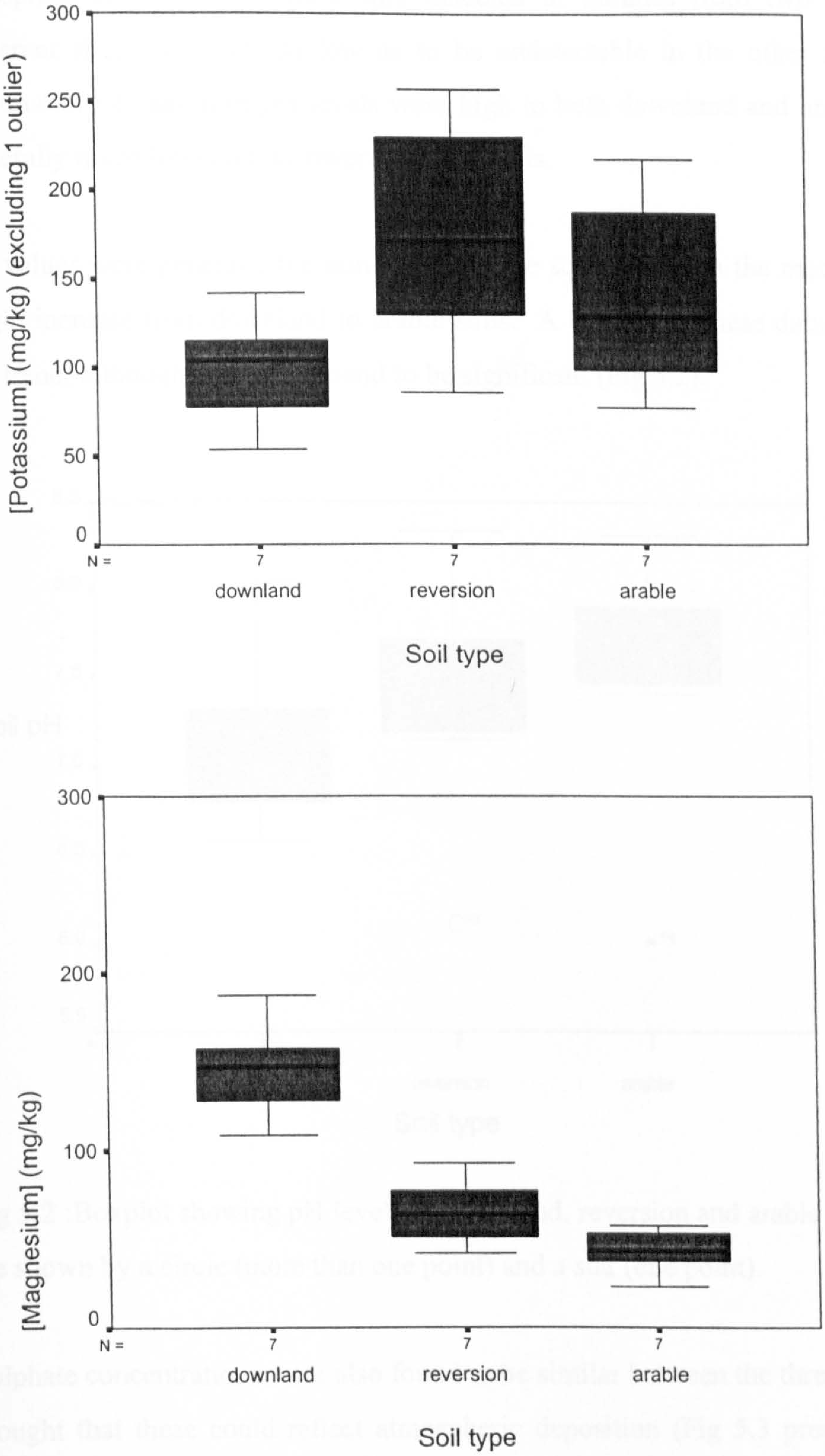


Fig 5.1: Boxplots showing magnesium and potassium concentrations in the different soils. Note the trend reversal between the two sets of results.

Phosphate concentrations were only detected in samples from two soils (at two different sites) and were so low as to be undetectable in the other samples. By contrast nitrate and nitrogen levels were high in both downland and arable soils and generally much lower on the reversion field soils.

pH values were generally the same for all three soils, although the means do show a slight increase from downland to arable soils. A boxplot of these data demonstrates the trend, although it was not found to be significant (Fig 5.2).

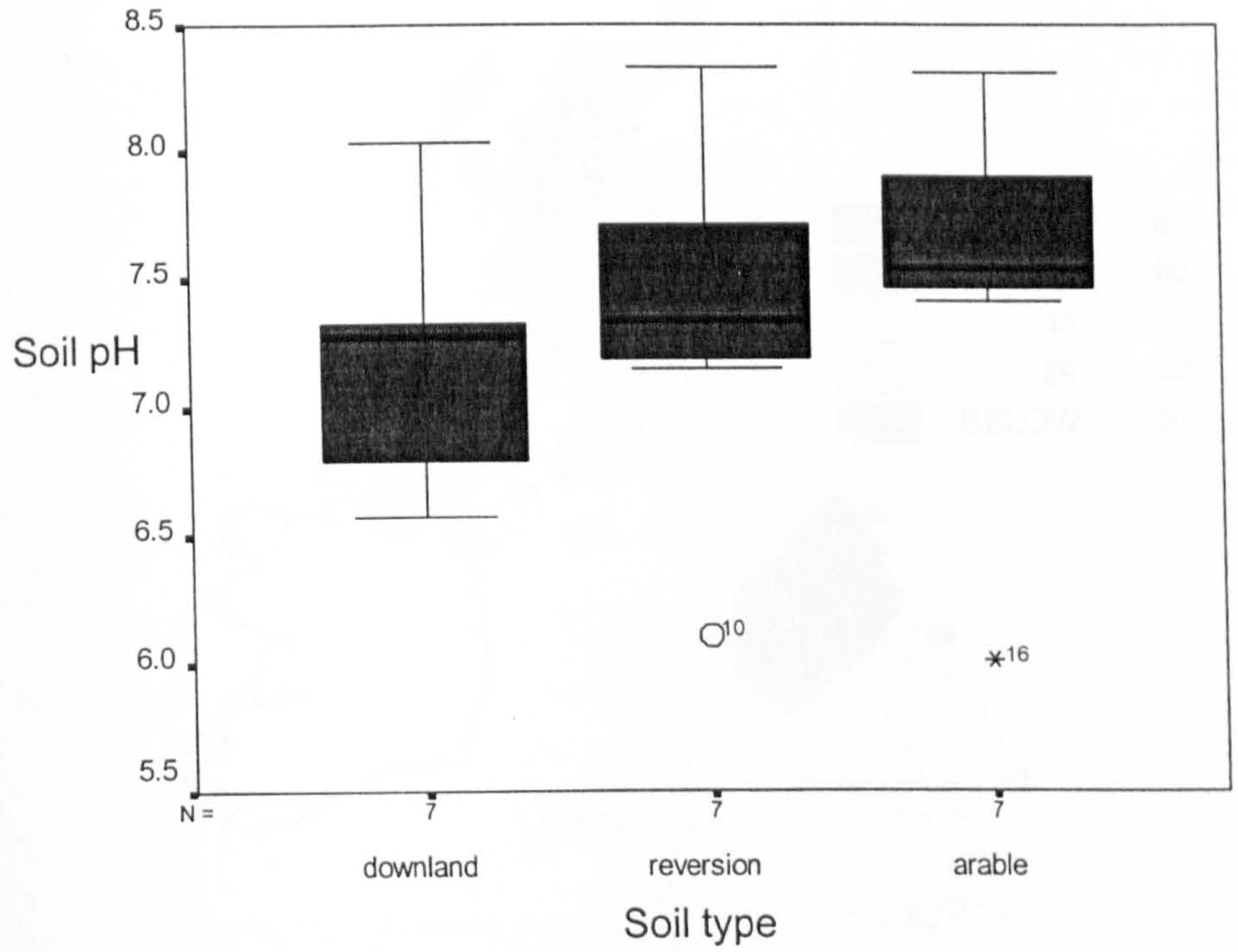


Fig 5.2 :Boxplot showing pH levels of downland, reversion and arable soils. Outliers are shown by a circle (more than one point) and a star (one point).

Sulphate concentrations were also found to be similar between the three soils and it is thought that these could reflect atmospheric deposition (Fig 5.3 presents a map of sulphate deposition).

The soil processes which underly these findings are discussed in section 5.3. This section also links these results with those from sections 5.2.2. and 5.2.3 to examine the potential effect of soil type on one plant species.

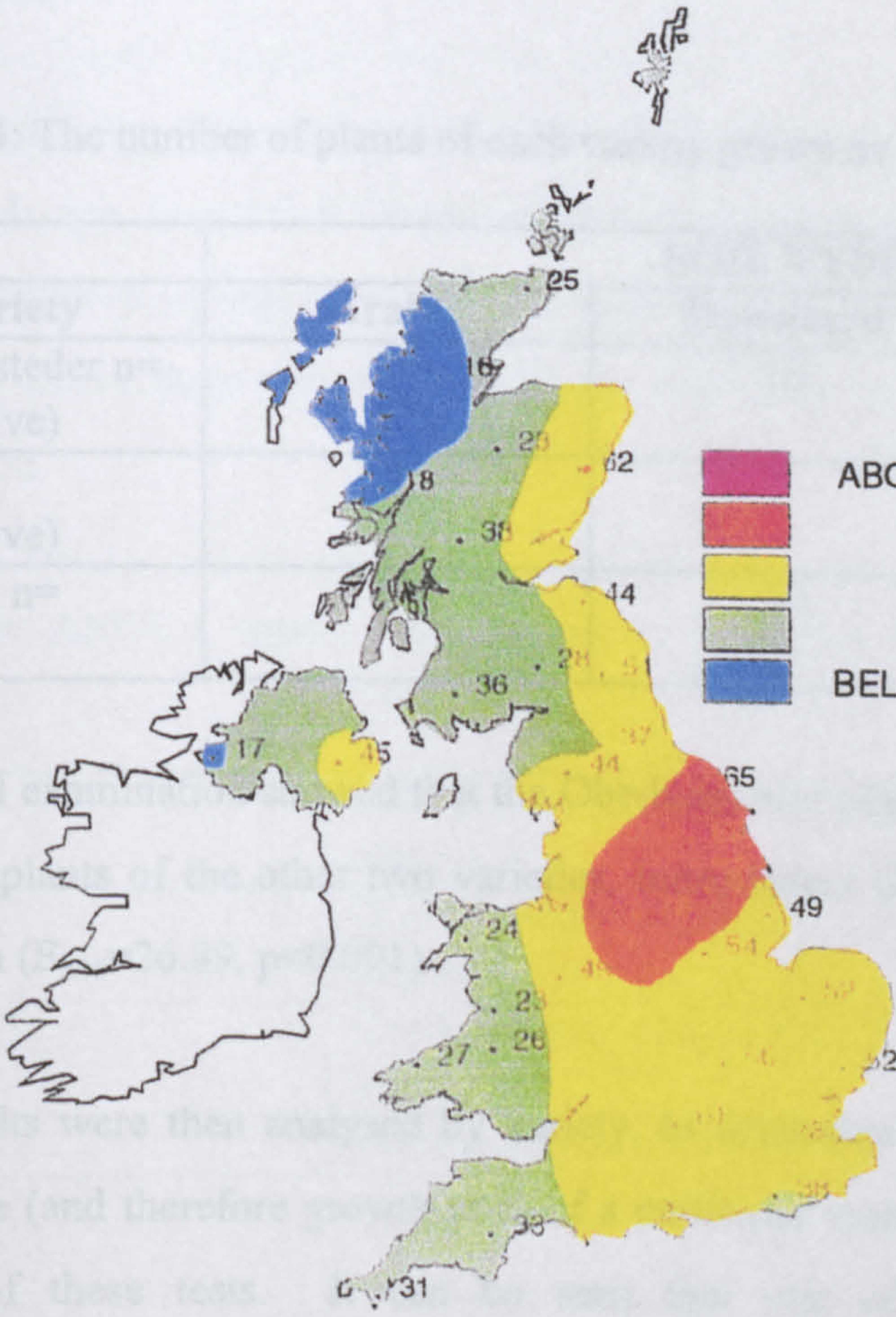


Fig 5.3: Dry sulphate deposition levels in 1996 in the UK. (Precipitation weighted annual mean in milliequivalents per litre). Source: AEA Technology, Report No. 2766/20017201 Issue 1.

5.2.2 The growth form of *Lotus corniculatus* varieties on different soil types.

Due to erratic germination the number of plants of each variety used in this experiment was not equal. Table 5.3 shows the number of plants of each variety grown on each soil; it can be seen that Leo variety *Lotus corniculatus* did not germinate well. This resulted in fewer plants of this variety being used in the experiment.

Table 5.3: The number of plants of each variety grown on each soil.

	SOIL TYPE		
Variety	**Arable**	**Downland**	**Compost**
Oberhausteder n= (non-native)	10	10	10
Leo n= (non-native)	7	7	5
Fontmell n= (native)	10	10	10

An initial examination showed that the Oberhausteder plants were significantly larger than the plants of the other two varieties, independent of which soil they had been grown on ($F_{2,76}$=26.89, p<0.001).

The results were then analysed by variety, to determine whether soil type affected plant size (and therefore growth rate) of a particular variety. Table 5.4 presents the results of these tests. It can be seen that one of the non-native varieties, Oberhausteder, was not affected by the soil in which it grew. The other non-native (Leo) and the native variety (Fontmell) were affected and, by examining the means of these two varieties, (as described in Chapter 3) it was found that they both performed significantly better (produced larger plants) when grown on compost.

Table 5.4: ANOVA results from analysing each variety by soil type.

Variety	Significantly larger when grown on which soil type?	Calculated F statistic and degrees of freedom.
Oberhausteder	None	$F_{2,27} = 1.07$
Leo	Compost *	$F_{2,16} = 4.39$
Fontmell	Compost **	$F_{2,27} = 5.28$

* = p<0.05
** = p<0.01

The results were then analysed for the affect of soil type on the growth of each variety. It was found that Oberhausteder plants were significantly larger than the other non-native variety (Leo) and the native plants (Fontmell) on all soils except compost, where there was no significant difference between the mean plant size (Table 5.5).

Table 5.5: ANOVA results from analysing the affect of soil type on each plant variety.

Soil type	Affects which variety and how?	Calculated F statistic and degrees of freedom.
Arable	Oberhausteder plants are larger ***	$F_{2,24} = 14.22$
Downland	Oberhausteder plants are larger ***	$F_{2,24} = 22.89$
Compost	No significant difference	$F_{2,22} = 2.96$

*** = p<0.001

These results show that the Oberhausteder variety of *L.corniculatus* performs equally well on all soils. They also show that Oberhausteder grows significantly larger than one other non-native variety and native *L.corniculatus* when grown on soils other than compost.

The implications of these results, when considered alongside data on soil nutrient status and the affect of *L.corniculatus* variety on an associated herbivore, are discussed in section 5.3. The limitations of the work are also discussed.

5.2.3 The physiological affect of rearing *Polyommatus icarus* larvae on non-native *Lotus corniculatus* varieties.

Within the South Wessex Downs ESA almost all the *Lotus corniculatus* sown under the reseeding requirements for chalk downland re-creation is non-native. The results presented below (from the second experiment carried out using *Lotus corniculatus* varieties) evaluate whether these 'alien' varieties affect the development and physiology of one of their associated herbivores, *Polyommatus icarus*.

5.2.3.1 The effect of different Lotus corniculatus varieties on Polyommatus icarus

The effects of the three different varieties (Maitland, Leo and Lewisham) of *Lotus corniculatus* on *Polyommatus icarus* were evaluated by using Analysis of Variance (ANOVA) to look for differences in mean larval development time, weight gain, amount of food eaten, pupal development and imagal weight between the groups of larvae reared on each variety. Results are summarised in Table 5.6.

The experiment showed that larvae fed on Maitland (non-native) variety were consistently different to those fed on the native *L.corniculatus* and the Leo variety. Larvae in the Maitland group showed a significantly higher mean weight gain and mean development time than those in the other two groups. In addition, larvae in the Maitland group ate significantly more than the larvae reared on Leo or Lewisham variety *L.corniculatus*. An explanation of how the amount ingested by each larva was calculated is given in section 5.2.3.2.

Table 5.6: Summary results of the ANOVA performed to determine significant differences between the means of the parameters listed below. (NS = not significant).

	Significantly greater for larvae fed on which variety?	**size of sample (n)**	**Calculated F statistic**	**Degrees of Freedom**
Larval development (days)	Maitland $p<0.1$	33	2.51	2,30
Larval weight gain (g)	Maitland $p<0.01$	33	4.87	2,30
Amount ingested (g)	Maitland $p<0.01$	29	5.22	2,26
Time of pupal development (g)	NS			
Imagal weight (g)	Maitland $p<0.04$	30	3.55	2,27

To eliminate possible error resulting from a difference in the initial weights of larvae in the three groups, an ANOVA was carried out on the weights of the larvae at the start of the experiment. This showed that there was no significant difference in the mean weights of larvae in the three different groups ($F_{2,30}$=1.364, $p<0.27$) and implies that any subsequent difference is due to external factors. The differences in development time cannot be attributed to the larvae being at different stages of development at the start of the experiment as they were all collected from the same egg batch and emerged at the same time.

The larvae fed on Maitland variety *L.corniculatus* produced imagos of significantly heavier mean weight which, after mating with males from within the same group, produced a smaller mean number of second generation larvae as is shown in Table 5.7. The homogeneity of the data was evaluated by using a Chi-squared test and it was found that the number of second generation larvae produced by females fed on Maitland *L.corniculatus* was significantly fewer (χ^2_2 = 9.87, $p<0.01$).

Table 5.7: Mean larval second generation produced by female *P.icarus* reared on different varieties of *L.corniculatus*.

***L.corniculatus* variety**	**Leo**	**Maitland**	**Lewisham**
Mean number of larvae produced per female	18	3.25	13.33
Number of females producing second generation	2	4	3

Because of the methodology used to gather these data, it was impossible to comment on the size of individual egg batches or on the survivorship from them. However, the hatching rate from each flight cage was observed to be fairly consistent - almost all ova were viable and it is known that all available females were mated.

In contrast to the group of larvae reared on Maitland variety *L.corniculatus*, the group reared on the native Lewisham variety were shown to develop in the fastest time and to gain least weight prior to pupation (Fig 5.4). This can be seen from the results of the above quoted ANOVA tests, where further analysis (using a Tukey Test) showed the highest significant difference to be between larvae reared on Maitland and Lewisham varieties (Development time data: Test statistic=0.755, $q_{3,30}$=3.02 Weight gain data: Test statistic=0.012, $q_{3,30}$=3.49).

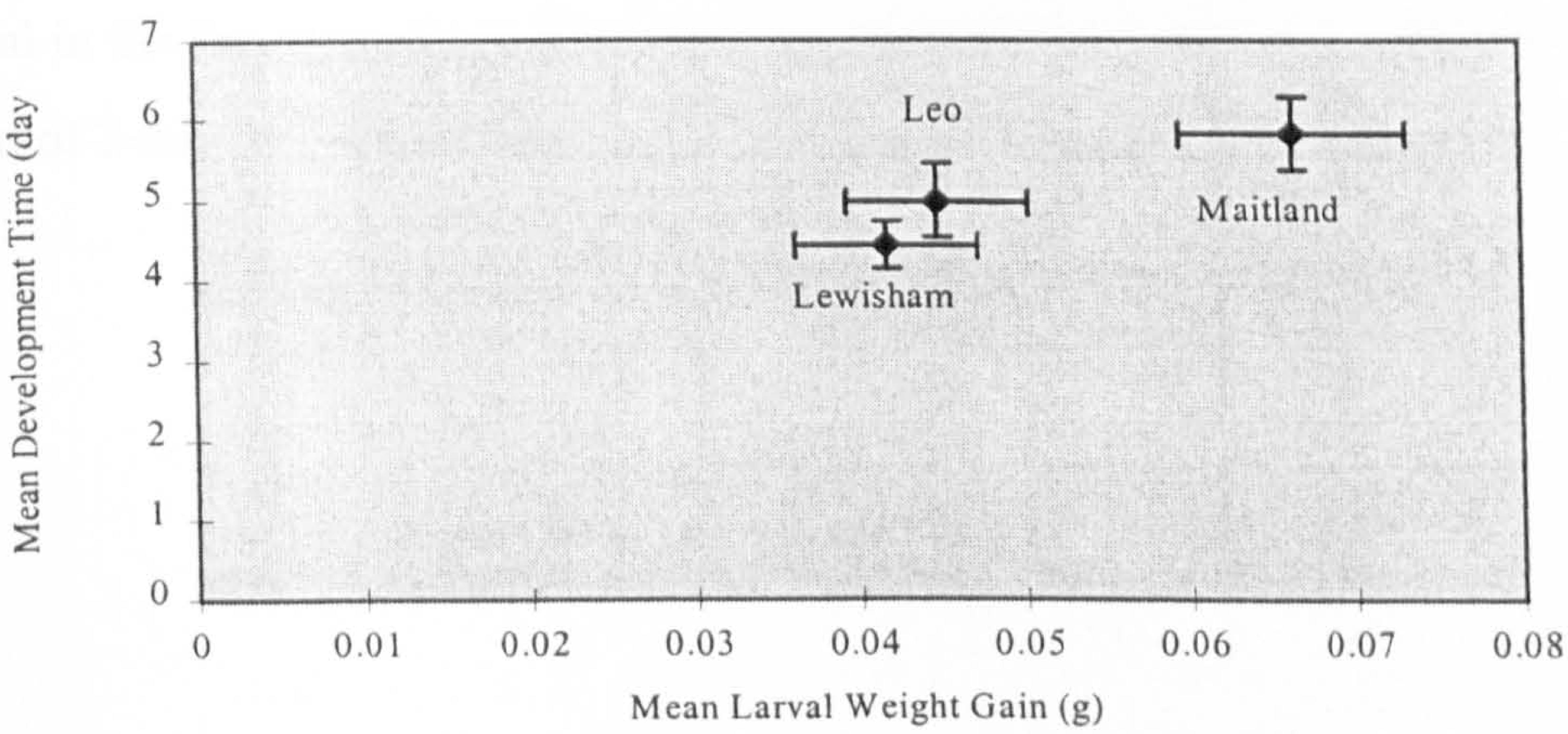


Fig 5.4: The mean development time and weight gain of larvae reared on three different varieties of *L.corniculatus*.

5.2.3.2 An evaluation of the possible causes of these effects.

There are several possible reasons for the effects observed from rearing *P.icarus* larvae on three different varieties of *L.corniculatus*. These include the nutritional quality of the food, the condition of the food (whether it is wilted or heat stressed) which affects the nutritional quality (Clark 1982; McDaniel 1982; White 1984) and physiological effects induced by differing chemical composition of the three varieties (such as variation in level of cyanogenic compounds (Jones et al. 1978; Scriber 1978)). Further analysis of the data is presented below and possible causes are evaluated.

The amount of plant material eaten by each larva was calculated by using the control trays of air dry material which were replaced at the same time as the plant material in the larval food trays. The wet/dry weights of each batch of control plant material were plotted as a regression, as shown in Figure 5.5. The regression coefficient for the plant material in each control batch was then used to calculate the expected dry weight of each set of plant material in the larval food trays (a set of food plant material represented the material fed to all larvae in each two day period). This was done by multiplying the fresh weight of each sample of plant material by the coefficient from the relevant control group. The observed weight of the plant material in the larval food trays was subtracted from this expected weight to give the amount of 2-day dry weight plant material eaten by each larva in each set.

