An investigation into the performance of species in ecologically based ornamental herbaceous vegetation, with particular reference to competition in productive environments.

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ABSTRACT

The use of ornamental herbaceous plants in ecologically based planting schemes (EBPS) requires selection of species which are compatible, particularly for productive environments where competition is likely to be intense. Competitor, Stress tolerator, Ruderal (CSR) theory is considered and rejected as a guide to plant selection, although some of its insights are regarded as valuable. Competition between component taxa in EBPS is considered a key issue. Researching competition for practitioners in horticulture and allied industries involves a less reductionist and a greater observational methodology than is customary amongst plant ecologists. Simple competition trials are evaluated with regard to not just their outcomes in terms of understanding competition, but also their suitability for practitioners.

A system for the classification of ornamental herbaceous plants is suggested, based on easily recognised aspects of their morphology and phenology. Plant architecture, the potential to spread through ramets and an ability to exploit growing seasons of various lengths are regarded as key variables. Relationships between the suggested categories and estimates of competitive performance in garden and EBPS conditions are considered. Biomass, as represented by a combination of canopy height and spread, an ability to spread extensively through ramets and an ability to grow over a long growing season are suggested as key factors in predicting both long-term survival and competitive performance.

A knowledge of plant traits is suggested as being of key importance to practitioners in predicting plant performance over time, more so than comparison of environmental conditions in the region of origin and in cultivation. The contribution of genetically derived traits to distinct growth characteristics in different growing conditions is recognised, and their relevance to practitioners working with a variety of different design methodologies is discussed.

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NOTES ON NOMENCLATURE OF SPECIES DISCUSSED

The Royal Horticultural Society Plant Finder (20th edition) has been used. All names are in conformity with this, except where noted. Specimens of all taxa listed are from forms generally current in UK commerce, unless noted. Where specific cultivars of a species have been used, but not always mentioned specifically in the text this is noted.

Achillea millefolium – wild form

Aconitum arctuatum - BSWJ 864 , may possibly be *A. ceolense* (personal communicaiton, B.Wynne-Jones)

Aconogonon 'Johanneswolke' – still listed by RHS as *Persicaria polymorpha*

Anemone x hybrida – unidentified hybrid

Artemesia lactiflora - cultivar 'Rosenschleier'

Aster cordifolius - cultivar 'Little Carlow' which may be *Aster cordifolius x A. laevis* (Picton 1999)

Aster novi-belgii - unidentified cultivar

Aster puniceus – wild collection origin

Calamintha grandiflora – wild collection origin

Cirsium canum – wild collection origin

Cirsium rivulare – cultivar 'Atropurpureum'

Dianthus carthusianorum - wild collection origin

Eupatorium maculatum - wild collection origin, exact identity unclear, could be *E. fistulosum*

Filipendula rubra - cultivar 'Venusta'

Filipendula ulmaria – wild form

Geranium asphodeloides – is subsp. *asphodeloides*

Geranium phaeum - cultivar 'Lily Lovell'

Geranium sylvaticum – cutivar 'Birch Lilac'

Geranium x oxonianum – the plants studied were either cultivar 'Claridge Druce' (if specified) or possibly *G. endressii*. Confusion between this species and its hybrid with *G.versicolor* is common. Morphologically and phenologically they are very similar.

Inula cf. *racemosa* – identity unclear

Kniphofia var. - identity unclear, a typical commercial hybrid

Miscanthus sinensis – cultivar 'Silberfeder'

Monarda hybs. – various Oudolf-bred cultivars

Papaver orientale – unidentified commerical hybrid

Phlox paniculata – wild form

Salvia nemorosa – cultivar 'Ostfriesland'

Solidago rugosa – cultivar 'Fireworks'

Stipa arundinacea – now regarded as *Anemanthele lessoniana*

Thermopsis caroliniana – possibly *T.fraxinifolia*

ABBREVIATIONS and TERMINOLOGY

EBPS – Ecologically-based planting scheme

Wintergreens – this term is preferred to evergreens, and is used here to refer to species which normally keep functioning leaves over the winter in the British Isles, whatever the lifespan of those leaves.

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INTRODUCTION AND LITERATURE REVIEW

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1.1 INTRODUCTION

1.1.1 Background

Trees and grass have traditionally provided the essential framework of urban parks worldwide, with high-visibility sites planted with annual bedding. Herbaceous plants in particular can seem an attractive additional option, as they can offer a long season of floral interest, the element of seasonal change, and unlike annual bedding with its yearly costs of planting and removal, considerable savings in maintenance costs. Generally speaking, the few herbaceous plants in public spaces were traditionally organised into narrow borders, but recently there has been much interest in a more extensive use of herbaceous ornamentals in public space (Erasmus 1997, Plenk 1998, Dunnett & Hitchmough 2004), which has been closely linked to a style of planting that can be described as 'naturalistic' or 'ecological'. An exact definition of an ecologically based planting scheme (EBPS) is difficult to agree, but includes the notion of a species-rich, complex and dynamic vegetation, which regenerates itself with a minimum of inputs, and is thus can be regarded as largely 'sustainable' (Dunnett & Hitchmough 2004). The potential of this planting style has been explored largely in Germany and The Netherlands, but even in these countries is not widely seen. The UK, despite a very strong horticultural tradition, has seen little application of it so far.