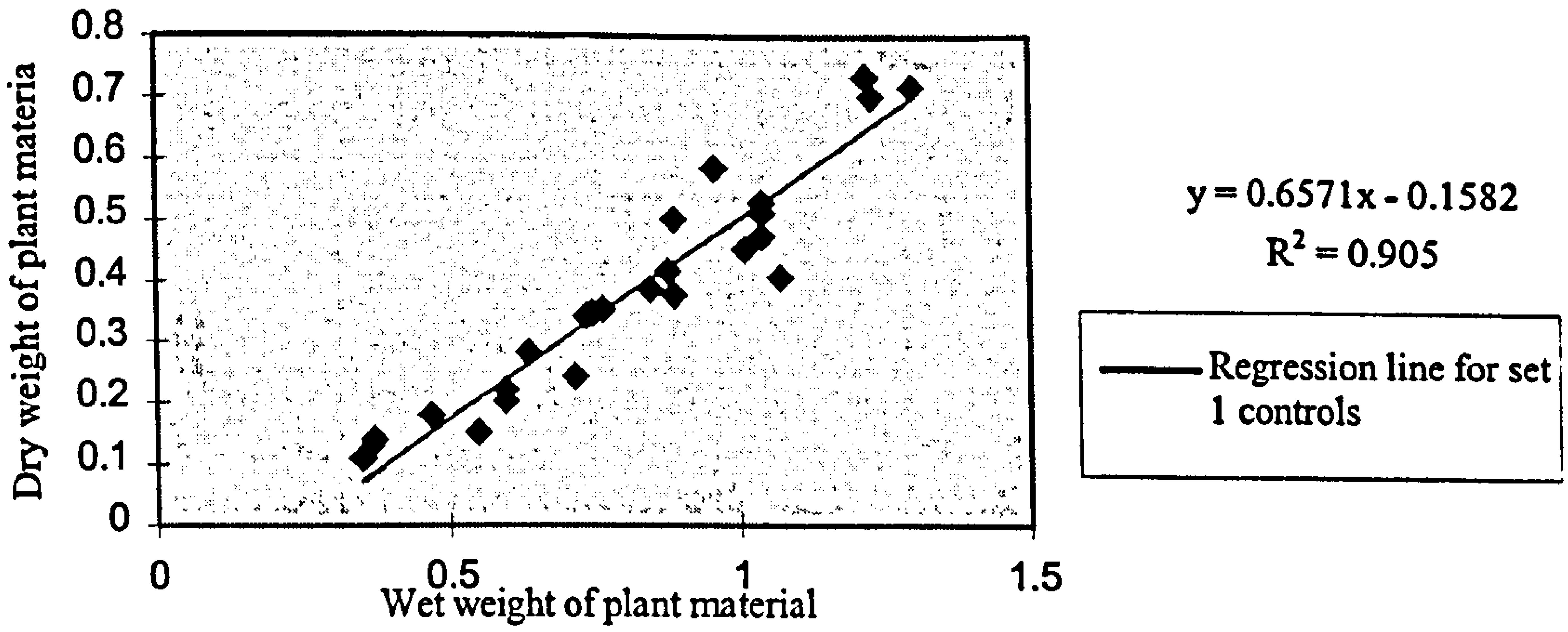


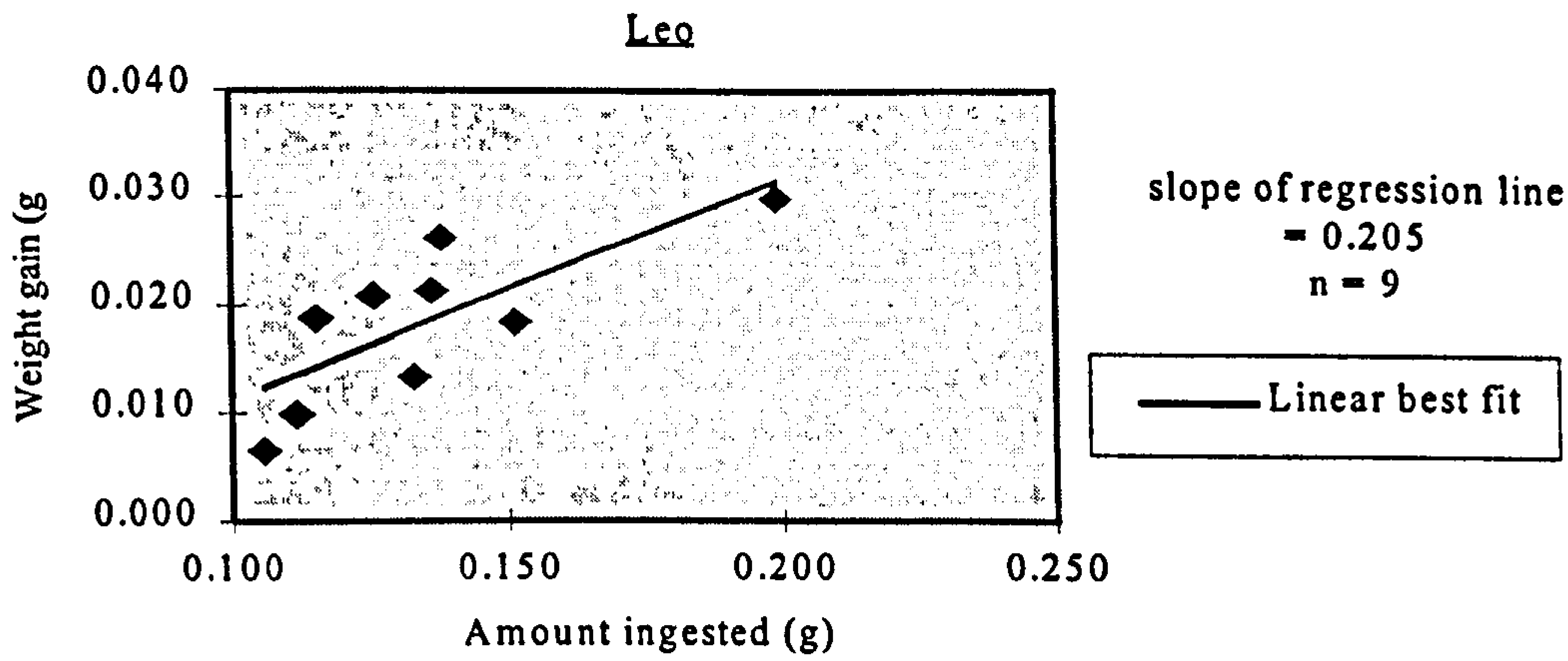
Fig 5.5: Regression line from control plant material in set 1, used to obtain the coefficient to calculate the amount ingested by larvae in set 1.

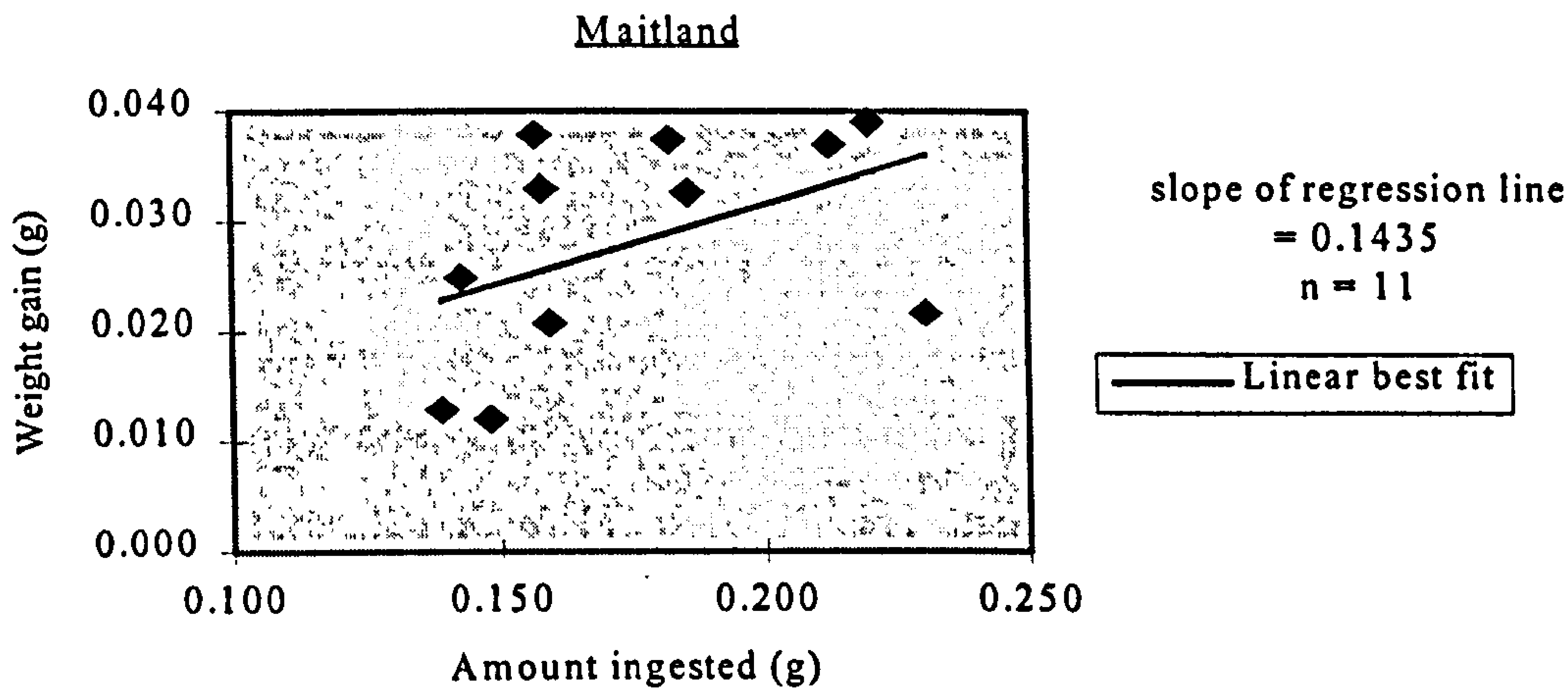
The fit of the data to the regression line (given by the R-squared value) in each set of control material varied from 90.5% (set 1) to 57.2% (set 4). This variation could be accounted for by differing amounts of moisture loss between the three varieties within each set of plant material. When the mean moisture loss of each variety of plant material was compared within sets (using ANOVA) it was found that for the first two sets of control plant material there was a significant difference in the mean water loss between plant varieties, but for the second two sets of control plant material there was no significant difference (results are presented in Table 5.8). Because of these inconsistent results it was decided to only calculate one regression coefficient for each set of plant material (comprising all three varieties of *L.corniculatus*), instead of one coefficient for the plant material of each variety within a set and to accept the error inherent in this method.

Table 5.8: Results of ANOVA to determine whether moisture loss between different *L.corniculatus* varieties was significantly different in the four sets of plant material. (n = number of samples, d.f. = degrees of freedom).

	Significant difference in moisture loss between varieties:	**Calculated F statistic**	**n**	**d.f**
Set 1 control plant material	Lewisham variety lost significantly more moisture ($p<0.001$)	9.04	24	2,21
Set 2 control plant material	Leo variety lost significantly less moisture ($p<0.001$)	15.94	24	2,21
Set 3 control plant material	Not significant			
Set 4 control plant material	Not significant			

The relationship between ingested plant material and larval growth was examined by plotting the total amount of plant material ingested by each larva against the total larval weight gain within each variety group. Fig 5.6 shows that the slope of each relationship is different, implying that some factor apart from the amount ingested affects larval weight gain. This is probably not due to a difference in the mean initial weight of larvae in the three groups because they were shown to be drawn from populations with similar means (see section 5.2.3.1).





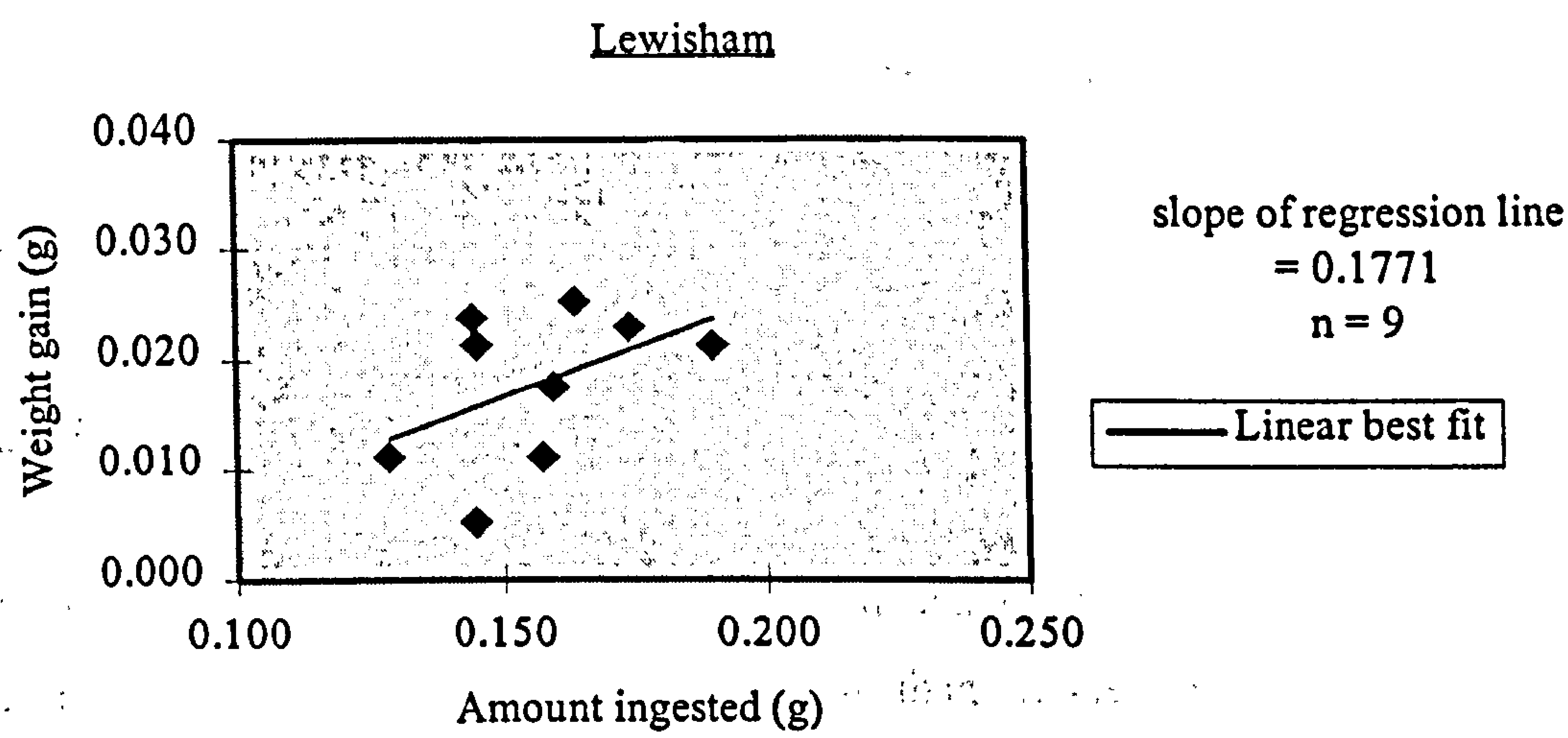


Fig 5.6: Amount ingested plotted against weight gain of larvae fed on Leo, Maitland and Lewisham varieties. Note the variation in slope.

The experimental results were examined in more detail by calculating a nutritional index: Relative Consumption Rate - wet food basis (RCR). Results are presented in Table 5.9. It should be remembered that they only represent the first two day period when the larvae were fed with the different varieties of *L.corniculatus*.

Table 5.9: Calculated Relative Consumption Rate of larvae fed on the three varieties of *L.corniculatus*, presented as averages per group of larvae with standard error and variance.

***L.corniculatus* variety / Nutritional index**	**Leo**	**Maitland**	**Lewisham**
RCR (g/g day)	3.96±0.62	7.12±1.30	4.32±1.04
RCR variance	4.94	22.14	9.77
Number of samples (n)	12	12	9

Even over such a short sample period (2 days), the *L.corniculatus* variety ingested was found to affect the relative consumption rate; larvae fed on Maitland showed a significantly higher rate of consumption than those larvae fed on Leo or Lewisham (Kruskal-Wallis results: $K_2=6.44$, $p<0.05$), and also appeared to feed at the most variable rate. Waldbauer (1968) states that when consumption rate is calculated from the dry weight values it is a measure of the rate at which nutrients are entering the insects' digestive system. The calculations presented here are based on the wet weight values and are a measure of the insects' behavioural response to the food. On this basis it appears that Maitland variety *L.corniculatus* increases the relative consumption rate of *P.icarus* larvae.

<u>*5.2.3.3 The second generation*</u>

As mentioned in section 5.2.3.1, it was found that larvae which ingested Maitland produced significantly larger/heavier imagos than larvae which ingested Leo or Lewisham varieties. When the total weight gained by each larva in all groups was plotted against resulting imagal weight, the Maitland imagos are not disproportionately larger but they appear to be responding to a direct relationship between larval wt gain and imagal weight (Fig 5.7).

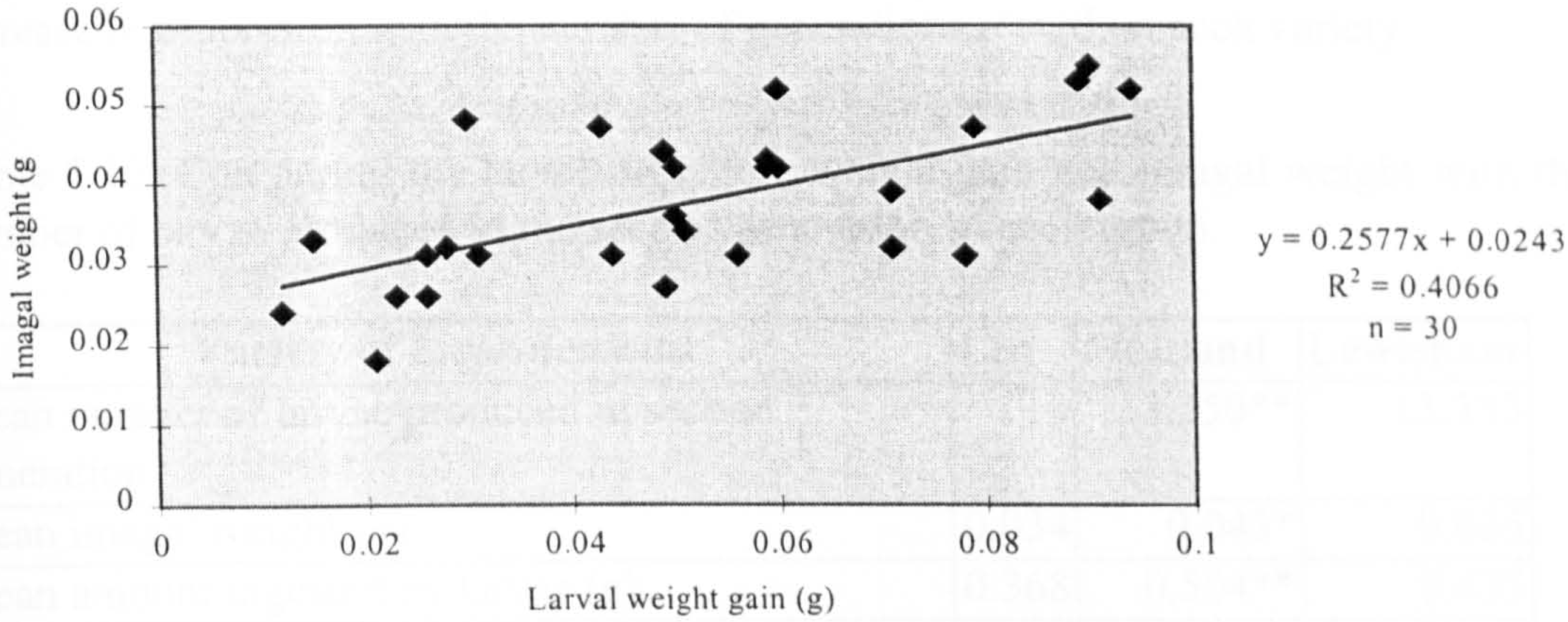


Fig 5.7: The relationship between larval weight gain and resulting imagal weight for all larvae.

Research has shown that the number of eggs produced by a female butterfly is closely linked to the food reserve accumulated in the larval stages, and therefore that the largest/heaviest females tend to produce most eggs (Porter 1992). This is especially significant for those butterflies which develop some or all of their eggs whilst in the pupa and it is thought that *P.icarus* falls into this category. However, this is not the case for the adults which were reared on Maitland. Although these adults were significantly the heaviest of the three groups (Table 5.1) the average number of larvae produced per female was significantly lower than those produced from adults which had been reared on Leo or Lewisham. Table 5.10 presents the mean larval weight gain, mean adult weight and mean no. of second generation larvae produced per group of larvae and shows clearly that, although larvae fed Maitland *L.corniculatus* ingested more, gained more weight and produced heavier adults, the second generation of larvae produced was significantly smaller.

The results also demonstrate that larvae which ingested Leo variety and native (Lewisham) *L.corniculatus* did not differ significantly in their weight gain, amount ingested, imagal weight and number of second generation larvae produced. It appears that, of the two non-native varieties investigated in this study, only one significantly affected it's associated herbivore. However, the experimental results represent the effects from rearing only one generation and it is not known whether these would increase in proportion with the number of generations reared on each variety.

Table 5.10: Comparing the larval ingestion, weight gain and imagal weight with the number of larvae produced in the second generation of each group.

Variety of *L.corniculatus*	Leo	Maitland	Lewisham
Mean number of larvae produced in second generation	18	3.250**	13.333
Mean imagal weight (g)	0.034	0.043*	0.035
Mean amount ingested by larvae (g)	0.368	0.504**	0.435
Mean larval weight gain (g)	0.045	0.066**	0.042

** = significance level $p<0.01$

* = significance level $p<0.05$

5.2.3.4 Summary

It was found that *P.icarus* larvae reared on one non-native *L.corniculatus* variety (Maitland) developed differently to larvae reared on a second non-native *L.corniculatus* variety (Leo) and on native *L.corniculatus* (Lewisham). Larvae fed on Maitland variety *L.corniculatus* gained more weight, ingested a larger quantity of food, took longer to develop and produced larger imagos (all of these differences were significant). The average number of second generation larvae produced from imagos reared on Maitland was significantly lower than the number produced from imagos reared on the other two varieties of *L.corniculatus*.

When these results were analysed further it was found that the Relative Consumption Rate of larvae which ingested Maitland *L.corniculatus* was significantly higher than that of larvae fed the other two varieties of *L.corniculatus*.

5.3 Discussion

5.3.1 Soil nutrient status

The executive summary of a report to MAFF on "Nutrient cycling on arable reversion grasslands in the South Downs ESA" (ADAS 1997), states:

> Concerns had been widely expressed by farmers and the MAFF Project Officer, that a number of arable reversion and semi-improved grassland swards in the South Downs Environmentally Sensitive Area, had deteriorated markedly and were now lacking in density, with moss and bare ground increasing. Even the low stocking rates prescribed in the guidelines could not be supported by grass growth.

Similar comments have been made by land owners within the SWD ESA and the results presented in this thesis appear to validate them. Although soil stripping is often advocated as a first step in the reversion process (as a way of reducing soil nutrient status) it appears that ex-arable soils do not suffer from the problem of high nutrient status which is encountered in other situations. It is tempting to view the nutrient status of arable reversion fields as an intermediate stage between arable and established downland soil but this is not the case. The results presented in this chapter have shown that ex-arable soils can be of lower nutrient status than downland soil initially and the processes which lead to these results are explored below.

Section 5.2.1 shows that generally reversion field soil has a lower nutrient status than both downland and arable soil. This is also shown by data from the ADAS project quoted above which found that mineralisable N (a measure of the available nitrogen) was highest in established downland soil, and that nitrogen in the form of nitrate (as applied in agricultural fertilisers) was highest in the arable soils (see Table 5.11).

Soil mineralisable nitrogen is a limiting factor for plant growth (Brady 1990) and therefore one of the most important considerations when looking at soil nutrient status. The low concentrations of nitrogen and nitrate found in SWD ESA reversion soil are due to the process of immobilisation, which occurs when nutrients in the inorganic form are converted to organic form (Brady 1990). This in turn is linked to the amount of soil organic matter (expressed through the C:N ratio). When soil organic matter (SOM) is low (a low C:N ratio) immobilisation increases as denitrifying bacteria convert nitrogen to an organic form. At high amounts of SOM this process gives way to mineralisation, where nutrients are converted to an inorganic state via processes such as nitrification (the production of nitrate by nitrifying soil bacteria). It can be seen from the % organic matter figures in section 5.2.1 that reversion and arable soils have far less SOM than downland soil, which is classified as having an organic texture (ADAS 1998), leading to expected mineralisation in downland soil and immobilisation in the arable and reversion soils.

Table 5.11: Mean mineralisable nitrogen and nitrate levels within the South Downs ESA (ADAS project BD0327).

Soil type	Mineralisable N (kg/ha)	NO_3N (kg/ha)	Number of samples
Downland	415	36	13
Reversion	250	36	4
Arable	295	42	13

The arable soil nitrate/nitrogen concentrations were similar to those in the downland soils, despite the decreased soil organic matter concentrations which should reduce the amount of nitrification occurring. This apparent conflict of theory and experimental result is explained by the high rates of fertiliser applications to arable soils which artificially raise the soil nutrient status. Fertiliser is no longer applied to reversion soil and as a result the true soil processes are revealed, showing the influence of very low organic matter content leading to immobilisation and decreased levels of soil nitrogen.

It was expected that pH would be higher on arable and reversion soils due to the high quantity of basic chalk found in the plough horizon and due to the acidifying effect of the humic layer found in downland soil. This was found in the soil analysis at Parsonage Down NNR in Wiltshire where the pH of recently cultivated fields is higher than on established downland (see Table 5.12). pH levels measured in this experiment fell within the range identified by ADAS as typical for the SWD ESA (pH 6.5-8.2 (ADAS 1998)) and downland pH was slightly lower than reversion/arable pH. The difference between soils could be effected by soil nitrogen concentrations as it is known that high nitrogen concentration can decrease soil pH (Brady 1990).

Table 5.12: Soil pH levels at Parsonage Down NNR, Wiltshire (ADAS 1991).

Field usage	pH levels
Arable	7.8
Established downland	6.9

Phosphate concentrations were too low to be detected in the DIONEX analysis used in this experiment, but would be expected to show the same trend as above - artificially high in the arable soil, and normal concentrations in the downland soil, but extremely low levels in the reversion soil due to the cessation of fertiliser applications and the low organic matter causing immobilisation of the nutrient.

The third nutrient normally applied in agricultural fertiliser, potassium, was found in high concentrations in both arable and reversion soil. This is probably due to previous fertiliser applications leading to high residual potassium in the reversion soil. Downland soils are naturally deficient in potassium. This is because the high concentration of calcium anions (brought about by the soil parent material) in the soil occupy most of the exchange sites so the amount of exchangeable or available potassium (measured in this analysis) is reduced.

In contrast to potassium levels, magnesium was found at a far higher concentration in downland soil than in reversion or arable soil. Magnesium is not added as a fertiliser which often results in magnesium deficient arable soils. The slight rise in Mg concentration from arable to reversion soil (although not found to be significant) could reflect an increasing amount of soil organic matter which would effect the release of magnesium via mineralisation. Downland soil magnesium concentrations reflect background levels of this element.

By comparing the concentrations of potassium and magnesium detected in this experiment to levels used by MAFF in their "agricultural index" it is possible to evaluate the relative nutrient status of the different habitats. It was found that magnesium is at a satisfactory concentration (101-175 mg/l - index 3) in the downland soil and moderate to satisfactory (26-100mg/l - index 1-2) in reversion and arable soils. Potassium was found at moderate concentrations in the downland soil (61-120 mg/l - index 1) and at satisfactory concentrations in the arable and reversion soil (121-240mg/l - index 2). These concentrations can be compared with the findings of a MAFF survey of all ESA grasslands which included samples from the SWD ESA (ADAS project BD0321) (see Table 5.13).

Table 5.13: Potassium and magnesium index in downland soils from the SWD ESA, (ADAS 1998)

Habitat/Area	**Potassium index and concentration**	**Magnesium index and concentration**
SWD ESA chalk downland	2 (121-240 mg/l)	3 (101-175 mg/l)

Concentrations of sulphate and chlorine (normally found as the chloride ion) were not found to be significantly different in the soils from each habitat. Sulphate is mainly added to the soil via acid deposition (both dry and in rainwater) and levels will therefore be linked to the amount of deposition which occurs in this region (see Fig 5.3). Chlorine, an essential micronutrient in phososynthesis, is found in small amounts in the soil and is often added incidentally to arable soils along with fertiliser dressings. The normal range of this nutrient is from 7 - 50mg/kg (Brady 1990) but in alkaline soils chlorine is found in higher concentrations due to its association with calcium. The most significant influence on its concentration is the amount which is added via rainwater, so it is to be expected that this nutrient would be found in relative similar concentrations across all soils.

It can be seen from the trends in this data that reversion soils have a lower nutrient status than both arable and downland soils and that this is linked to the amount of organic matter in the soil. The soil nutrient status of arable fields is shown to be artificially high due to the application of agricultural fertilisers, and also to be independant of the amount of organic matter. Once fertiliser applications stop, and the field is taken out of arable use and entered into the SWD ESA downland re-creation tier, nutrient status drops and will probably take many years to alter (Wells 1990). It should be remembered that the fields sampled in this study had been under downland re-creation management for 1-3 years at the time of sampling.

It is known that reduced fertility is desirable in the establishment of species rich grassland (Hutchings and Booth 1996). This is partly because low nutrient status encourages those species adapted to these conditions, including calcicolous grassland species, and partly because it discourages the more competitive weed species. However, the establishment of these species does not just depend on soil nutrient status, but also on the presence of associated bacteria and mycorrhiza, as well as an appropriate soil structure (Rizand et al. 1989; van der Heijden et al. 1998). It has been shown that these factors can take years to re-establish themselves (Wells et al. 1994). An additional problem, unique to recreated grasslands within the ESA programme, is that the swards are expected to be productive enough to support moderate stocking rates without the aid of fertiliser applications or high rates of leguminous species sown into the sward. This conflict of interest is something which will have to be resolved if chalk grassland re-creation (both as an ecological tool and a scheme management option) within the SWD ESA is to succeed.

There are limitations which should be applied to the interpretation of this data. Nitrate analysis was not carried out immediately after the collection of samples, meaning that further nitrification would have occurred and changed the concentration of this nutrient. The change in temperature and moisture of the soil after being removed from field conditions would also have slightly altered the concentration of these nutrients before they were measured (Rowell 1994). Calculation of available (mineralisable) nitrogen was carried out from the nitrate data, although total mineralisable nitrogen should also include nitrogen held as ammonium ions and this might have resulted in lower calculated nitrogen levels than were actually present in the soil. However, it is known that the concentration of ammonium in calcareous soils is very low (Rowell 1994) and for this reason the assay for ammonium was ommitted.

Soil organic matter content was calculated from loss on ignition data. This process actually measures the fraction lost from the soil when it is heated to 450^{0}C, which can include significant amounts of water held in the soil matrix if the soil has a high clay content (Rowell 1994). This could have affected SOM figures for some samples if they were taken from fields on the clay-with-flint substrate often found over chalk but variance within the %OM data was consistent, indicating that this was not a major problem.

Finally, to eliminate bias from the time of year in which sampling was carried out, a repeat of the sampling should have been performed in the autumn. This would give information in the arable field nutrient status after cropping, as well as in the spring when fertiliser is being applied and would also allow comment on the variation in nutrient status and pH with seasonal temperature. Due to time constraints the repeat sampling was not feasible in this study.

5.3.2 The growth form of *Lotus corniculatus* varieties on different soil types

The results from this first experiment using different varieties of Birds Foot Trefoil showed that one non-native variety (Oberhausteder) grew equally vigorously independant of the soil it was using. In addition, the results showed that native (Fontmell) *L.corniculatus* was affected by the soil in which it grew; impoverished downland and arable soils produced smaller plants when compared to the plants which were grown on compost. This is supported by work showing that certain non-native varieties of *L.corniculatus* have a higher survival rate than native *L.corniculatus* when transplanted onto road verges (Jones 1990).

These results are relevant to habitat re-creation of many kinds, where non-native varieties are sown instead of the native species. They imply that some non-native varieties are able to grow faster than their native counterparts and are also better at utilising impoverished soils. These findings were repeated in work at the University of York (Bullard and Crawford 1995) where it was also found that yields from UK native and Norway native *L.corniculatus* were very low in comparison to yields from agricultural cultivars (non-native varieties). Experiments using native and Hungarian *Crataegus monogyna* have also found similar differences in growth rate (Jones and Evans 1994). Where habitat re-creation is implemented adjacent to existing habitat (such as chalk grassland) it must also be considered that some non-native varieties are likely to successfully compete with the native varieties and affect the structure of the sward. One of the aims of habitat re-creation is to provide buffer zones around existing habitat to help prevent further erosion of the existing habitat. If the re-created sward in these zones has the potential to damage existing habitats then it is not only failing to achieve one of the aims behind its creation but is actually working against that aim.

It has already been shown that hybridisation occurs between non-native and native *L.corniculatus* and also that (as appears to be the case in this experiment) non-native

L.corniculatus can have a higher post-seedling growth rate than native *L.corniculatus* (Jones 1990). These findings emphasize the importance of sourcing seed for habitat re-creation from at least a native, if not a local site. The experiment also highlighted the variation which occurs between non-native varieties of *L.corniculatus*, and it would be interesting to discover whether the same scale of variety occurs within native ecotypes of the species. An experiment examining the differences between native and 'alien' *Plantago lanceolata* found that, although the native species exhibits a high degree of phenotypic plasticity, alien varieties were consistently different to native populations and showed a 40-95% reduction in seed yield when compared with the native species (Van Tienderen and Van der Toorn 1991). This appears to support the proposal that variation between non-native and native varieties cannot be accounted for by the natural variation within native populations of a species. However, further work needs to be carried out to substantiate this as new evidence has emerged showing that significant variation between native and non-native varieties is not a common theme for all species (Jones and Hayes 1998).

It is recognised that there are sources of potential error in this experiment. During the four months in which the plants were grown it was observed that at least some of them became potbound and this source of stress would have affected their growth (Clark 1982). However, this mainly occurred within the Oberhausteder group where plants were found to be significantly larger than in the other two groups. In addition, plant size was not measured before potting the different varieties into the different soil, meaning that it was not possible to know whether the plants were significantly different in size at the start of the experiment. However, significant differences were found in plant size which related to substrate as well as variety, so it is likely that the affects of variety and soil type detected were true, and not biased by start size of the plants. Compost has a different texture to arable and downland soil, which might have affected establishment and nutrient uptake, leading to differences in plant size. To eliminate this source of error, the two field soils were sieved to achieve an even texture as well as removing all stones.

Finally, it was assumed in this experiment that the size (growth rate) of the plant was a good indicator of survivorship in the wild environment. This assumption has limitations in that large plants might be more visible to grazing herbivores, leading to a higher mortality in the population of non-natives. The plants might also be growing at a faster rate as a response to lack of nutrients, which may mean that survivorship is affected in the long term, whereas the native plants are better adapted to these conditions and have a higher survivorship over time.

5.3.3 The effect of *Lotus corniculatus* variety on an associated herbivore

It has been demonstrated that the nutritional quality of a foodplant can influence the physiology of its associated herbivores (Fraenkel 1951; Scriber and Slansky 1981; Lincoln 1985) and research has often focused on plant nitrogen content as a limiting factor in larval development (Mattson 1980; Thomas and Hodkinson 1991; Joern and Behmer 1997).

In recent years research has shown that the provenance of a foodplant can also affect herbivore development. Leather (1997) showed that *Pinus contorta* of five different provenances ingested by *Panolis flammea* (Pine Beauty moth) larvae resulted in varying development and weight gain. Murray (1997), in an experiment where *Colias croceus* (Clouded Yellow butterfly) larvae were reared on native and agricultural (non-native) varieties of *L.corniculatus*, found that larvae assimilated carbon at different rates.

The work presented in Section 5.2 confirmed that non-native *L.corniculatus* affects the development of an associated herbivore, *P.icarus*. Although the nutrient status of the three varieties of *L.corniculatus* used in the experiment was not evaluated, data from the Institute of Terrestrial Ecology at Merlewood (A.Dickinson, *pers.comm*), which examined the macro- and micro-nutrient concentrations of *L.corniculatus* plants from different locations around Britain showed that there was relatively small variation in the content of elements such as nitrogen which are known to be limiting factors for larval development (White 1984). This is corroborated by the work mentioned in section 5.3.2 above. It was therefore assumed that if there was a significant variation in the nutrient status of the three varieties of *L.corniculatus* it was probable that the native *L.corniculatus* was significantly different from the non-native varieties.

This conclusion was verified by the calculation of a nutritional index which also showed that there was a significant difference in the amount of plant material assimilated. Similar findings were reported in a study rearing *P.icarus* larvae on four plant species and an artificial diet (Burghardt and Fiedler 1996); larvae reared on the artificial diet and on unnatural low-quality food plants (*Medicago sativa* and *Coronilla varia*) developed more slowly and pupated at a lower weight.

These findings have implications for the development of other invertebrate herbivores (such as the Hemiptera and the Coleoptera) which utilise the plant species regularly used in habitat re-creation. The results must also be considered in the context of the amount of seed being sown under habitat re-creation; around 18,120 kg has been sown under the downland re-creation Tier within the SWD ESA alone (R.Belding, *pers.comm.*). At Lower Pertwood Farm, one of the sites used in this study, a re-creation field adjacent to established downland was sown with a seed mix which included a high proportion of agricultural *L.corniculatus*. It was observed during the course of the summer that more *P.icarus* imagos were seen on the re-creation field than on the existing downland. If these sightings were proportional to the amount of egg laying (Chapter 6 discusses this assumption) then it is likely that a significant proportion of the *P.icarus* colony reproduced using non-native *L.corniculatus*. The results presented in this experiment demonstrate that the consequences of this can include prolonged development time (perhaps leading to increased predation or higher mortality in years where the weather is a limiting factor) and smaller second generation size.

Possible limitations on these results include the fact that the nutritional index was only calculated from the first two day feeding period (although it is likely that the affects observed would be magnified, not reduced, as development continued). Also, larvae were reared under lab conditions to eliminate unwanted sources of variation from the experiment. These conditions could have introduced error into the experiment; plant material was picked before being fed to the larvae, which led to wilting over each two day period and it has been shown that wilting affects plant nutrient status by causing an increase in the amount of soluble nitrogen (McDaniel 1982; White 1984). The supply of *P.icarus* was kept in a 'poly-tunnel' on a raised gravel bed to decrease herbivory and insect attack but the temperature in this environment is often high and the plants would have been subject to heat stress and wilting, leading to raised soluble nitrogen levels and decreased concentrations of other nutrients as photosynthesis was affected (McDaniel 1982). The plants also became potbound towards the end of the experiment which would have affected nutrient uptake (Clark 1982).

5.4 Summary

The results presented in this chapter are concerned with the quality of re-created downland for its associated insect herbivores. They show that reversion soils are of a lower nutrient status than downland or arable soils and imply that it will probably take many years for nutrient concentrations to improve, along with the soil structure and associated micro-fauna.

These nutrient levels will encourage those species which survive best in conditions of low available nutrients, and it appears that some non-native *L.corniculatus* competes successfully against native *L.corniculatus* in these conditions. However, nothing is known about survivorship in subsequent years and the large size of non-native *L.corniculatus* could result in selective grazing herbivory and a subsequent decrease in the plant size or population size.

The vigorous, competitive growth of non-native *L.corniculatus* may lead to the erosion of native *L.corniculatus* populations adjacent to re-creation sites. This should be considered alongside the results presented in section 5.2.3 which show that non-native *L.corniculatus* has a significant effect on the larval development of *P.icarus* (used as an indicator species for other insect herbivores). It is likely that these effects will be cumulative and increasingly widespread given the effects on *P.icarus* larvae and the plant characteristics of Maitland variety of non-native *L.corniculatus*.

Chapter 6 - The use of ESA habitats by invertebrate indicator species

6.1 Introduction

This chapter presents the results of work investigating how re-created downland is used by selected invertebrates. Two different groups of indicator species, Lepidoptera and Homoptera, were used in the evaluation. The chapter is divided into two sections:

- Section one evaluates the presence of these indicator species on several different habitats which are a representative range of the non-wooded habitats within the ESA. The habitat types are explained in Chapter 3. Butterfly transect results are presented (giving information on butterfly/presence absence) as well as the results of D-Vac sampling to ascertain whether different species of leafhopper (indicative of habitat type) are found on the different ESA habitats.

- Section two is divided into two parts and evaluates how these habitats are used by the indicator species. The first part examines factors affecting general butterfly species richness and the second part looks at two species in particular.

    - In part one the emergence trap results are presented, showing which butterfly species are breeding on the re-created and established downland. These results are investigated further by examining the relationship between larval food plant presence/absence and adult distribution within downland and re-created downland at six of the study sites. Finally, the results of a correlation relating general butterfly species richness with environmental variables are presented in an attempt to ascertain which other variables might influence butterfly distribution on the different transect habitats.

- Part two presents the results of work examining the behaviour of individual butterfly species, *Maniola jurtina* and *Polyommatus icarus*. Findings from observational work on *M.jurtina* are examined and the relationship between larval food plant presence/absence (at one study site) and adult distribution is investigated via a Spearman rank correlation. The results of work examining oviposition on downland and re-created downland are also presented.

Section 6.3 discusses the possible reasons for these results and relates this work to other studies in the same subject area.

6.2 Results

6.2.1 Presence of indicator species on different ESA habitats.

6.2.1.1 Butterfly species richness

Analysis of variance (ANOVA) was performed on the butterfly transect data from each site, to discern whether there were significant differences in the mean abundance of butterflies in each transect section/habitat. Mean abundance was calculated by summing the number of butterflies recorded on each visit from each transect section/habitat and then dividing by the number of visits. The results were sub-divided into three data sets for analysis:

- total number of butterflies per 100m standard length of transect section
- total number of butterfly species per 100m of transect section
- number of selective/non-mobile species per 100m of transect section.

The transect sections (habitat types) were:

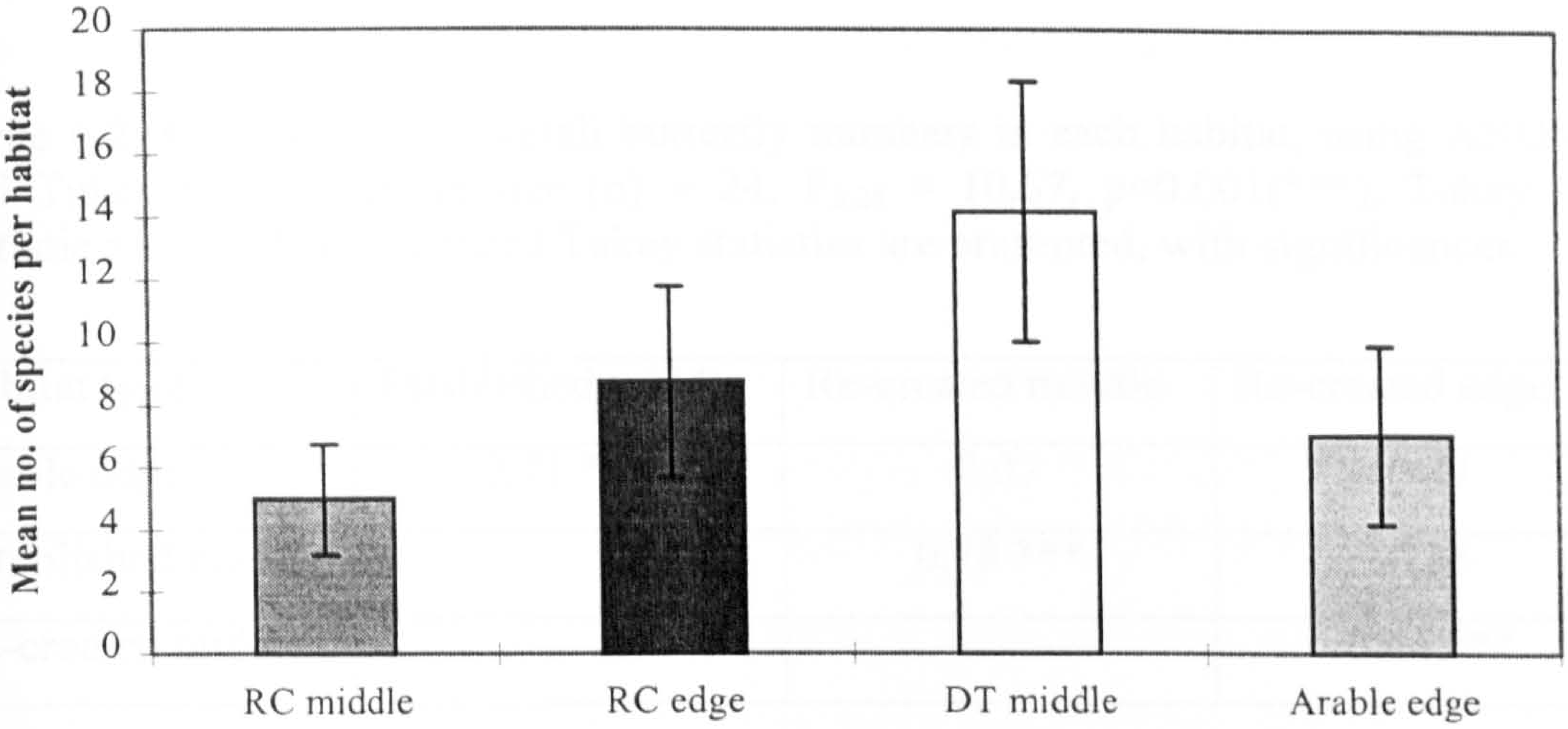
- re-created downland edge adjacent to established downland
- re-created downland middle
- downland middle
- arable edge adjacent to established downland.

All data was transformed (logn+1) to normalise the distribution and reduce the variance within each set of results.

Transect counts showed that established downland contained a higher density of butterfly species and butterfly individuals, followed by restored downland edge and arable edge. The lowest species and lowest density were found in the centre of the restored downland, indicating that this habitat was less attractive to butterflies than the arable edge (Table 6.1). The number of butterfly species and the number of butterfly individuals found on each transect habitat in the 1996 season are presented in Fig 6.1.

Table 6.1: The mean number of species/individuals found within each habitat (±standard error).

Habitat	**Total number of butterflies (mean)**	**Total number of species (mean)**	**Selective / non-mobile species (mean)**
Re-created downland middle	23.29 (±5.13)	5 (±0.72)	2.57 (±1.18)
Arable edge	31.0 (±9.04)	7 (±1.18)	3.29 (±2.18)
Re-created downland edge	67.14 (±13.06)	8.71 (±1.25)	6.00 (±2.72)
Downland middle	124.86 (±11.66)	14.14 (±1.70)	9.43 (±3.24)



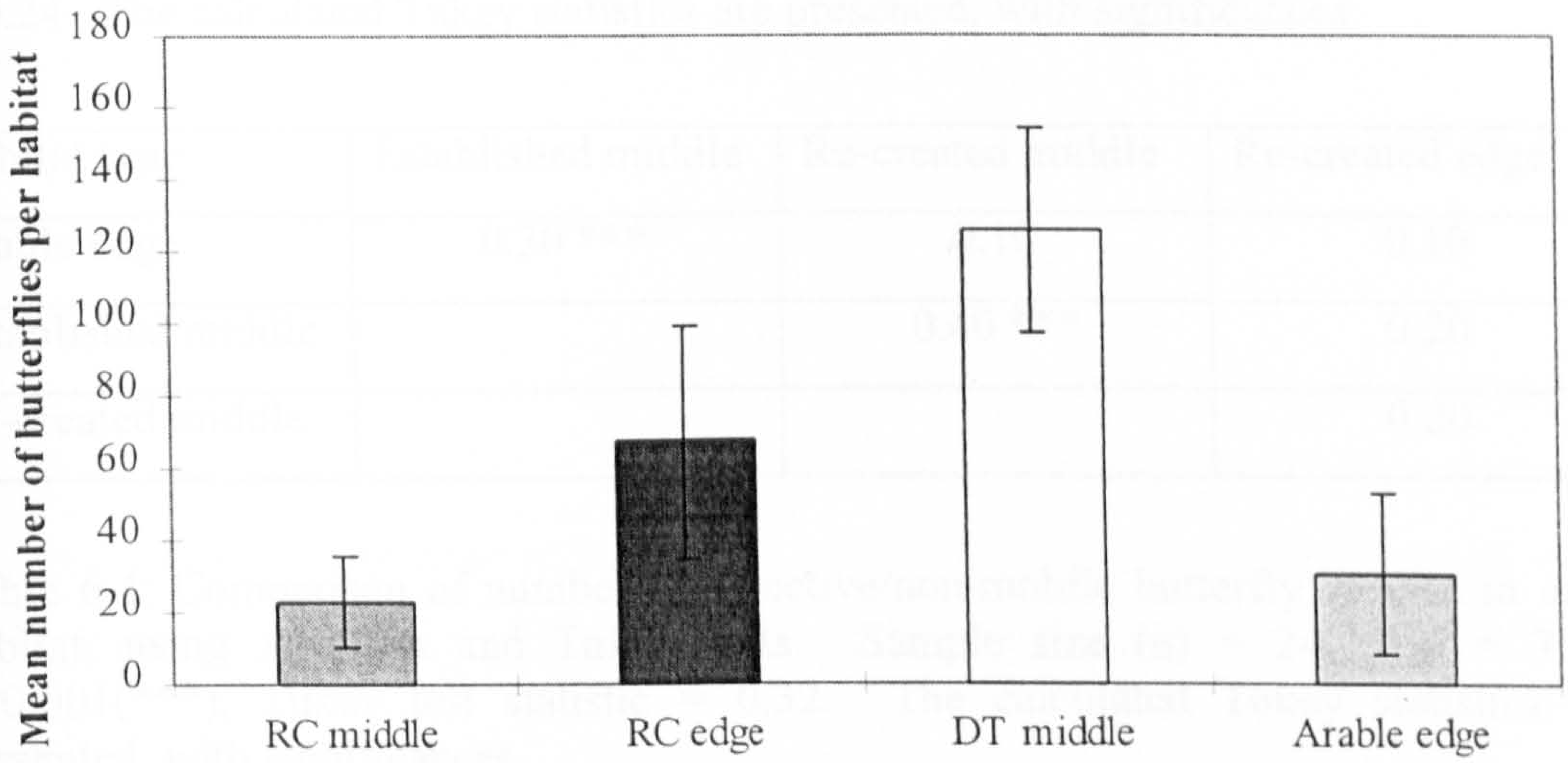


Fig 6.1: The mean number of butterfly species and individuals (and confidence limits) found on each habitat within a 100m standard section. (DT = downland turf, RC = re-created downland turf).

Each data set was analysed by one-way ANOVA and a Tukey test was then performed to identify the significant differences (Tables 6.2 to 6.4).

Table 6.2: Comparison of overall butterfly numbers in each habitat, using ANOVA and Tukey tests. Sample size (n) = 24, $F_{3,24}$ = 10.67, p<0.001(***), Tukey test statistic = 0.43. The calculated Tukey statistics are presented, with significances.

Habitat type	Established middle	Re-created middle	Re-created edge
Arable edge	0.71 ***	0.07	0.37
Established middle		0.78 ***	0.33
Re-created middle			0.44 ***

Table 6.3: Comparison of number of butterfly species in each habitat, using ANOVA and Tukey tests. Sample size (n) = 24, $F_{3,24}$ = 7.73, p<0.001(***), Tukey test statistic = 0.24. The calculated Tukey statistics are presented, with significances.

Habitat type	Established middle	Re-created middle	Re-created edge
Arable edge	0.30 ***	0.10	0.10
Established middle		0.40 ***	0.20
Re-created middle			0.20

Table 6.4: Comparison of number of selective/non-mobile butterfly species in each habitat, using ANOVA and Tukey tests. Sample size (n) = 24, $F_{3,24}$ = 7.25, p<0.001(***), Tukey test statistic = 0.32. The calculated Tukey statistics are presented, with significances.

Habitat type	Established middle	Re-created middle	Re-created edge
Arable edge	0.44 ***	0.02	0.26
Established middle		0.46 ***	0.18
Re-created middle			0.28

Established downland and re-created downland

The tables show that in all cases the established downland habitat contained significantly more species/individuals of butterfly than the re-created downland middle and the arable edge habitats.

They also show that there was no significant difference between the established downland and the edge of the re-created downland. It is tempting to conclude that this is because the habitats are similar and therefore attract similar numbers of butterflies. However, the data are not conclusive enough to state this with certainty; it can be seen that no significant difference was found between habitats such as re-created downland edge and arable edge or arable edge and re-created downland middle and this suggests that there is too much variance within the data to detect any significant differences other than the largest ones.

Re-created downland edge and middle

The results also show that the difference found between the mean number of species on the middle or edge of the re-created downland is not significant. This contrasts with the analysis of number of individual butterflies where significantly more were found on the edge than the middle of the re-created downland.

The change in significance in these two re-created downland habitats when different subsets of the data are examined indicates that although there is a difference in the number of individual butterflies found at the edge and middle of the re-created downland there was no difference in the number of species. Fig 6.1 shows that the number of species found on the re-created downland habitats is low compared with those species found on the established downland but it also seems that more individuals of these species are found at the edge of the re-created downland than in the middle. This suggests a gradient of number of individuals (if not number of species) from the downland to the re-created downland.

Established downland compared to re-created downland and arable.

The total butterfly species were divided into sub-sets; selective/non-mobile species associated with specific aspects of chalk downland and generalist/mobile species which range more widely and occur in a wider range of habitats. They also correspond with species which exist in open or closed populations (Thomas 1989). For selective/non-mobile species the only significant differences were between established downland middle and re-created downland middle and established downland middle and arable edge. The mean number of selective species on the re-created downland edge also falls between that of established downland middle (mean difference 3.43 species) and arable edge habitat (mean difference 2.71 species). This also illustrates how the re-created downland edge is more similar to arable edge habitat than to established downland middle habitat and using similar reasoning it can be seen that all three of the re-created/arable habitats are more similar to each other than to the established downland.

The next section presents comparative presence/absence work using the Hemiptera as an indicator species and the results from both sections will be discussed in section 6.3.

6.2.1.2 Homopteran species richness

The methodology by which Hemiptera (Homoptera, Auchenorrhyncha) samples were collected from each study site is described in Chapter 3. After identification the samples were amalgamated to provide a total species list for the downland and re-created downland habitats (Table 6.5).

Table 6.5: Number and species of leafhoppers collected from established and re-created downland within the South Wessex Downs Environmentally Sensitive Area in August 1996. Nomenclature follows (LeQuesne and Payne 1981).

Classification (PART; Group; Family)	Species	Number recorded/habitat	
AUCHENORRHYNCHA;		Downland	Re-created downland
Cicadomorpha;			
Cicadellidae	*Macrosteles laevis*	1	3
	Streptanus aemulans	4	
	Streptanus marginatus	1	
	Euscelis incisus	52	32
	Euscelis obsoletus		3
	Paluda adumbrata	1	
	Agallia venosa	3	
	Megophthalmus scanicus	1	
	Aphrodes albifrons	6	
	Aphrodes bicinctus	17	3
	Aphrodes flavostriatus	5	
	Aphrodes bifasciatus		1
	Deltocephalus pulicaris	155	5
	Recilia coronifera	1	
	Psammotettix confinis	9	32
	Psammotettix nodosus		23
	Arocephalus punctum	1	
	Turrutus socialis	38	1
	Arthaldeus pascuellus	1	8
	Paluda adumbrata	1	
	Rhytistylus proceps	1	2
	Macustus grisescens		1
	Doratura stylata	3	
	Batrachomorphus irroratus	3	1
Cicadomorpha;			
Cercopidae	*Neophilaenus exclamationis*	26	1
	Philaenus spumarius	4	1
Fulgoromorpha;			
Delphacidae	*Javasella pellucida*	6	20
	Javasella dubia		1
	Hyledelphax elegantulus	1	
	Kosswigianella exigua	6	
Number of individuals / habitat		335	84
Number of species / habitat		24	9

The results show that more species and more individuals of most of these species were found on the established downland. The most abundant species on the established downland was *D.pulicaris* and the most abundant on the re-created downland was *P.confinis*. The suite of species collected includes some which are recognised indicators of chalk grassland such as *T.socialis*, *P.adumbrata*, *R.proceps*, *A.punctum*, *B.irroratus* and *N.exclamationis*. Table 6.5 shows that four of these species, *R.proceps*, *B.irroratus*, *N.exclamationis* and *T.socialis* were found on the re-created chalk downland, indicating that they are at least exploring this habitat if not breeding on it.

The results also show that *P.confinis*, *E.incisus* and *J.pellucida* were all found in relatively large numbers on the re-created downland (*J.pellucida* was more abundant on the re-created downland). The following paragraphs examine these results in more detail.

Hemiptera are used as indicator species because some species are selective in their choice of breeding habitat or larval food plant and also because they exist in macropterous (large winged) and brachypterous (short winged) form (Waloff 1980). Both forms can occur within a single species or a species can be wholly macropterous/brachypterous. Most species tend to be habitat selective rather than specific to a particular host plant and can be linked with short or long turf or new or established grassland. For instance, *M.laevis* recolonises recently cut grasslands rapidly and is also the most abundant leafhopper in disturbed and artifical meadows (Andrzejewska 1962). This species was found more frequently in the re-created downland than on the established turf in this study.

Macropterous individuals are capable of flying to new habitats and initiating colonisation and this means that species capable of macroptery or those which are wholly macropterous tend to be found in areas where there is more migration/emigration occurring. This includes species such as *M.laevis* (wholly macropterous) and *J.pellucida* and *A.pascuellus* (mostly macropterous individuals within a population). All of these species were found more frequently on the re-created downland than the established downland in this study. This is perhaps expected as *J.pellucida* is known to be an extremely mobile species (Waloff 1980) (as well as being the vector for the European wheat striate mosaic virus (Watson and Sinha 1959)).

In addition, species are bivoltine and univoltine (Table 6.6) and bivoltine species tend to colonise new habitat faster than the slower developing univoltine species.

Table 6.6: Some known uni- and bi-voltine species of Auchenorrhyncha. (M.G.Morris, *pers.comm.* and Waloff (1980))

Univoltine species	Bivoltine species
Paluda adumbrata	*Psammotettix confinis*
Turrutus socialis	*Euscelis incisus*
Aphrodes albifrons	*Deltocephalus pulicaris*
Doratura stylata	*Javasella dubia*
	Javasella pellucida
	Arthaldeus pascuellus
	Macrosteles laevis
	Macustus grisescens

There is a clear indication from the results in Table 6.6 that more bivoltine species are occurring on the re-created grassland than univoltine species, indicating that colonisation from the downland to the re-created downland is occurring within these species.

Five species were found only on the re-created downland in this study; *M.grisescens, J.dubia, A.bifasciatus, E.obsoletus* and *P.nodosus*. It is known that the first two species are bivoltine (Waloff 1980) and therefore more likely to explore the new habitat. *Euscelis obsoletus* and *P.nodosus* both also belong to genus' with bivoltine species. *A.bifasciatus* belongs to a genus with known univoltine species (see Table

6.6) and the fact that this species was found on the re-created downland could imply that colonisation is starting to occur among species which are more sedentary. However, all these species are common on grasses in dry to damp conditions (LeQuesne 1965; LeQuesne 1969) and are therefore expected to be found on the re-created downland.

These results are discussed further in section 6.3.

6.2.2. Habitat use by Lepidopteran species

This section investigates how the habitats in this study are used by one of the indicator species groups, the Lepidoptera, and focuses on general species richness first, before looking at two species in particular.

6.2.2.1 General species richness

i) The use of re-created downland as a breeding habitat.

In order to determine which species were breeding on the re-created downland habitat, and to also compare this with those breeding on adjacent downland, emergence traps were set up on one study site, Langford Farm. Emerging butterflies were recorded for a period of five months and results are presented in Table 6.7.

Many more species of butterfly and more individuals of these species emerged on the established downland than on the re-created downland. However, two species were confirmed to be breeding in re-created downland, *M.jurtina* and *L.phlaeas*, and numbers of *M.jurtina* were almost as high as on the established downland.

Table 6.7: The number of butterflies recorded from emergence traps covering $40m^2$ on each habitat; figures in brackets indicate numbers emerging per hectare.

Butterfly species	**Habitat**	
	Re-created downland edge	**Established downland middle**
Lycaeca phlaeas	1 (250)	----
Maniola jurtina	8 (2000)	9 (2250)
Aphantopus hyperantus	----	5 (1250)
Pyronia tithonus	----	2 (500)
Melanargia galathea	----	3 (750)
Polyommatus icarus	----	1 (250)
Total emergences	9 (2250)	**20 (5000)**

The emergence trap data can be used to estimate total numbers of butterflies emerging per site (Table 6.8). From this it can be seen that the total emergences on the edge of the re-created downland represented only 9% of the emergences on the established downland. However, when the number of emergences per unit area is compared it can be seen that those on the re-created downland represent almost half (45%) of the emergences on the established downland middle. This seems to indicate that many butterflies are using the re-created downland edge area to breed in but it should be noted that most of the emergences on the re-created downland edge were of *M.jurtina*, whose density was similar on the two habitats despite their different sizes.

Table 6.8: Estimated total number of butterflies emerging per habitat area; calculated by multiplying the emergence data by area of each site. (Re-created downland edge area = $2500m^2$, Established downland middle area = $12000m^2$).

	Re-created downland edge area	**Established downland middle area**
Number of butterflies per habitat area	562.5	6000

The next section links adult presence/absence with the presence/absence of the larval food plant on each downland habitat.

ii) Presence/absence of larval food plant on re-created and established downland

The transect and quadrat data were combined to establish the proportion of butterfly species found on each of the above habitats for which the larval food plant was present. This should be seen as a measure of the possibility that oviposition can occur, rather than a measure of actual oviposition. The list of main larval food plants used to separate the quadrat data is shown in Appendix 3.

Butterfly species on each habitat (re-created downland edge/middle and established downland middle) were divided into two groups; generalist species and selective/non-mobile species (following the classification of butterfly populations as open or closed by Thomas(1989)). Fig 6.2 presents the mean proportion of selective and generalist species whose food plant was present in each habitat. Fig 6.3 shows the average number of selective and generalist species found within each habitat expressed as a proportion of the total species. There are no error bars because the percentages were calculated by summing the number of species from each site within each category and calculating the percentages from these totals, rather than summing the percentages from each site.

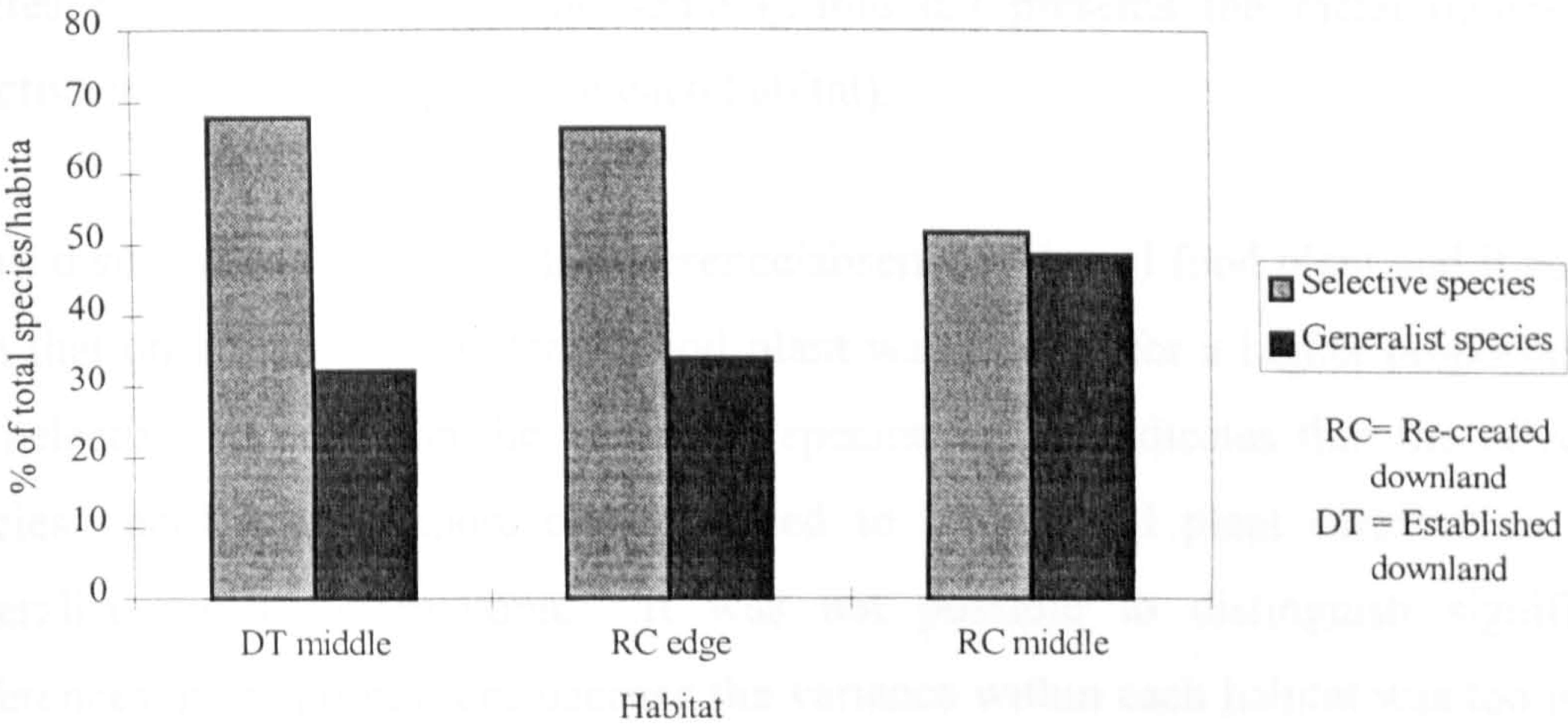


Fig 6.2: The proportion of selective and generalist species found within each habitat. No. of visits per site = 7 (8 at Peckons Hill Farm).

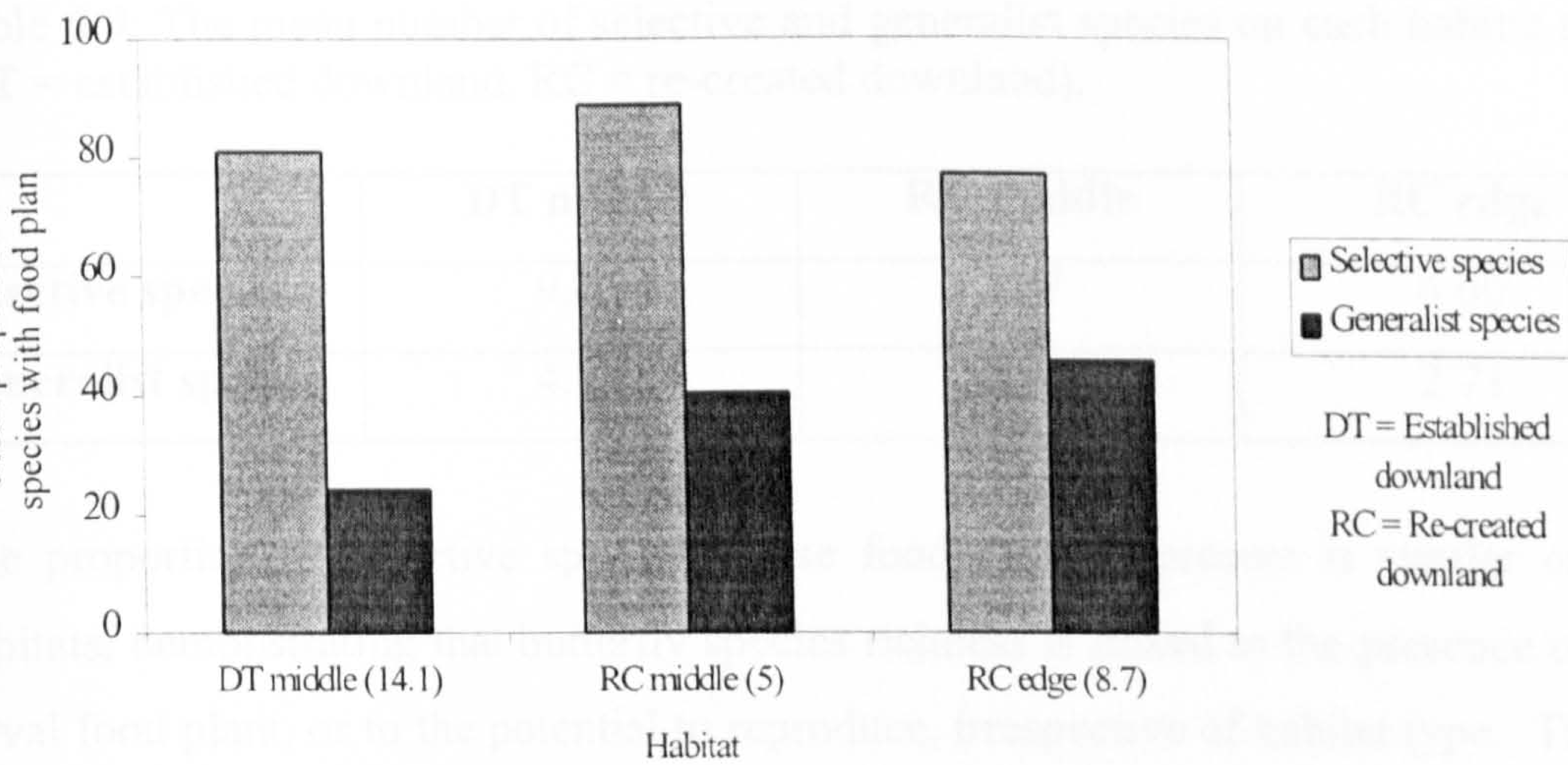


Fig 6.3: The proportion of selective/generalist species for which the larval food plant is present, in each habitat. No. of visits per site = 7 (8 at Peckons Hill Farm). Numbers in brackets after the habitat type represent the mean number of species recorded on that habitat).

A large proportion of the total species present on the established downland and the edge of the re-created downland were selective species. This was not the case in the middle of the re-created downland where the proportion of selective and generalist species present were nearly the same (Table 6.9 presents the mean number of selective and generalist species on each habitat).

Adult distribution is linked to the presence/absence of larval food plant and it can be seen that on all habitats the larval food plant was present for a higher proportion of the selective species than the generalist species. This indicates that the selective species distribution is more closely allied to larval food plant distribution than generalist species distribution. It was not possible to distinguish significant differences in the proportions because the variance within each habitat was too great. However, the information implies that on the re-created downland, where fewer larval food plants are present there will be fewer selective species and this was found to be so (Table 6.9).

Table 6.9: The mean number of selective and generalist species on each habitat type. (DT = established downland, RC = re-created downland).

	DT middle	RC middle	RC edge
Selective species	9.43	2.57	6.00
Generalist species	4.71	2.43	2.71

The proportion of selective species whose food plant is present is similar on all habitats, demonstrating that butterfly species richness is linked to the presence of the larval food plant, or to the potential to reproduce, irrespective of habitat type. This is particularly the case for the group of butterfly species classed as specialist/non-mobile because of their relatively sedentary and tendency for the population to breed within a well defined area (Thomas 1989). The next section includes other environmental factors in a Spearman rank correlation to test whether butterfly species richness is related to any other measured variable.

iii) Factors determining butterfly species richness within each habitat.

Butterfly species richness was correlated with several environmental variables within each of the following habitats:

- established downland turf middle
- re-created downland turf edge
- re-created downland turf middle

Table 6.10 presents the data set used in the correlations. When the environmental variables were correlated with species richness between all three habitats the only significant correlations were between slope and rank nectar abundance ($r_s = +0.472$, $p<0.01$) and slope and total species richness ($r_s = +0.524$, $p<0.05$). This probably reflects the results presented in Chapter 4, where plant species richness was found to correlate significantly with slope because the downland habitat was always found on the steeper slopes. The significant correlations presented above show that the highest rank nectar abundance and butterfly species richness were found on the downland habitats.

Table 6.10: The data set used to correlate environmental variables with butterfly species richness within three habitats.

(DT = established downland turf, RC = re-created downland turf, total sp. = total number of species within each habitat at each site from 1996 transect data, select sp. = number of selective/non-mobile species within each habitat at each site from 1996 transect data, food plant total sp. = the proportion of all species whose food plant is present (%), food plant select sp. = the proportion of the selective/non-mobile species whose food plant is present (%), aspect = mean habitat aspect (degrees), slope = mean habitat slope (degrees), turf height = 1996 mean turf height (cm), bare ground = 1996 mean bare ground (%), rank nectar abundance = sum of number of species with nectar abundance rank >2 (see methods section in Chapter 3 for explanation of ranking system)).

Habitat	Site	total sp.	select sp.	food plant total sp.	food plant select sp.	aspect	slope	turf height	bare ground	rank nectar abundance
DT middle	Langford	18	13	66.7	84.6	344	22.3	10.95	0	7
	Huish	20	12	75	83.3	307	23	3.6	0	27
	Court	9	4	33.3	75	354	24.3	4.55	0.5	33
	Throope	11	10	72.7	80	277	24	10.3	0	38
	Coombe	15	11	80	100	235	25	10.4	0	42
	Peckons	17	11	58.8	63.6	57.3	24.7	7.35	7	35
RC middle	Langford	9	5	88.9	100	344	4.75	6.4	0	7
	Huish	5	2	80	100	251	9.7	7.4	25	3
	Court	5	2	40	100	112	4	7.1	2	19
	Throope	4	3	25	33.3	----	0	12.15	11	9
	Coombe	5	3	100	100	270	6	17.85	1.5	15
	Peckons	3	1	33.3	100	37	6	7.05	0	17
RC edge	Langford	11	8	90.9	87.5	344	4.75	6.9	13.5	12
	Huish	11	5	54.5	80	251	11	4.35	6.5	7
	Court	4	2	25	50	54	5	10.35	0	5
	Throope	9	5	77.8	80	215	5.5	7.05	34	9
	Coombe	13	11	84.6	90.9	253	4	6.9	0.5	20
	Peckons	5	4	60	75	37	6	5.85	1.5	19

Downland middle habitat

Within the established downland habitat, despite the small sample size, there were two significant correlations, rank nectar abundance with slope (r_s = +0.829, $p<0.05$) and percentage bare ground with the proportion of selective/non-mobile species whose food plant was present (r_s = -0.845, $p<0.05$).

Slope

The first correlation (Fig 6.4) suggests that steeper slopes have more available nectar sources than those with a shallower gradient and is hard to interpret, although there could be a link with grazing, suggesting that the steeper slopes are not grazed as hard, leading to a greater abundance of flower heads.

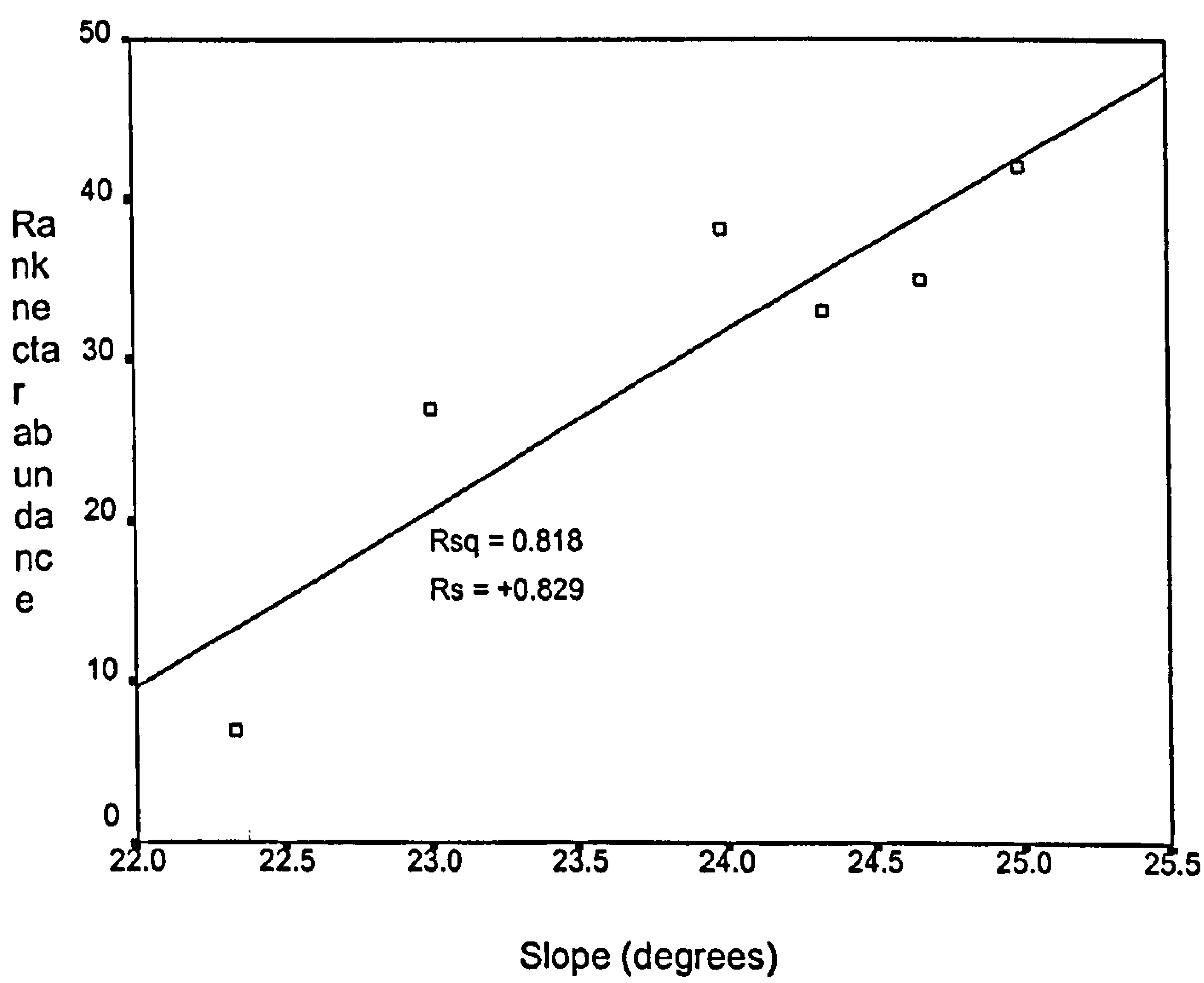


Fig 6.4: Scatter plot of slope and rank nectar abundance within the established downland habitat (the Spearman coefficient and r-squared value are shown).

Bare ground

The correlation involving bare ground suggests that on sites with less bare ground a higher proportion of the selective butterfly species find their larval food plant present (see Fig 6.5). This implies that where there is more bare ground there are fewer plant species present although it can be seen that the range of bare ground is only from 0-7%. However, results presented in Chapter 4 showed that there was a negative correlation of plant species richness with bare ground within this habitat so it appears likely that the correlation with the number of butterfly species richness whose food plant is present is indeed a reflection of the number of plant species present. The correlation is only significant for the selective/non-mobile species and this reflects the results in the above section where it was shown that this group of species are more highly linked to presence/absence of larval food plant than all the butterfly species (including the generalists).

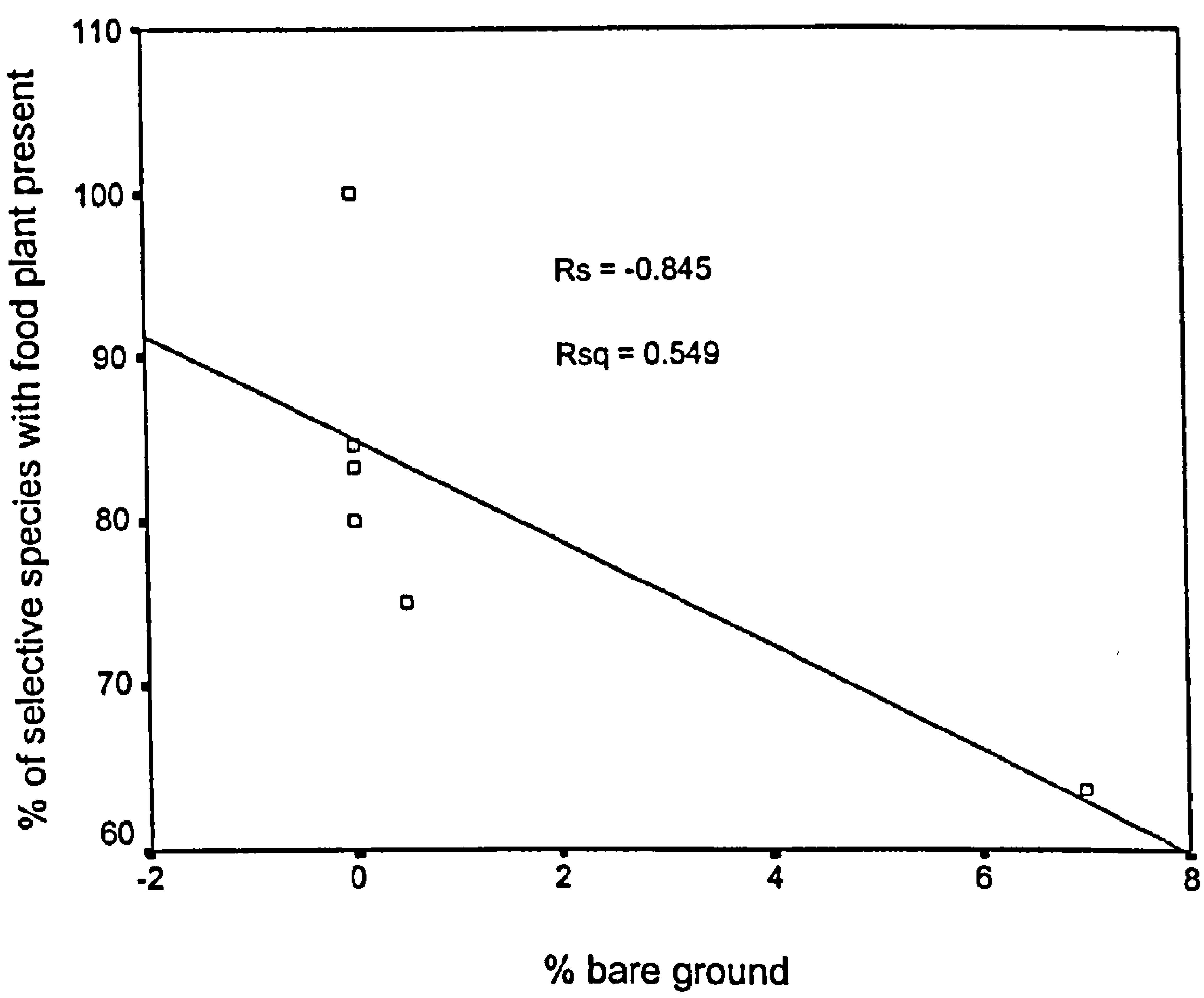


Fig 6.5: Scatter plot of % bare ground and % of species whose food plant is present within the downland habitat (the Spearman coefficient and r-squared value are shown).

Re-created downland middle habitat

The re-created downland middle habitat correlations were all connected with aspect and are shown in Table 6.11.

Table 6.11: The significant correlations within re-created downland middle habitat (correlation coefficients and significances are shown; ** = p<0.01, * = p<0.05)

Environmental parameters:	Total species	Selective/non-mobile species	% of species whose larval food plant is present
Aspect (degrees)	+0.894 *	+0.975 **	+0.900 *

Aspect

The correlation of species richness (total and selective species) with aspect shows that more butterfly species are found on west than on east facing slopes, and that this is more significant within the selective/non-mobile group of species (Fig 6.6).

However, this could be an artefact of the west facing downland sites being more butterfly species rich than the east facing ones, reflecting species spread from the downland to the re-created downland. This is refuted by the lack of any correlation between selective/non-mobile butterfly species richness and aspect on the downland (Fig 6.7). It appears that the link between species richness and aspect on the re-created downland middle is genuine and is explained by some other factor such as increased larval food plant abundance or microclimate. Possible explanations for this are discussed in section 6.3.

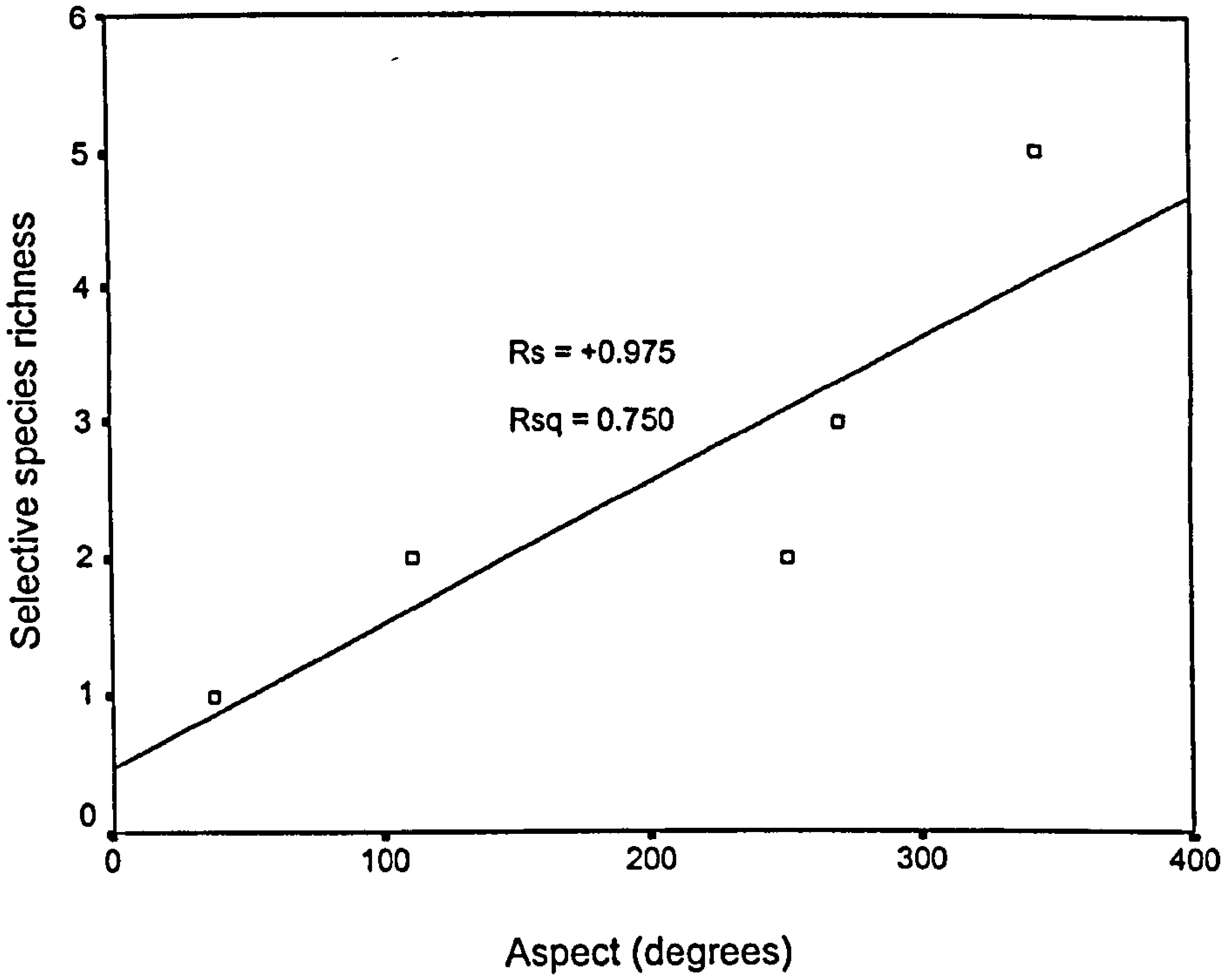


Fig 6.6: A scatter plot of selective butterfly species richness and aspect within the re-created downland habitat (showing the correlation coefficient and r-squared value)

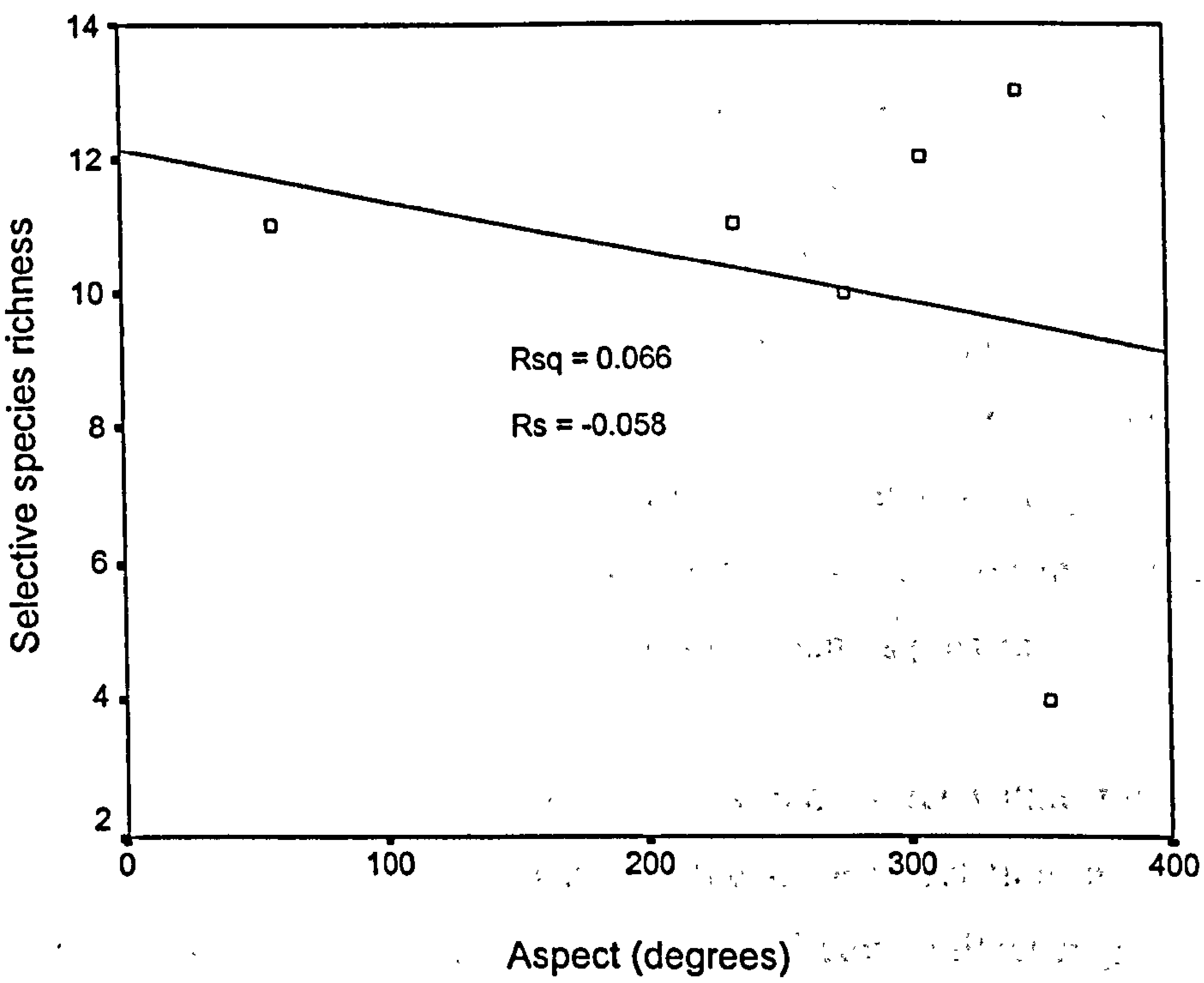


Fig 6.7: A scatter plot of selective butterfly species richness and aspect in established downland habitat (showing the correlation coefficient and r-squared value)

Presence of larval food plant

The third correlation shows that on the western facing slopes the larval food plant is present for a higher proportion of all species. There is no correlation between overall plant species richness and aspect in this habitat (r_s = -0.205, p<0.741) so it appears that some butterfly species actually prefer western facing slopes, but are also influenced by presence of their larval food plant. These are the two most important factors influencing butterfly distribution in this habitat.

The correlation corroborates the results presented earlier in this chapter which also found that butterfly species richness was linked to the presence of the larval food plant.

Re-created downland edge habitat.

Aspect

Within the re-created downland edge the proportion of selective species whose larval food plant is present is also linked with species richness and aspect (Table 6.12). This suggests that fewer butterflies are found where there are fewer available food plants and vica versa and again shows how important the presence of the larval food plant is to the presence of such species. As in the middle of the re-created downland there is no significant relationship between aspect and plant species richness (r_s = +0.543, p<0.266) so it appears that the butterflies found on the western slopes are influenced by aspect and by whether their food plant is present.

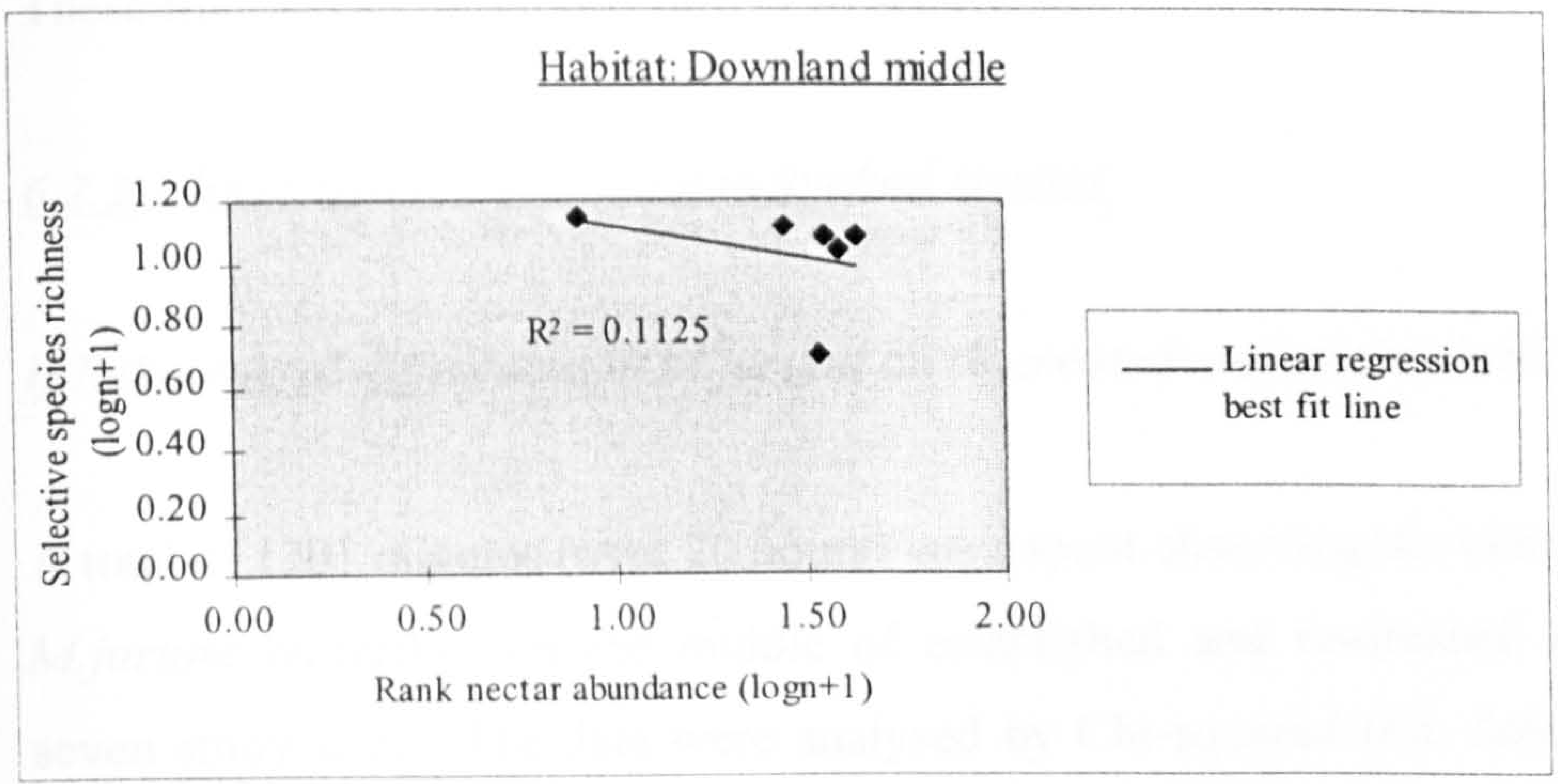
The correlation of butterfly species richness and aspect within the edge of the re-created downland is less significant than the same correlation in the middle of this habitat. This suggests that there are other factors influencing butterfly species richness. One possible factor, nectar abundance, is examined below.

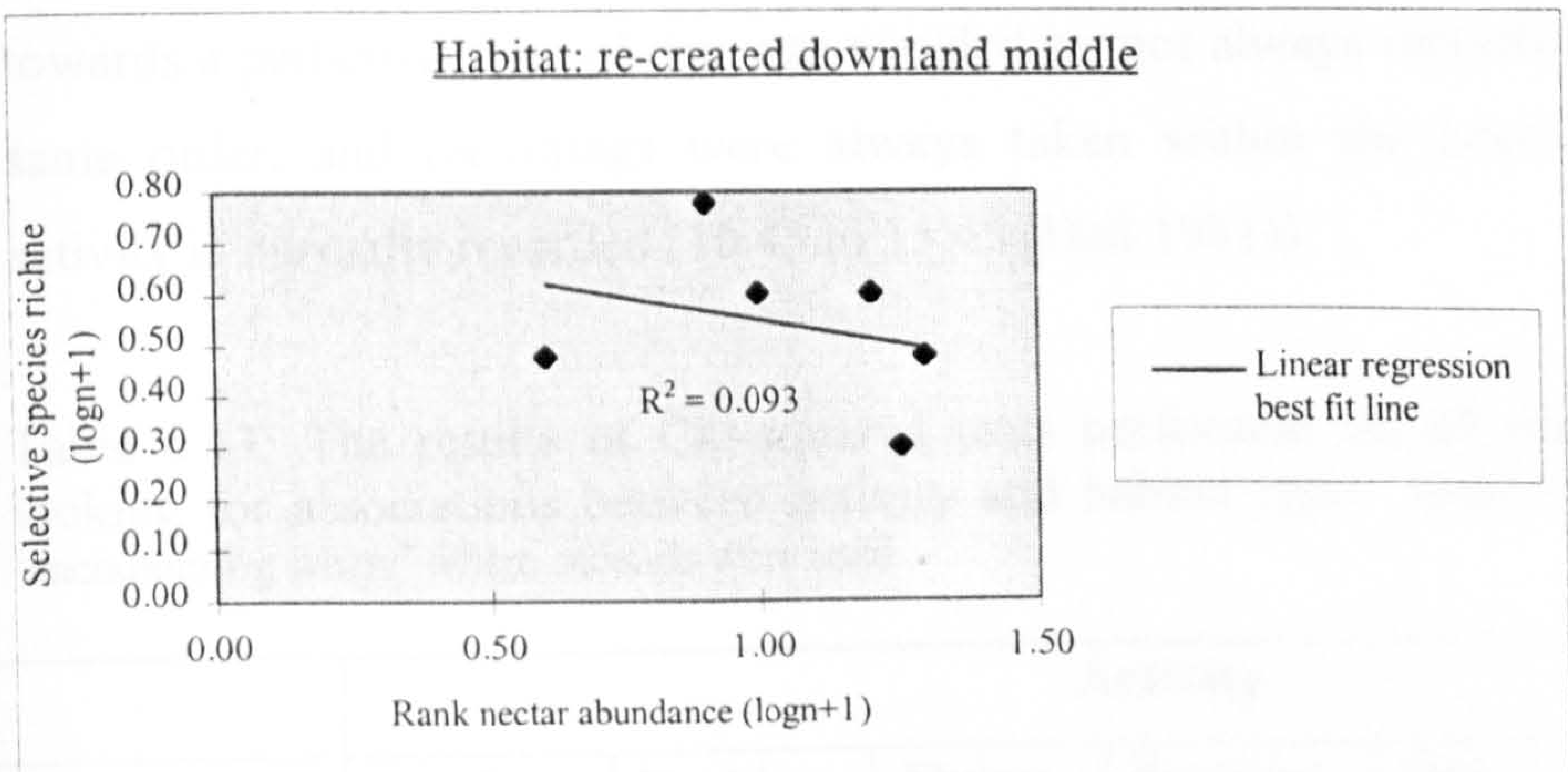
Table 6.12: The significant correlations within the edge of the re-created downland (correlation coefficients and significances are shown; ** = p<0.01, * = p<0.05).

Environmental variable:	Total species richness	Selective/non-mobile species richness	% of selective species whose larval food plant is present
% of selective species whose larval food plant is present	+0.956 **	+1.000 **	-----
Aspect (degrees)	+0.841 *	+0.870 *	+0.870 *

Nectar abundance

Fig 6.8 shows the relationship between rank nectar abundance and selective species richness within each habitat. There is no relationship between these two variables on the downland or the middle of the re-created downland, but the relationship is significant within the re-created downland edge habitat. This suggests that nectar availability is an important factor determining butterfly species richness on this habitat and could help to attract butterflies onto the edge of the re-created downland.





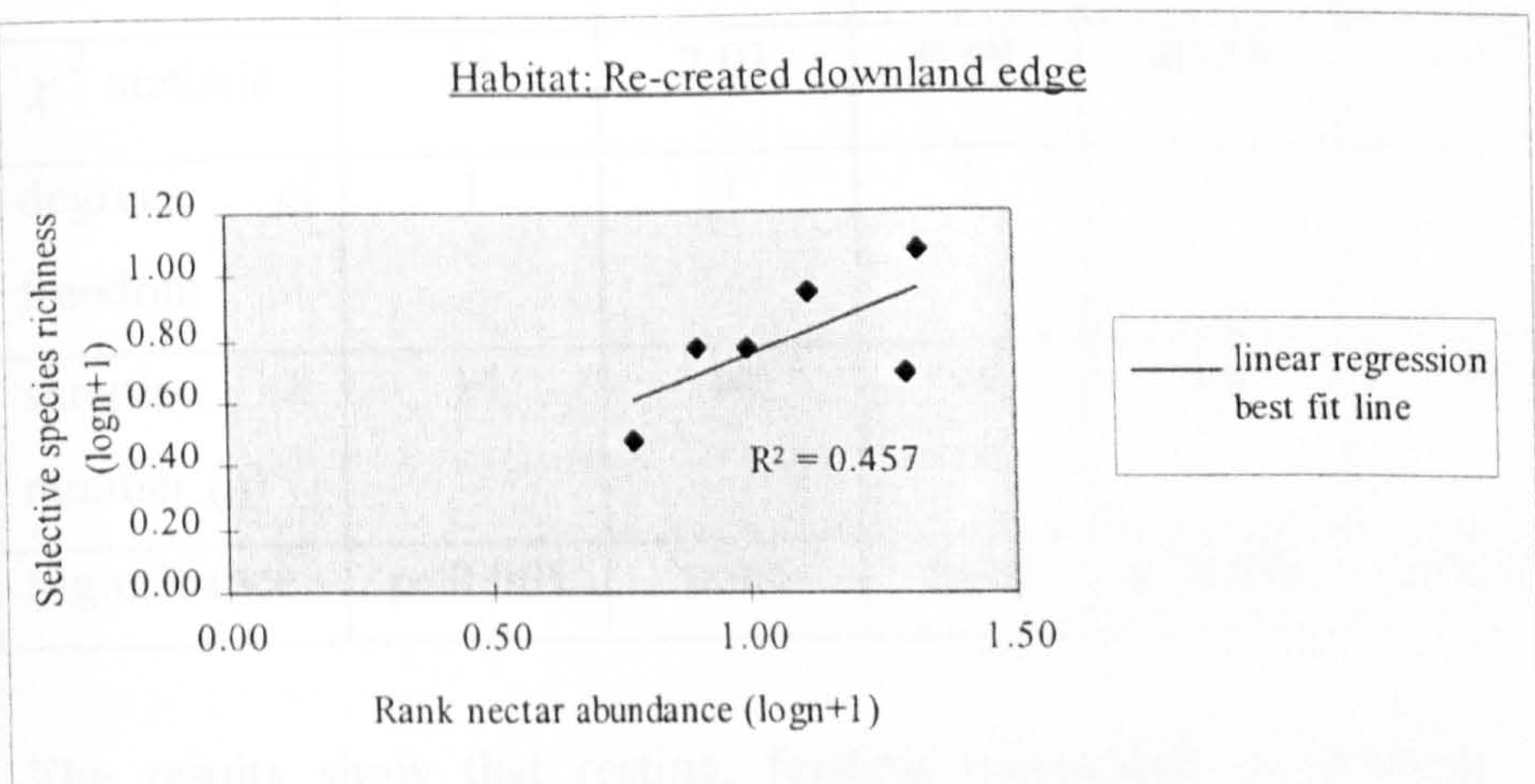


Fig 6.8: Scatter plot of rank nectar abundance and selective/non-mobile species richness within downland, re-created downland edge and middle habitats. The linear best fit and r-squared values are shown on each graph.

These findings are discussed further in section 6.3.

6.2.2.2 Investigations involving individual species

i) Behavioural differences in M.jurtina on re-created and established downland.

A total of 1201 minutes (over 20 hours) were spent observing the behaviour of female *M.jurtina* butterflies on the middle of established and re-created downland at all seven study sites. The data were analysed by Chi-squared test, linking a behaviour with habitat type to look for associations between these variables (Table 6.13). Bias towards a particular time of day was avoided by not always recording habitats in the same order, and recordings were always taken within the hours when butterfly activity is normally recorded (10.45 to 15.45 (Hall 1981)).

Table 6.13: The results of Chi-squared tests performed on all observational data, looking for associations between activity and habitat type. Units = minutes except for 'encountering others' where seconds were used.

	Activity					
Test results:	**Resting**	**Basking**	**Flying**	**Feeding**	**Ovi-positing**	**Encount-ering others**
χ^2 statistic	24	2.03	0.49	80.88	6.14	10
degrees of freedom	1	1	1	1	1	1
sample number (n)	14	14	14	14	14	14
Significance	**p<0.001**	none	none	**p<0.001**	**p<0.05**	**p<0.01**

The results show that resting, feeding (nectaring), ovipositing and encountering others were not distributed evenly between habitats. The summary data show that more resting and ovipositing was carried out on the re-created downland but more nectaring and encountering others occurred on the established downland (Table 6.14).

It should also be noted that the total observation time was divided so that 706 minutes was spent on the downland and 495 minutes was spent on the re-created downland. This means (for example) that although the amount of time *M.jurtina* adults were recorded flying on the re-created downland was less than that on the downland, it actually represents a greater proportion of the total recorded activity time in these habitats.

Table 6.14: The summary data of *M.jurtina* behavioural activity on established and re-created downland over a 1201 minute period.
Ovip = ovipositing, Encount = encountering others (seconds), %established/re-created downland = the % of the total activity time in a particular habitat spent on a particular activity ie 22% resting in established downland is interpreted as '22% of the total time spent on all activities on the downland turf is spent resting'.

	Activity					
	Resting	**Basking**	**Flying**	**Feeding**	**Ovip**	**Encount**
% Established Downland	22.4	30.0	9.1	32.6	5.7	0.2
% Re-created Downland	35.5	34.2	10.5	10.3	9.4	0.1

Resting activity

The greater time spent resting on re-created downland turf might indicate that butterflies spend a greater amount of time replenishing energy by resting in the warmest situations, those of a south-western aspect.

Oviposition activity

It was also found that far more oviposition activity (by *M.jurtina*) took place on the re-created downland than on the established downland, possibly due to the large grass component. However, the emergence trap results (section 6.2.1) from one study site show that slightly more *M.jurtina* emerged on the downland than on the re-created downland habitat. If these results are representative and reflect the number of eggs laid, then it appears that re-created downland attracts a greater amount of oviposition but larval survival is poorer. It was also observed that *M.jurtina* females alternated periods of nectaring with periods of oviposition and it could be that if nectar sources are limited they do not oviposit as successfully as when they are fully fed before each period of oviposition.

Encountering others

The association of time spent encountering others with downland habitat is unsurprising given the greater numbers of *M.jurtina* found on downland when compared to re-created downland (Table 6.15).

Table 6.15: The number of *M.jurtina* on established and re-created downland habitat. Data from 1996 butterfly transects at all sites (n=7).

	Habitat	
	Downland turf middle	**Re-created downland turf middle**
Number of *M.jurtina*/ 100m transect section.	340	45

Nectaring activity

The amount of time spent nectaring was far greater on downland where far more nectar sources were present. *M.jurtina* utilised a wide range of nectar sources, but the most preferred species were not commonly found on the re-created downland (Table 6.16). Earlier results show that nectar sources are not abundant on re-created downland and act as a limiting factor on the number of butterflies found there.

Table 6.16: The species utilised as sources of nectar by *M.jurtina.*

Data is presented as total time spent nectaring per plant species (seconds) and as % of the total time spent nectaring on all species (from observations collected over 1201 minutes). Mean length of visit is calculated by dividing the total nectaring time by the number of visits. Plant species are arranged in decreasing order of time spent nectaring from them.

Plant species	**Total nectaring time / species (no. of visits)**	**% of total nectaring time.**	**Mean length of visit**
Succisa pratensis	5286 (85)	31.4	62.2
Scabiosa columbaria	2912 (77)	17.3	37.8
Cirsium arvense	1994 (11)	11.8	181.3
Centaurea nigra	1229 (19)	7.3	64.7
Leontodon hispidus	1006 (45)	6.0	22.4
Hypochoeris radicata	949 (44)	5.6	21.6
Cirsium acaule	859 (21)	5.1	40.9
Medicago lupulina	646 (5)	3.8	129.2
Lotus corniculatus	604 (22)	3.6	27.5
Trifolium pratense	377 (19)	2.2	19.8
Leontodon autumnalis	332 (3)	2.0	110.7
Achilea millefolium	233 (5)	1.4	46.6
Hypochoeris glabra	203 (7)	1.2	29.0
Ranunculus repens	70 (4)	0.4	17.5
Trifolium repens	60 (5)	0.4	12.0
Crepis capillaris	25 (1)	0.2	n/a
Galium mollugo	21 (2)	0.1	10.5
Veronica chamaedrys	13 (1)	0.1	n/a
Stachys officinalis	5 (1)	<1	n/a
Daucus carota	4 (1)	<1	n/a
Plantago lanceolata	3 (1)	<1	n/a
Leucanthemum vulgare	2 (1)	<1	n/a
Total time spent nectaring	16833	100	

Use of different nectar sources

The mean length of visit to each nectar source shows that, although *Succisa pratensis* and *Scabiosa columbaria* were visited for the longest total time, the mean length of visit to these species was not particularly long. Mean visit length to *Cirsium arvense, Medicago lupulina* and *Leontodon hispidus* was found to be longer than to any of the other species, suggesting that these species are favoured nectar sources of *M.jurtina.*

However, without data on the relative abundance of these nectar sources at each site it is difficult to draw definite conclusions about the butterflies preferences. From the data available it does appear that flowers from the Compositae family, and especially those coloured yellow or purple are favoured.

Observations on *M.jurtina* showed that female nectaring behaviour was always interspersed with short periods of flight and females regularly paused to rest or bask for some seconds before resuming nectaring behaviour (see Appendix 4). Egg-laying behaviour was characterised by very infrequent nectaring; instead short periods of flight were interspersed by periods of ovipositing and 'testing' for suitable oviposition sites. At intervals throughout this behaviour the butterfly often paused to rest or bask before resuming (see Appendix 4).

These findings are discussed in section 6.3.

ii) The relationship between P.icarus adult density and larval food plant occurrence on re-created and established downland.

Quadrat and transect information was combined to evaluate the relationship between adult *P.icarus* occurrence and the presence of the larval food plant on downland middle and re-created downland (middle and edge area) habitat. Within each quadrat the % cover of three known *P.icarus* larval food plants was recorded and this information was divided into two groups for the correlation presented below;

- % cover of *Lotus corniculatus*
- % cover of *L.corniculatus, Medicago lupulina* and *Trifolium dubium.*

These totals were correlated against the total number of *P.icarus* recorded per 100m habitat section along the transect at each site.

The only signifciant correlation of adult abundance with larval food plant was between the % cover of all three larval food plants and the number of *P.icarus* adults in the middle of the re-created downland ($r_s = +0.845$, $p<0.05$). This corroborates the findings from earlier work where it was found that the presence of the larval food plant was an important determinant of adult distribution, especially in the middle of the re-created downland.

There was also a close correlation of all larval food plants with *P.icarus* adult abundance on the edge of the re-created downland although this was not quite significant ($r_s = +0.778$, $p<0.06$). Apart from this there was no relationship with larval food plant and adult distribution on the downland, suggesting that on the edge of the re-created downland and particularly the downland middle there were other factors determining adult distribution. These are discussed elsewhere in this chapter.

The correlation of food plant abundance within the three habitats demonstrated some links between the downland and re-created downland. Significant correlations are shown in Table 6.17.

Table 6.17: Significant correlations found between larval food plant cover on re-created and established downland. (Correlation coefficients and significances are given; ** = p<0.01, * = p<0.05, n=6 sites)

% cover	All food plants on downland turf middle area	All food plants on re-created downland middle area
All food plants on re-created downland middle area	-0.899 *	----
All food plants on re-created downland edge area	-0.986 **	+0.943 **
L.corniculatus on downland middle area.	+0.841 *	----

The correlation of *L.corniculatus* % cover with all food plant % cover on re-created downland middle probably reflects the equal proportions of each of the three larval food plants sown into the re-creation sward. This is also the case for the correlation of all food plant % cover on the re-created downland middle and edge.

However, the negative correlations in Table 6.17 imply that on sites where the established downland turf has a higher % cover of the three larval food plant species, re-created downland middle and edge sward has a lower abundance of these species. But because the re-created downland is predominantly an artificial sward, there is a very low probability that these correlations are the result of a natural process and the correlations could instead result from chance variation in the sowing rate of these species at each site.

iii) The relationship between oviposition and site factors

Quadrats were carried out at Coombe Bisset Down, to search for eggs of *P.icarus* and to record variables within each quadrat which might influence the egg abundance within each habitat. However, the number of eggs found was too low (n=9) to relate these factors to choice of oviposition site with any confidence (Table 6.18).

Table 6.18: The number of eggs found per habitat (from a search within 20 quadrats per habitat) and mean site parameters.
(DT = downland turf, RC = re-created downland, mean height = mean height of *L.corniculatus* and *M.lupulina* within each quadrat, % cover = mean % cover of *L.corniculatus* and *M.lupulina* within each quadrat, %brgrnd = mean % bare ground within each quadrat, nectar = mean number of species in flower per quadrat. The median of each parameter is given in brackets because the large variance within each parameter renders the standard error meaningless).

	Mean height (cm)	**%cover**	**%brgrnd**	**Nectar**	**Number of eggs**
DT middle	8.49 (5.85)	16.90 (17.50)	0.95 (0.50)	4.15 (4.00)	4
DT edge	10.04 (11.45)	20.30 (19.50)	1.45 (0.00)	4.45 (4.50)	3
RC middle	9.07 (13.50)	6.21 (8.00)	0.00 (0.00)	1.17 (1.50)	0
RC edge	12.22 (12.15)	7.00 (6.00)	0.00 (0.00)	1.40 (1.00)	2

The sparse data obtained seems to show that egg abundance might be related to the % cover of the larval food plant and to the number of nectar sources available. This reflects previous results presented in this chapter which show that adult abundance correlates with presence of larval food plant and that, on the re-created downland, nectar abundance is an important factor. However, further samples are needed to state these conclusions with any confidence. It would also have been useful to carry out butterfly transects in this year so that relative butterfly abundance could have been included in the correlation.

6.3 Discussion

6.3.1 Presence/absence of indicator species

Both leafhoppers and butterflies were used to evaluate the distribution of invertebrate indicator species on the re-created downland, established downland and arable habitats. The leafhopper results are discussed first.

6.3.1.1 Homopteran diversity on established and re-created downland

The D-Vac sampling showed that some species associated with chalk downland are found on the re-created downland. However, most species occurring on the re-created downland were bivoltine, macropterous and therefore indicative of recently disturbed/new grassland habitat (Waloff 1980). Work at Grange Farm, Royston, which examined the Homopteran fauna of two sown grasslands on calcareous substrate found that indicator species such as *Rhytistylus proceps* established on the new grasslands in the first two years, albeit at low densities (Morris 1990). It would be interesting to determine whether the chalk downland indicator species found on the re-created grassland in this study are actually reproducing (as was determined for the Lepidoptera at Langford Farm (section 6.2.2.1ii).

Homopteran distribution depends on the morphology of adult form which is in turn determined by the nutritional value of the host plant and by the population conditions within a particular area. It has been found that if conditions are crowded or if the sward structure deteriorates more individuals develop into macropterous form (May 1971). Newly created grassland represents a new resource to Homoptera and one would expect colonisation to occur because of their relative mobility. Those species sampled from the re-created downland were mainly macropterous and mobile species, as well as those which rear two generations in a year and are capable of responding faster to change. A similar phenomenon was recorded in previous studies on re-seeded grassland plots at Royston, Herts (Morris,1990).

The nutritional value of grasses used as larval food plants is also an important determinant of Homopteran community composition (Prestidge and McNeill 1982). The results presented in Chapter 4 showed that the soils on which re-created grasslands develop are less fertile than those under downland - meaning that in general the grasses will not be as attractive to the Homoptera as those on the downland which contain more soluble nitrogen. This will also alter seasonally and to gain a more accurate picture of the colonisation processes occurring several samples should have been taken throughout the active season of April to September (Waloff 1980). Also, many species (eg *Euscelis incisus*, *Recilia coronifera*, *Javasella pellucida*) use grasses such as *Dactylis glomerata*, *Holcus lanatus* and *Lolium perenne* which, although present in the re-created grassland are not abundant and may limit their distribution.

Sward height is also an important determinant of community composition (Waloff 1980). *Psammotettix confinis* and *Deltocephalus pulicaris* use *Agrostis tenuis* as their host plant (Prestidge and McNeill 1983) but *D.pulicaris* is not linked with short sward height and is found more abundantly on the downland. *P.confinis* prefers shorter swards and is found in greater numbers on the re-created downland which is both cut for hay and grazed in the first three years after establishment.

The species assemblage on the re-created downland will change with time. At present they include early successional species such as *Macrosteles laevis* (Andrzejewska 1962) and *Arthaldeus pascuellus* (Morris 1990) but these should eventually be replaced by species indicative of a more stable community structure. As the nutrient status of the habitat increases (via build-up of organic matter and increased mineralisation) it is likely that the number of species colonising will also increase and so there will be a time lag between the creation of the habitat and colonisation by saprophytic insects such as the Homoptera. In addition, the greatest Homopteran diversity is usually found on rank grasslands and those managed less intensively (Morris 1973; Morris and Plant 1983) and it has already been mentioned that species such as *P.confinis*, which prefers short grass, are found in greater numbers on the re-created downland than the established downland. The constant grazing of the re-created downland turf will mean that fewer species are attracted on to the new habitat than might otherwise be the case in the first few years of establishment.

It has been shown that in dispersing populations the number of macropterous individuals increases (Waloff 1980), and it would be interesting to monitor the macropterous component of downland Homoptera before and after adjacent downland re-creation occurred. An increase in macropterous individuals after re-creation would indicate that dispersion was occurring onto the new habitat and it has been shown that this can occur over distances of 1500m or more (Schultz and Meijer 1978). Conversely, a decrease in macropterous forms on the re-created downland with time would indicate that conditions were becoming more suitable (increase in fertility and biomass) and that stable populations of some species were developing.

These discussions demonstrate the many different factors which affect Homopteran distribution within and between habitat. It has also been shown that correlations of certain species with particular nitrogen levels or turf height are not always consistent and that in one case *P.confinis* was negatively correlated with hay yield (Morris 1992). Despite this the results presented in section 6.2 show clear differences in species assemblage on the two habitats and can be said to demonstrate the worth of the Homoptera as indicator species.

6.3.1.2 Lepidopteran diversity on established and re-created downland

Results from butterfly transects showed that more individuals were found on the edge of the re-created downland than in the middle and that there was no significant difference between the number of individuals on the edge of the re-created downland and in the middle of the downland. However, this result was not consistent when the number of species (total or selective) was examined and shows (in agreement with the Homoptera results) that fewer species are found on the re-created downland than on the established downland. This result is perhaps less reliable than for the Homoptera because of the greater mobility of most butterfly species than most leafhoppers. It is more representative than the Homopteran data because the transects recorded activity throughout the season rather than just once as was the case with the D-Vac sampling.

There was considerable variation between sites and standard errors were too large to make more than basic comparisons between established and re-created downland. Given this large variability it would have been preferable (with the benefit of hindsight) to have had larger samples.

It was also expected that there would be significant differences in the distribution of selective/non-mobile and mobile butterfly species between the different downland habitats and this was not found to be the case. The definition of these species was based on the division of butterfly species into open and closed populations (Thomas 1989) and this classification system defines some species as forming closed populations of up to and greater than 50 hectares. This area is large enough to enclose both downland and re-created downland at several of the study sites so it appears that the specification of selective species is not a particularly useful one when dealing with areas of habitat of the size used here. Nevertheless, the differences in number of species and individual did appear to show that there is migration of butterflies from the established downland to the re-created downland.

6.3.2 Factors affecting habitat use

6.3.2.1 General discussions

The Homoptera work demonstrated that a wide variety of factors affect the distribution of species within a site. Similar factors were found to effect butterfly species distribution. Arable edge habitat attracted more species and individuals of butterfly than the middle of the re-created downland, despite the fact that vegetation work (Chapter 4) found many of the larval food plants of these butterflies (especially the Satyridae and Vanessidae) are present on the re-created downland. Possible explanations include an increase in nectar supply on the arable edge, or the fact that there is not much difference betwen the two habitats but the edge of the arable is geographically easier to reach than the middle of the re-created downland; random excursions by butterflies from the established downland are thus more likely to be recorded on the edge of a habitat than in the middle. It should be remembered that these results only refer to adult butterflies, and do not give any information on their behaviour on the habitat types.

However, the emergence trap results showed that a sub-set of the butterflies whose larval food plant was present were breeding on the edge of the re-created downland at one site. Although far fewer were found here than on the downland, indicating that other factors influence oviposition as well as presence/absence of larval food plant, *Maniola jurtina* was found to emerge at almost equal densities on both habitats. These results only give data on the number of butterflies who successfully develop within the habitat, and a limitation on the work is that it gives no information about the level of oviposition underlying the emergences. An idea of the levels of oviposition occuring on downland and re-created downland was obtained from observational work on one particular species, *Maniola jurtina* and this is discussed in a later section.

6.3.2.2 Larval food plant

The above conclusion should be considered alongside observations made on *Maniola jurtina* which spent proportionately more time ovipositing on the re-created downland than on the established downland at all sites. If the results from the emergence traps at Langford Farm are consistent at other sites it appears that larval mortality may be higher on the re-created downland than on the established downland and despite increased oviposition on the re-created habitat fewer adults emerge. The work presented in Chapter 5 found that one non-native variety of *Lotus corniculatus* retarded development of *Polyommatus icarus* larvae in laboratory conditions, an effect which could influence survival in the field. It is known that all the grasses sown under downland re-creation in the SWD ESA are non-native in provenance and it must be considered that these food sources could influence the development of *M.jurtina* larvae in the same way as they have been shown to influence *P.icarus* larvae. It has also been shown that *M.jurtina* is somewhat indiscriminate when ovipositing and, like many of the butterfly species whose food plant is superabundant, will lay on unsuitable vegetation or bare ground (Wiklund 1984). This could account for the increased oviposition on the re-created downland as the areas resemble a superficially ideal habitat due to their high grass component.

The data that these discussions are based on is taken from a total of 20 traps placed within one study site. It is likely that the results vary with sward height and nectar availability as well as other factors such as type of grazing and availability of shelter (Gibson et al. 1987; Warren 1993; Welch 1994) and it would therefore be useful to widen the number of sites used and establish whether the results from Langford Farm are similar to those observed on other sites.

Oviposition by butterflies requires not only the presence of suitable larval foodplant but also suitable habitat conditions. The influence of presence/absence of larval food plant on adult distribution was evaluated by correlation (using *P.icarus*) and also by examining how closely butterfly distribution is tied to larval food plant distribution. Section 6.2.2.1ii found that the selective species were more closely allied to the distribution of their larval food plant than the generalist species which highlights the importance of obtaining the right species mix in the re-created downland sward if those butterflies characteristic of established downland are to be encouraged to breed on this habitat. Fig 6.2 also showed that selective species made up 65% of the total species on the re-creation edge but only 55% on the downland middle. Although this was not found to be a significant, it suggests that these species are exploring the re-created downland and links with results in Chapter 4 which showed that spread of plant species from the established downland to the re-created downland edge was occurring.

The correlation results presented in section 6.2.2.2ii showed that the abundance of one butterfly, *P.icarus*, was only correlated significantly with food plant abundance in the middle of the re-created downland turf. Although food plant is an obvious and important influence on adult distribution, there are other factors involved, especially in habitats where there is an abundant supply of larval food plant, such as downland and occasionally re-created downland edge. While gathering data on *P.icarus* it was observed that ovipositing females visited many small herbs (such as *Sanguisorba minor*, *Hippocrepis commosa* and *Trifolium pratense*) in the vicinity of the larval food plant and spent some time walking over the vegetation before finding a oviposition site. This has been observed in *Leptidea sinapis* (Warren 1981; Wiklund 1984) and is thought to be typical of butterflies whose larval food plant is inconspicuous.

In the middle of the re-created downland potential foodplants are relatively scarce and the amount of time spent searching for them might restrict butterfly abundance due to the amount of energy wasted. This, coupled with the lack of nectar from which to replenish energy, probably explains the significant correlation in this habitat as the larval food plant supply is a limiting factor on butterfly abundance.

Section 6.2.2.1iii correlated butterfly species richness with several different site and environmental factors and showed that aspect and nectar availability were important as well as presence absence of food plant. The correlations differed between habitat type, perhaps reflecting the relative strength of each factor in each habitat.

6.3.2.3 Habitat aspect

Aspect correlated with species richness within the re-created downland habitat, and was not explained by an increase in plant species richness or rank nectar abundance on the west facing slopes. A possible explanation was obtained from the observational work on *M.jurtina* where the butterfly spent proportionately more time resting on the re-created habitat than on the established downland and proportionately less time nectaring on the re-created downland. It might be that butterflies on the re-created downland do not find as much nectar as they need to replenish energy reserves and therefore rest more than on the downland. This could also be explained in terms of optimisation of fitness theory or optimal foraging approach (Charnov 1976; Parker and Stuart 1976) where models predict that in an environment where nectar supply is patchy the overall stay time will be longer, and include longer periods between nectaring. The warmest situations on this habitat would be those facing south and west - represented by a higher number of degrees on a compass.

It is also likely that aspect was an important factor determining butterfly distribution on the downland but, as with larval food plant distribution, the transect data was not sufficiently detailed to demonstrate this. Warren (1993) found that different butterfly species showed definite preferences for certain aspects and it would be interesting to extend the study of re-created downland to examine the impact of this factor in more detail. It might be found that the aspect preferences differ on downland and re-created downland as the differences in vegetation structure cause variation in microclimate. This would undoubtedly affect activities such as oviposition.

6.3.2.4 Nectar abundance and oviposition

Section 6.2.2.1iii found that the correlations with aspect on the re-created downland edge were slightly less significant than in the middle of this habitat, implying that other factors were involved in edge habitats. Rank nectar abundance related to species richness within this habitat and corroborates the results discussed earlier which showed that the number of individual butterflies spreading onto the edge of the re-created downland is similar to those found on the downland but that the number of emerging adults on this habitat is far fewer as is the number of species present. These findings imply that the habitat is mainly used for other activities such as nectaring and resting.

The fact that nectar is not related to species richness in the middle of the re-created downland shows that the presence/absence of butterflies here is influenced more by aspect and presence/absence of larval food plant (both identified by the correlation in section 6.2.2.1iii). The transect data shows how few species were recorded in this habitat and the vegetation data in Chapter 4 shows how few plant species are present to provide possible larval food sources. In other words the relationship between species richness and presence/absence of food plant does not imply that the habitat is particularly suitable for butterflies but that these factors limit the number of species present.

Previous studies have demonstrated that mobile species are attracted to increased availability of nectar on road verges (Munguira and Thomas 1992). It is possible that an increase in nectar supply would increase the butterfly number as the middle of the re-created downland would then be more similar to the edge of the re-created downland

By contrast very few significant correlations were identified within the downland, implying that many factors contribute to the suitability of this habitat for butterflies.

The lack of nectar sources on the re-created downland could reduce the fecundity and oviposition of butterflies using this habitat, including *P.icarus* and *M.jurtina*. It is known that nectar is a more important resource for female *M.jurtina* than males (Brakefield 1982a). Both of these species have relatively small minimum breeding area requirements; 0.065-0.85ha for *M.jurtina* (Brakefield 1982a) and 1-2ha for *P.icarus* (Thomas 1989) and it is thought that the actual breeding habitat for many species may be smaller than estimated due to the selectiveness exhibited by butterflies when ovipositing (Warren 1992). The size of most of the re-created downland areas is at least 2ha (and could therefore support a population of *M.jurtina* or *P.icarus*) and it has been shown that there are fewer nectar sources and that butterflies spend less time nectaring within these areas.

While evaluating the effect of adult diet on the biology of *Jalmenus evagoras*, the Common Imperial Blue, Hill (1989) found that, as is common in other species (David and Gardiner 1962), nectar availability affected fecundity by influencing female body weight. Reproducing populations of *P.icarus* and *M.jurtina* based within re-created chalk grassland are not likely to realise their full body weight, and resulting fecundity, due to the shortage of nectar supply. This will affect egg weight (Boggs 1986) and could account for the apparently high rate of larval mortality on this habitat. It is also known that even under normal field conditions female *M.jurtina* lay an estimated 66 eggs in their lifetime, which is only 0.37 of mean egg production under laboratory conditions (Brakefield 1982b).

6.3.2.5 Other behavioural patterns

The observational work presented in section 6.2.2.2i yielded information on the behavioural patterns of *M.jurtina* and can be compared with other information on how this and other species of butterfly partition their activities. *Anthocharis cardamines* shows very similar patterns of nectaring and egg-laying, although there is less of a distinction between the two activities than was found in *M.jurtina* in this study. In both species periods of flight are interspersed with feeding activity and oviposition occurs after short flights to find suitable larval food plants (Dennis 1986).

It has also been shown that butterfly species can 'serialise' their behaviour if nectar sources and oviposition sites are not in close proximity; egg-laying occurs for a while in one place, followed by a move to the habitat where more nectar sources are available. *M.jurtina* does not normally fall into this category as its larval food plants (a range of Graminae) are almost always present where there are good nectar sources. However, the division of activity observed on re-created downland habitat could indicate that the lack of nectar sources in this area causes this species to serialise its activity. This has been observed in populations of *Leptidea sinapis* (Wiklund 1977) and of *Hipparchia semele* on the Great Orme - those whose resources are spatially separated serialise their behaviour but those whose resources are close together intersperse feeding with ovipositing, much as *A.cardamines* does (Shreeve 1992). *M.jurtina* females were rarely observed performing any active behaviour other than nectaring or ovipositing and this is consistent with other observations on this species which have found that the females only fly to lay eggs or to feed and spend long periods resting or basking (Brakefield 1982a; Emmet and Heath 1990).

It is interesting that the observational work presented here found that *M.jurtina* nectared on flowers which were all members of the Compositae. This was also found in work comparing butterfly abundance and diversity on conservation headlands with that of normally managed field margins (Dover 1989) where female *M.jurtina* were found to utilise *Cirsium arvense*, *Knautia arvense*, *Carduus nutans* and *Cirsium vulgare*. Data compiled from many studies (Shreeve 1992) has shown that *M.jurtina* utilises species from other families such as Rosaceae, Labiateae and Ranunculaceae. Pollard (1981) concluded that the butterfly is an opportunist flower-feeder but these findings did not weight the species usage by nectar source abundance and it would be interesting if this had been carried out. Unpublished data by Porter, K. in Shreeve (1992) showed that when the use of a range of nectar sources by *M.jurtina* was weighted by availability *C.arvense* was preferred. This flower was visited for longer periods in the current study, lending support to this conclusion.

It also seems likely that *M.jurtina* utilises different nectar sources depending on availability with each habitat. Work which modelled the nectaring behaviour of *Thymelicus lineola* (Pivnick and McNeil 1985) found that optimal nectar concentration should be highly preferred by insects with high feeding costs (such as increased risk of predation or distance from nectar supply) and that the preferred nectar concentration would probably shift in relation to distance to supply; higher concentrations sought by those insects flying further and vica versa. On the re-created downland where nectar sources are scattered (representing a high feeding cost) it would be interesting to determine whether the favoured nectar source is dependant on relative species abundance or on nectar concentration.

6.4 Summary

The studies presented in this chapter attempt to clarify what is undoubtedly a complex set of interactions determining invertebrate distribution and abundance on the habitats used in this study. It was found that aspect, nectar abundance and presence of the larval food plant were important factors but that they varied between habitat. It was also found that on the established downland no one factor emerged as particularly significant, whereas on the re-created downland correlations appeared to show that nectar supply and presence of larval food plant were limiting, although further investigation is required. The arable edge habitat was found to be more attractive to butterflies than the middle of the re-created downland. This in itself was an interesting finding given that much money and time is spent on re-creating downland with the aim of attracting associated species and helping conserve them. There have been many studies on the importance of arable field edges and conservation headlands for butterflies (for example Feber (1995)) and it would be useful to determine whether this is solely because of their nectar abundance or because of the increase in larval food plant abundance as well.

Suggestions for further work have been made earlier in the discussion and there are many improvements which could have been made to the experimental designs used, mainly centering around expanding the number of replicate study sites used, and repeating experiments for a second or third year rather than performing them once. It would be particularly interesting to repeat the experiment presented in Chapter 5 (examining the effect of non-native provenance *L.corniculatus* on *P.icarus* larvae) using *M.jurtina* larvae on a range of the grasses sown into re-created downland fields within the SWD ESA. The results of this might resolve the question of what causes the apparently high mortality which occurs between oviposition and adult emergence in this butterfly on the re-created downland. It would also have been informative to collect Homoptera samples from throughout the year to increase sample size and gain more information about the abundance and distribution of species on the two habitats.

It would have been useful to use this group of species more in evaluating re-created downland habitat as it appears that they are sensitive indicator species.

The next chapter presents a general discussion and conclusions about the findings of the work presented in this thesis. This leads to a set of recommendations about the implementation and management of downland re-creation within the SWD ESA and on a wider scale.

Chapter 7 – General Discussion

7.1 Introduction

Chapter 7 discusses the work presented in this thesis, including the methodology, and some suggestions for further study are made. Finally, some general conclusions are drawn and these lead to a set of recommendations intended to advise current management guidelines within the South Wessex Downs ESA.

7.2 Discussion of methodology and design of experiments

7.2.1 Overall experimental design

The overall experimental design of the thesis, based around seven study sites, should have provided seven replications of each experiment. Pseudo-replications within each site were acknowledged by averaging data from each study site before comparing the data from all sites. In 1998 one of the study sites was removed from the ESA scheme, reducing the number of replicates to six, but this only affected the vegetation work carried out in the final year of the study.

Chapters 4 and 6 evaluate this experimental design by examining the similarity of the study sites and it was found that there were differences between them which affected their use as replicates. Analysis of the quadrat data showed that the vegetation composition of the sites in Wiltshire was subtly different from that of those in Dorset. Although the sites were mainly the same NVC classification, differences in the vegetation were identified during ordination analysis and these were attributed to a climatic influence; the Dorset sites receive an average of 200mm more precipitation than the Wiltshire sites. Soil analysis (Chapter 5) showed that soils from the same habitats at different sites were similar and this also suggests that the vegetation differences are due to climatic influence.

There were differences in the seed mixes sown on the re-created downland, between and within sites, which made use of the sites as a set of replicates difficult. Choice of seed mix depends primarily on the position of the re-created fields with reference to established downland but other influences, such as a need to increase the legume content to improve grazing, or the purchase of seed mixes from different seed companies were also in action. Despite this variation within habitat types, significant differences between habitats were still identifiable (see Chapter 4).

Inter-site variation was also identified from the butterfly transect data (Chapter 6) which was difficult to evaluate due to differences in butterfly population numbers. This will be due partly to the vegetation but also to other influences such as shelter, quality of surrounding habitat and adjacent butterfly populations. These limitations have been identified in other studies and it is felt that the experimental design could have been improved by increasing the number of study sites used.

7.2.2 Individual experimental design

The methodology used in this thesis was a combination of accepted, tested methods (such as the vegetation quadrats and soil sampling), adaptations of established techniques (such as the observational work and the butterfly transects) and novel procedures devised for specific experiments (such as the *Lotus corniculatus* / *Polyommatus icarus* work).

These methodologies are evaluated in the section below. Suggestions for improvements are also made, where these have not been discussed earlier in the thesis.

The use of a time series – vegetation and invertebrate indicator species work.

It would be useful to continue the butterfly transects/Homoptera sampling and the vegetation quadrats every other year so that they provide a time series. The initial cross over of downland calcicoles onto the edge of the re-created downland is detectable even five years after sowing, and it would be interesting to follow this process, detecting species spread further into the new habitat and an increase in the number of species occurring. Conversely, the degradation of established downland edge areas might be expected to lessen with time as the adjacent habitat improves and the application of fertilisers and herbicides ceases. Although other studies have identified this edge effect (Kleijn and Snoeijing 1998) there is no information available about the time span required to reverse this effect, if it is possible.

The invertebrate indicator work provides a counterpoint to the vegetation work by following the insects which are associated with specific plants or habitat types. It has been shown in this study that some indicator species are already using the re-created downland to breed. By continuing this work and the quadrats it would be possible to link increasing numbers of indicator species with the relative abundance of their food plants, as well as tracking the process of colonisation on the re-created habitat.

The use of Lepidoptera as indicator species

Some of the issues arising from the use of indicator species (such as limitations and previous work) are addressed in Chapters 1 and 6. However, the Lepidoptera are more mobile than many other invertebrates and this will affect the interpretation of results obtained from this group. The use of Homoptera (less mobile than the Lepidoptera) as a second indicator group provided a useful comparison of the two indicator groups and showed that butterflies and Homoptera have started to colonise the re-created downland. However, information about more detailed butterfly behaviour (such as which factors control their distribution between habitats) should be extrapolated to other groups with caution as the findings will be closely linked to specific behavioural traits.

For instance, some butterfly species exhibit hilltopping behaviour, and this is not often found in other invertebrate groups (Scott 1970). The arable fields which are put into downland re-creation tend to be those of marginal arable use, often on windy hill tops. The introduction of butterfly food plants to these areas (through re-seeding) might mean that hilltopping species colonise faster than other invertebrate groups, implying that colonisation rates calculated from Lepidopteran data should be examined carefully. However, the species which exhibit this behaviour tend to be large, strong fliers (not characteristic of the downland species) so if the downland indicators are separated from the more generalist species (as in this thesis) then the results are less likely to be biased by hilltopping.

Insects in general are seen as vital to the establishment and success of habitat re-creation (Majer 1997); assisting in propagule dispersal, nutrient turnover and soil structure. For these reasons alone it is interesting to determine the invertebrate presence on re-created downland, using the information gained as an indicator of habitat development, as well as colonisation success.

Evaluating the effect of non-native Lotus corniculatus varieties

Other vegetation work carried out in this thesis examined the effects of non-native plant varieties on their insect herbivores. Quadrat work enabled the results of these experiments to be extrapolated to field conditions as the abundance of the non-native varieties was known (see Chapter 5, section 5.3). The *L.corniculatus/P.icarus* work was designed especially for this thesis and in the course of the experiment it became clear that improvements could have been made:

- The number of larvae obtained for the experiment was small and this meant that the number of replicates fed on each plant variety was low and led to large error margins when analysing the data. This problem also affected the number of days of data which could be analysed because once the larvae started to pupate the number of replicates became even smaller.

- It would also be better to rear the larvae from hatching on the different varieties of *L.corniculatus*, rather than from the second instar, which reduced the recordable development time.

These two problems would be solved by placing a fertilised female *P.icarus* in a flight cage with plants of the three different *L.corniculatus* varieties, so that larvae could be reared on the separate varieties from the beginning. Also, an attempt was made to rear a second generation of larvae. This failed due to the very low number of replicates and increased mortality, possibly due to inbreeding from the first generation. A repetition of the work (via a second generation) would have been useful because biomagnification might have increased the *L.corniculatus* varietal effects and an increased first generation size might have made this possible.

A third issue which might have affected this study was the absence of any analysis of plant cyanide or nitrate content. It has been shown that the cyanide content of plant tissue can affect larval development in associated herbivores (Compton and Jones 1985) and this could have been a significant factor affecting the experimental results. Chapter 5 found that one non-native variety (Oberhausteder) performed significantly better than one other non-native and native *L.corniculatus*. Although no nitrate analysis was performed it seems likely that the non-natives contain different levels of this nutrient to the native (see section 5.3) and it is also known that cyanide functions as a nitrogen store as well as a defensive chemical (Crawford 1989). Given this link with cyanide and nitrogen, an analysis might have shown significantly different nitrogen and cyanide levels in the non-native (Maitland) which affected larval development. A repetition of the two experiments using *Lotus corniculatus* (evaluating it's effect on larval development and its performance on different soils) would have benefitted from cyanide and nitrate analysis.

Emergence traps

The traps designed for this thesis appeared to fulfill their function of maximising the catchment area using the least possible netting. The broad-based pyramidal shape meant that the traps were not very high and it was expected that there would be problems identifying emerged butterflies in the vegetation and with predation. These issues were largely avoided by moving the traps regularly, before the vegetation grew to fill the traps. However, the data collected from the emergence traps was fairly thin and the study would benefit from repetition and from using a larger number of emergence traps on the two habitats.

Behavioural differences on re-created and established downland.

Observational work determined clear differences in *Maniola jurtina* behaviour on re-created and established downland, using the seven replicate study sites. This methodology is well developed (see section 6.3 in Chapter 6) and it is relatively easy to gain useful information from a limited period of work. One source of error in the experiment could have occurred due to the timing of the work. Observations were made quite late in the season when it is known that several species of butterfly exhibit different behaviour to earlier in the year or lifespan (Boggs 1986). To eliminate this, the observational work could have been carried out on more than one species (doubling the experimental time) and earlier in the season to verify the behavioural patterns. The use of more than one species would also allow comparison of the behaviour on re-created downland of butterflies which have different mating and oviposition strategies, as evaluated by Wiklund (1984).

Correlations were also used to evaluate the effect of environmental variables on butterfly distribution and included variables such as nectar availability, larval food plant availability and % cover. However, the importance of shelter for butterflies has been identified as an important factor, especially in marginal habitats (Dover et al. 1997) and the inclusion of this in the correlations would probably have identified it as a significant factor determining butterfly abundance on the re-created downland and established downland. Re-created downland is notable for its lack of shelter from scrub or trees, other than the surrounding hedgerows. Observations during the course of the study suggest that on windier days butterflies were found in far greater numbers in sheltered areas (around scrub on established downland for instance) where they can remain active, whereas those on the more exposed re-created downland were forced to remain relatively immobile until conditions improved.

It has also been shown that *M.jurtina* emergence varies with the amount of shelter available (Brakefield 1987) and it would have been interesting to examine differences in phenology of this species on the re-created and established downland where there are differences in the amount of available shelter. If these differences were found to be significant they could even be used as a way of evaluating the increasing similarity between the two habitats by tracking the changes in emergence phenology over time.

Factors affecting oviposition

The results from this work were not very conclusive or informative. Egg searches were carried out late in the season, resulting in very few eggs being found and therefore no significant results. The experiment would benefit by being repeated in June/July when most *Polyommatus icarus* eggs are laid (Thomas 1993). Measurement of adult densities at the site (by butterfly transect) would also have contributed to interpretation of these results.

Observational work showed that *Maniola jurtina* butterflies spent more time laying on the re-created downland than the established downland but that adult emergences were greater on the downland. It would be interesting to investigate whether this is true for *P.icarus* (whose larval food plant is not as abundant on the re-created downland as that of *M.jurtina*) or whether oviposition is related more strongly to larval food plant density and the butterfly lays more on the downland. Results from the oviposition work did suggest this but were not conclusive.

7.3 General discussion of results

7.3.1 Introduction

The work presented in this thesis has focused on the differences between re-created and established downland and evaluated re-created downland in terms of its value for invertebrates. Results from the two groups of invertebrates have also been used to indicate the habitat value for other species found on downland. Discussions at the end of each results chapter focus on the detail of each set of work and the paragraphs below present an overall view of the findings in this thesis, attempting to put them into context with other studies on the subject area.

7.3.2 Summary and Discussion

The soils on which downland is re-created contain low amounts of organic matter and soil nutrients. In contrast to arable soil, concentrations of nutrients such as nitrate reflect soil processes (eg immobilisation) rather than artificial fertiliser inputs, and this reveals the impoverished state of the soil used for downland re-creation.

The resulting re-created downland sward reflects these nutrient concentrations as well as the seed mixture used. There is a high proportion of grasses, with some forbs, depending on which were sown. At the edge of this habitat, on sites adjacent to established downland, native downland calcicoles are starting to colonise in low numbers. There is also a weed problem on many sites resulting from the arable seed bank and patchiness of the re-created sward as it establishes on impoverished soils.

In contrast the established downland is species rich and sward structure is far more complex, with local variation in species composition resulting from years of grazing management as well as factors such as rainfall and slope. The edge of this habitat, adjacent to the formerly arable fields, is degraded and contains fewer true calcicoles than areas further from the influence of herbicides and fertilisers. Results presented in this study identified this effect but could not establish whether the establishment of re-created downland would reverse it in time.

The re-created downland is established with the aim of providing buffer zones around existing downland and also re-creating areas of this threatened habitat. The initial seed mix with which it is sown attracts some invertebrates and a subset of these was found to be breeding on the new habitat. However, there is a limited range of larval food plants and species richness overall is low; these were shown to be limiting factors on the abundance of butterflies on the habitat. Other factors which affected invertebrate use of the new habitat included nectar supply; work on *Maniola jurtina* showed that lack of nectar supply on this habitat caused serialisation of it's behaviour – long periods of egg-laying were not alternated with nectaring as they would normally be and this might effect the breeding success of this butterfly on the re-created downland.

Another factor which will affect invertebrate usage of the sward is the provenance of the species sown. Laboratory experiments proved that non-native provenance *Lotus corniculatus* can increase relative consumption rate while retarding *Polyommatus icarus* larval development time, whereas native *L.corniculatus* does not increase the relative consumption rate or retard larval development time.

These findings show how important the use of native seed is in habitat re-creation. The majority of seed sown within the South Wessex Downs ESA is non-native and this places more importance on the role which natural colonisation plays in establishing the new habitat. This thesis has also shown how non-native *L.corniculatus* grows more vigorously on a range of soils than native *L.corniculatus*. These results imply that even if native *L.corniculatus* is colonising the re-created downland it will not be able to compete well with non-native varieties and will not grow as strongly on the impoverished ex-arable soils. Although these results are only based on laboratory trials over a single season they still demonstrate the importance of using native seed or considering natural re-colonisation before re-seeding if at all possible. The vigorous growth of non-native *L.corniculatus* might also facilitate colonisation of the edges of the established downland which would create the opposite effect of that hoped for by the scheme.

The research found that arable field edges were used more by butterflies than the middle of re-created downland areas where nectar supply and larval food plant abundance were limited. Although it is not known whether the arable field edges were used for breeding as well as nectaring, this finding does imply that the downland re-creation needs improvement if, at the moment, it is not as well used as the arable field edges which were there previously. However, it is worth reiterating that these results are based only on butterfly transect data and information was not gathered on other invertebrates that might occur in the edges of arable fields or whether butterflies such as *M.jurtina* and *Lycaena phlaeas* (which were found breeding on re-created downland) also breed on these habitats.

Although the literature relating to re-created downland is currently quite limited, there are other studies which are relevant to these results; the degradation of species rich habitat as a result of fertiliser and pesticide application to adjacent arable land is discussed in Chapter 4, as are the findings of research at Twyford Down, Hampshire which showed that species spread on re-created downland was similar to that observed in this study.

The link of butterfly abundance with larval food plant abundance and vascular plant species richness was demonstrated in a study in Switzerland (Erhardt 1985). Butterfly species richness on cultivated grassland in a series of stages of abandonment was found to be linked to the species richness of vascular plants, and declined rapidly with the arrival of shrubs and trees. Work in Germany (Steffan-Dewenter and Tscharntke 1997) also found this link between vascular plant and butterfly species richness but went on to identify flower abundance as the most important factor, especially on early successional fields which are superficially similar to re-created downland. This study also demonstrated the change in the suite of species which occurs with time, from large bodied, migratory species to smaller, more sedentary species. The results were thus consistent with those of this thesis where it was found that many of the Lepidoptera on the re-created habitat were generalists and many of the Homoptera were also macropterous, dispersing species and those characteristic of young habitats.

Studies by the Game Conservancy Trust (Dover 1988; Dover et al. 1990) have demonstrated how small changes in habitat management increased the abundance of generalist butterfly species (the Pieridae in particular). The work presented in this thesis shows that with slightly larger changes – the sowing of a basic seed mix and positive management – other species are attracted onto the new habitat and even breed there. The constraints on colonisation of this habitat are discussed above and work in Switzerland and Germany as well as in England (Dover 1996) corroborates the importance of nectar and larval food plant abundance on these new habitats. Other studies have highlighted the importance of microclimate in larval development and breeding success (Brakefield 1987) and it seems likely that the structure of the re-created downland will lead to a microclimate which is profoundly different to that of established downland, affecting invertebrate development and colonisation on the habitat. It would be interesting to evaluate these differences.

7.4 General conclusions

Thousands of hectares of land have been entered into agri-environment schemes in the UK and habitat re-creation is seen as an important component of this. In addition many other habitat re-creation projects, large and small, are being undertaken with increasing frequency by conservation organisations, planning authorities and private individuals.

The potential of these schemes to encourage good conservation practice, aid in the conservation of endangered species, enlarge the amount of available habitat for many species and raise awareness of environmental issues is enormous.

It is thus important that the methods of habitat re-creation are soundly based, from the earliest stage of seed bed preparation to subsequent annual management regimes. This will help ensure effective conservation and also encourage faith in the potential of habitat re-creation (and the agri-environment programme) to deliver real benefits for wildlife. The work presented in this thesis shows that as well as seed bed preparation other considerations should be included such as:

- assessment of adjacent habitat and the potential for natural re-colonisation;
- the avoidance of non-native seed sources
- the availability of nectar, both to entice invertebrates onto the habitat and aid successful colonisation;

Although this thesis has concentrated on plants and insects, it is hoped that the data on invertebrate use of the re-created habitat can be used to provide an idea of its use by other groups such as birds. Other studies have shown that re-created downland is used by some bird species (see Chapter 1) and the value of the habitat as a food resource for birds and mammals could be considerable.

Even though the re-created chalk downland is currently far poorer as a habitat compared to established downland, the results show that there are benefits to wildlife very soon after its creation. These will presumably increase over time, provided areas of downland re-creation are retained in the future. In the mean time it is worth considering that as well as preserving endangered, rare habitats, areas such as these are useful to many species and can also provide corridors linking fragments of established habitat, much as green lanes and areas of rough grassland already do (see Dover (1997) for a discussion of this).

As well as using invertebrates to predict how changes in habitat management affect other groups of species it is important that we understand how the invertebrates themselves respond to this new habitat. It is estimated that invertebrates have matched or exceeded the extinction rates of vertebrates and vascular plants this century (Thomas and Morris 1994) and that many highly endangered invertebrates inhabit early or late successional habitats. Re-creation schemes aim to expand the amount of available ancient habitat but in their first years they could also provide important habitat for those invertebrates which inhabitat recently disturbed areas with a more dynamic vegetation structure.

With these findings and discussions in mind, a set of recommendations are presented below which are intended to improve and advise the implementation of downland re-creation in the South Wessex Downs ESA.

7.5 Recommendations

- **No fertiliser should be applied to re-created downland adjacent to established downland.** The degradation of established downland which would probably result is contrary to the aim of preserving these habitats by creating buffer areas around them. Instead scheme literature and guidelines should focus on the long term nature of the habitat re-creation and advocate supplementary feeding or staggered habitat re-creation to allow enough pasture to support livestock while re-created downland productivity is low. This should be planned as part of a whole farm management agreement (as is already practised in the SWD ESA) so that areas of habitat re-creation are not seen in isolation but as part of a working farm unit.

- **The potential of existing downland to aid natural re-colonisation should be considered before re-seeding.** Results presented in this thesis showed that even after five years significant numbers of naturally occurring downland calcicoles were found in the first ten metres of re-created downland adjacent to established downland, representing a reasonably fast rate of spread. This option should always be considered before re-seeding as the topography of some re-creation sites (for instance those at the bottom of established downland slopes) suggests that natural colonisation will occur quickly, perhaps only requiring a basic grass mix to help prevent weed problems. The potential for this should be assessed on a site by site basis and can be used to emphasise the long-term commitment of habitat re-creation and the ESA scheme. It would reduce the problems incurred by using non-native seed.

  It could be said that using natural re-colonisation represents less work and expense than downland re-creation and should be included in the scheme as a separate option to habitat re-creation using re-seeding. However, it is likely that weed control would be a greater problem; an initial seed mix might still have to be sown and the follow up management programme would be the same. So for simplicity the re-colonisation option could be appended to current Tier 2 Option 1 (downland re-creation) scheme guidelines.

- **Non-native seed of any kind should be avoided.** The results of this research showed that, of the two non-native *Lotus corniculatus* varieties used, one significantly affected larval development. Previous research and results presented in Chapter 5 also show that the colonising potential of non-native species is high and this alone should advocate a complete ban on non-native seed where re-created downland is adjacent to established downland. Although the non-native seed may create a pleasing initial effect, due to it's vigorous germination and establishment, the combination of its effect on invertebrates and ability to possibly out-compete native seed on impoverished soils demonstrates that non-native seed will probably do more harm than good in the long term.

  Instead, agreement holders and land owners interested in habitat re-creation should focus on seed harvesting and local seed supply, ensuring the use of native, preferrably local seed. Within the SWD ESA agreement holders are already subsidised to use native seed where possible but this should be changed so that only native seed is allowed. Supplies of native seed do not match demand at the moment but this situation is being addressed by local suppliers and it is recommended that habitat re-creation should be carried out slowly, in a series of smaller blocks, while seed supplies are increased via harvesting and propagation. It is better to wait until native seed supplies are available than establish a non-native sward which may cause problems in future years and this should be made clear to agreement holders, even if it means delaying the next available window for joining the scheme until the infrastructure to carry it out is in place.

  MAFF involvement in the co-ordination and perhaps subsidisation of local seed production (along with organisations such as Flora Locale) would ensure continuity within the scheme as well as a holistic approach to habitat re-creation; from seed production/harvesting to habitat re-creation and subsequent management and care. Existing downland at each re-creation site should also be used as a (supplementary) seed source as this would ensure the conservation of local genetic strains.

- **The seed mix used for downland re-creation should include a higher forb component.** It was shown that nectar abundance was a factor controlling butterfly abundance (and possibly other invertebrate abundance) on the re-created downland. This has also been found in other studies (Feber 1995; Sparks and Parish 1995; Dover 1996). Observational work showed that *Maniola jurtina* laid more on the re-created downland but fewer adults emerged on the habitat and it is known that butterflies do not oviposit as successfully when they are not fully fed (Dennis 1992). Nectar abundance affects the colonisation success of invertebrates and the subsequent distribution of other groups such as birds and mammals, partly linked to available food sources, will also be affected.

- **The structure of re-created downland habitat should be improved by planting clumps of scrub or trees for shelter.** Although the importance of shelter was not evaluated in this study, observations led to the conclusion that it was an important factor and published work acknowledges this fact. For migratory insects and other groups of species such as birds, trees and scrub provide shelter and add structure to the habitat and would aid colonisation of the re-created downland. Scrub removal on established downland is part funded by the scheme and the deliberate establishment of scrub on re-created downland could be seen as ridiculous by agreement holders. However explanation of the aims of the habitat re-creation, and what constitutes downland habitat, as well as the funding of this activity as a conservation item might help this.

- **Scheme monitoring should evaluate the development of the re-created downland as well as focusing on the changing status of the established downland.** One of the aims of the SWD ESA is to conserve existing areas of downland habitat; monitoring is focused on evaluating the success of the scheme in fulfilling this aim. Another aim is to create new areas of downland for eventual use by threatened species and to buffer existing downland. Without a monitoring programme to evaluate the success of this part of the scheme and identify areas which could be improved it will be difficult to say whether this aim is being achieved or not and possible problems (such as a lack of nectar sources or the use of non-native seed) will not be identified. It is important that a scheme with long term goals (such as the ESA scheme) is allowed to evolve and that monitoring is used to guide its development and improvement with time.

7.6 Suggestions for further study

Some suggestions for further study are made in section 7.2 and the results chapter discussions. There are many improvements which could have been made to the experimental designs used, centering around expanding the number of replicate study sites used, and repeating experiments for a second or third year rather than performing them once. Apart from these general points the main areas of this thesis which need to be investigated further are;

- The effect of non-native plant varieties on associated herbivores (using *Maniola jurtina* - see below);

- The rate of spread of downland calcicoles onto the re-created downland;

- The effect on the edge of the established downland of cessation of arable management and establishment of a re-created downland sward;

- The pattern of re-colonisation of the re-created downland by invertebrate indicator species, and how this is linked to changes in the vegetation (see below).

It would be particularly interesting to repeat the experiment presented in Chapter 5 (examining the effect of non-native provenance *Lotus corniculatus* on *Polyommatus icarus* larvae) using *M.jurtina* larvae on a range of the non-native grasses sown into re-created downland fields within the South Wessex Downs ESA. The results of this might resolve the question of what causes the apparently high mortality which occurs between oviposition and adult emergence of this butterfly on the re-created downland.

It would also have been informative to collect Homoptera samples throughout the year to increase sample size and gain more information about the abundance and distribution of species on the two habitats. This group of species appear to be sensitive indicator species and would be useful to include in further studies evaluating re-created downland.

8.0 Appendices

Appendix 1 – Management Guidelines for the South Wessex Downs ESA

Tier	Details
Tier 1 (Part 1 – all land) – baseline management guidelines onto which the more specific Tier guidelines are added.	Contains general guidelines for the maintainance of field boundaries, disposal of chemicals, management of ponds, woodlands and archaeological features. Also advises on general grazing regime.
Tier 1 (Part 2 – Permanent grassland)	Guidelines for management of permanent grassland – prohibit ploughing, installation of new drainage, use of fungicides/insecticides (except in certain circumstances), use of slag, lime etc and also regulate application rates of fertiliser.
Tier 1 (Part 3 – Downland turf)	Guidelines for downland management – prohibit ploughing, reseeding, hay-cutting, installation of drainage systems, use of fungicides/insecticides (as above), use of slag, lime and application of any fertiliser.
Tier 2 (Option 1 – Downland turf creation)	Guidelines for creation and subsequent management – cease arable use and re-seed to a permanent sward using an approved seed mix (see Appendix 2) in next 12 months. Subsequently, remove a hay/silage crop once a year for the first three years and graze with cattle or sheep at appropriate rates. Other guidelines referring to herbicide/ fertilisers etc are similar to Tier 1 (Part 3).
Tier 2 (Option 2 – Reversion of arable land to permanent grassland)	Guidelines for the creation of permanent grassland – cease arable production and re-seed with a suitable seed mix. Existing 'islands' of semi-natural grassland should be left. First year of agreement prohibits addition of any fertilisers/herbicides/insecticides/lime, slag etc. Subsequent years follow Tier 1 Part 2 guidelines.

Tier 2 (Option 3 – Conservation headlands)	Prohibits application of insecticides to a 6m wide strip around cereal field edges between 1 September and 31 December. Also prohibits most herbicides.
Tier 2 (Option 4 – Permanent grassland enhancement)	Guidelines to increase the nature conservation quality of permanent grassland. Prohibits chain harrowing or rolling from 1 April to 30 June. Excludes stock for 7 weeks before hay cutting. Prohibits use of fertilisers of hay/silage making between 1 July and 31 August and advocates topping areas not used for silage/hay making to prevent spread of coarse grasses.
Public access Tier	To provide new public access opportunities for walking and other re-creation. Includes keeping access routes open and free of litter, erecting signboards and waymarks and excluding bulls from access routes.

These summarised guidelines are taken from the Guidelines for Farmers in the South Wessex Downs ESA (MAFF, 1994b). They are intended to provide an idea of what is involved in entering an agreement within the scheme, rather than a comprehensive list of the management guidelines in the scheme. Management agreements last for 5 years; the first window for entry was in 1993, and a second window was opened in 1998.

Appendix 2 – Approved seed mixes for downland re-creation in the SWD ESA.

Mix No. 1 – Next to SSSI's on downland or other rich seed sources. 15kg/ha	
Grasses:	Weight of each component (kg/ha):
Festuca ovina	7.5
Cynosurus cristatus	3.0
Agrostis capillaris	1.5
Festuca rubra ssp. commutata	3.0
Mix No. 2 – Next to existing downland. 20kg/ha	
Grasses:	Weight of each component (kg/ha):
Festuca ovina	10
Agrostis capillaris	1
Cynosurus cristatus	4
Festuca rubra ssp commutata	4
Trisetum flavescens	0.2
Koeleria macrantha	0.1
Briza media	0.1
Anthoxanthum odoratum	0.1
Forbs (Native British Origin):	
Lotus corniculatus	0.1
Leontodon hispidus	0.1
Prunella vulgaris	0.1
Sanguisorba minor ssp minor	0.2

Mix No. 3 – Downland turf elsewhere. 20kg/ha	
Grasses:	Weight of each component (grasses - kg/ha, forbs – g/ha):
Festuca ovina	8
Agrostis capillaris	2
Cynosurus cristatus	4
Festuca rubra ssp commutata	5
Trisetum flavescens	0.2
Koeleria macrantha	0.1
Briza media	0.1
Anthoxanthum odoratum	0.1
Forbs:	
Lotus corniculatus	100
Leucanthemum vulgare	50
Prunella vulgaris	100
Sanguisorba minor ssp minor	100
Primula veris	20
Rumex acetosa	20
Galium verum	50
Leontodon hispidus	10
Centaurea nigra	25
Plantago media	25

The lists of approved seed mixes presented above were used within the SWD ESA for the first two years after its inception. Subsequent amendments included the addition of more forbs to mixes 2 and 3, but the agreement holders whose land was used in this thesis all used the original seed mixes.

Appendix 3

Table 1: Main larval foodplants of the butterflies found on re-created and established downland. (The list of foodplants is not a definitive one as it has been shown that availability of the main larval food plant is more closely linked to adult distribution than availability of all larval food plants (Brereton, 1997).

Butterfly species	Main food plant species
Lycaena phlaeas	*Rumex acetosa*
Cupido minimus	*Anthyllis vulneraria*
Aricia agestis	*Helianthemum nummularium*
Polyommatus icarus	*Lotus corniculatus*
Lysandra coridon	*Hippocrepis comosa*
Lysandra bellargus	*Hippocrepis comosa*
Celastrina argiolus	*Ilex aquifolium / Hedera helix*
Callophrys rubi	*Ulex minor / Helianthemum nummularium*
Hamearis lucina	*Primula veris*
Thymelicus lineola	*Dactylis glomerata*
Ochlodes venata	*Dactylis glomerata*
Thymelicus sylvestris	*Holcus lanatus*
Pyrgus malvae	*Fragaria vesca*
Erynnis tages	*Lotus corniculatus*
Colias croceus	*Trifolium sp.*
Gonepteryx rhamni	*Rhamnus catharticus*
Pieris brassicae	*Cruciferae (eg Reseda lutea, Brassica sp.)*
Pieris rapae	*Cruciferae (eg Alliaria petiolata, Brassica sp.)*
Pieris napi	*Cruciferae (eg Alliaria petiolata, Cardamine pratensis)*
Anthocharis cardamines	*Cardamine pratensis / Alliaria petiolata*
Cynthia cardui	*Cirsium/Carduus sp.*
Aglais urticae	*Urtica dioica*
Vanessa atalanta	*Urtica dioica*
Inachis io	*Urtica dioica*
Polygonia c-album	*Urtica dioica*
Argynnis aglaja	*Viola sp.*
Eurodryas aurinia	*Succisa pratensis*
Pararge aegeria	*Dactylis glomerata*
Pyronia tithonus	*Agrostis sp.*
Melanargia galathea	*Festuca rubra*
Maniola jurtina	*Graminae*
Aphantopus hyperantus	*Elytrigia repens / Poa pratensis*
Coenonympha pamphilus	*Festuca sp.*

Appendix 4 – Transcriptions of observations on the behaviour of M.jurtina females, demonstrating serialisation of nectaring and ovipositing.

Table 1: Sample activity log for *M.jurtina*, demonstrating typical observed nectaring behaviour (times are in seconds).

Activity				
resting	basking	flying	nectaring	species used
			15	*Leontodon hispidus*
		2		
			30	*Centaurea nigra*
		3		
			20	*Scabiosa columbaria*
		2		
			19	*Leontodon hispidus*
		2		
			21	*Leontodon hispidus*
		24		
	82			
4				
	22			
3				
	130			
		17		
			42	*Succisa pratensis*
		1		
			22	*Succisa pratensis*
		2		
			11	*Succisa pratensis*
		8		
			162	*Centaurea nigra*
		2		
			43	*Centaurea nigra*
		3		
			80	*Succisa pratensis*
		1		
			135	*Succisa pratensis*
		1		
			12	*Scabiosa columbaria*
		1		
			4	*Scabiosa columbaria*
		2		
			143	*Succisa pratensis*
		1		
			30	*Scabiosa columbaria*
		4		
			17	*Scabiosa columbaria*

resting	basking	flying	nectaring	species used
		22		
			70	*Succisa pratensis*
		3		
			32	*Succisa pratensis*
		22		
			92	*Succisa pratensis*
		1		
			29	*Succisa pratensis*
		19		
			30	*Cirsium acaule*
		2		
			11	*Succisa pratensis*
		19		
			17	*Succisa pratensis*
		3		
			22	*Cirsium acaule*
		1		
			28	*Cirsium acaule*
		15		
			11	*Cirsium acaule*
		8		
			32	*Scabiosa columbaria*
		3		
			11	*Cirsium acaule*
217				
		11		
			37	*Centaurea nigra*
		2		
			4	*Succisa pratensis*
		12		
	57			

Table 2: Sample activity log for *M.jurtina*, demonstrating typical observed egg-laying behaviour (times are in seconds).

Activity				
resting	basking	flying	nectaring	egg-laying
2				
		8		
			3	
		15		
	23			
		12		
			57	
		30		
126				
		7		
110				
		5		
10				
				8
		5		
23				
		11		
130				
		8		
28				
				35
		3		
				33
255				
				22
		7		
				26
		6		
				6
		3		
				30
		2		
18				
		2		
	43			
		6		
14				
		8		
				3
		11		
114				
	143			

resting	basking	flying	nectaring	egg-laying
53				
	21			
124				
	17			
282				
	6			
30				
	5			
138				
	39			
57				
	104			
57				
		3		
				8
		3		
				5
22				
		5		
				25
		10		
	14			
		12		
				23
19				
		9		
55				
		3		
				13
			5	
		3		
90				
		12		
				20
		5		
				45

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