A central paradox of horticulture is how little use the field has made of plant ecology. Conversely, plant ecologists have shown little interest in how plants function in horticultural settings, and may even question whether this is valid as a subject of study (Dunnett 2003a). The result is that we really know very little about the ecology of garden plants. However with ecologically inspired plantings, an understanding of plant ecology is absolutely vital, as plant combinations are created that combine a strong visual component with their own dynamic, and it is the presence of this dynamic that takes their management beyond the skills base of traditional horticultural management.

This research is part of a growing movement concerned with relating the lessons of plant ecology to horticulture, particularly public horticulture, and to develop a more sustainable and environmentally friendly style, largely using herbaceous species. The proposal aims to address an area that is central to the whole project, that of identifying the characteristics that make particular species potentially useful for ecologically based planting design. *This means that it essentially falls into the field of scientific plant ecology;* however, the vast majority of practitioners in this *field* have no particular understanding of this discipline; and the demands of the research, in terms of outcomes relevant to practice, strongly suggest an approach which involves what might be seen as less rigorous than the procedures normally performed by scientific plant ecologists. Practical horticulture demands a practical methodology, one that is relevant to practitioners and situations in the real existing world. Experimentation at a variety of levels is part of horticultural research, and this thesis should be seen as part of a growing field of what could be termed 'horticultural ecology'. Consequently, a strong theme in the methodology is the development of procedures that are potentially accessible to practitioners, without the need for specialist equipment of facilities.

1.1.2 Aims

Consideration has been given to the need for horticulture and landscape practitioners to have a clearer understanding of plant interactions in EBPS, and to research methodologies that would enable them to reach such understandings. In order to further this, the following are put forward as aims and objectives for this thesis.

1. To identify the characteristics of herbaceous ornamental plants that may make them appropriate for inclusion in ecologically-based planting schemes, with an emphasis on productive sites; in particular aiming to improve the ability of practitioners to predict competitive performance.
2. To attempt to create a series of meaningful and coherent categories for herbaceous plants, in order to improve the ability of practitioners to specify taxa, plan for visual quality and plan management strategies.
3. To evaluate the suitability of methodologies for testing competitiveness for practitioners outside academia.

1.1.3 Objectives

1. Can the Competitor, Stress-tolerance and Ruderal theory of plant functional traits (Grime 2001) contribute to an understanding of plant selection for EBPS?
2. What are the morphological and phenological characteristics of ornamental herbaceous taxa that might make them potentially valuable for EBPS?
3. What are the major factors that result in plant taxa having a low maintenance requirement in EBPS?
4. What are the plant characteristics that might help facilitate long-term community stability in species-diverse EBPS?
5. To produce outline indications for horticultural professionals which would enable them to identify taxa that are potentially valuable for EBPS.

1.2 A REVIEW OF LITERATURE AND PRACTICE: THE BASIS FOR PLANT SELECTION FOR HERBACEOUS PLANTINGS IN PUBLIC SPACES

1.2.1 Selection for stressful and competitive environments.

Good plant selection for environments which present plants with stresses, such as shortage of moisture, nutrients or light, which impose significant limitations on plant growth, will aim to select plants that will cope with those stresses. Grime argues that the stresses presented by dry, shaded, cold and unproductive environments have a shared underlying factor - that plants are subjected to a low nutrient regime (Grime 2001). Slow growth and longevity are characteristic of plants with S or S-C strategies, whilst S-R strategists tend to be opportunistic, exploiting spatial or phenological gaps. For EBPS this means that plantings for stressful environments involve working primarily with species that are relatively static over long periods and do not compete strongly, or with short-lived species whose growth does not impede others either because it is relatively light or is present when other plants are not actively growing. Grime emphasises that plant selection for productive environments does not have to select for conditions so much as for competition.

Herbaceous ornamentals for EBPS need to be selected that will compete with weeds, and that can compete with each other in such a way as to minimise weed competition but without eliminating each other so as to cause a major loss of diversity in the short or medium term. In the long-term, depending upon the type of planting, some sort of occasional management e.g. cutting or burning may be required to maintain diversity.

The aesthetic and functional value of competitive species (in the Grime sense) has been recognised by Schmidt (2006a) in assessing the work of designers for large-scale planting..

1.2.2 English language horticultural and professional landscape literature

Conventional horticultural and landscape literature does not pay much, if any attention, to ecological or naturalistic planting beyond the use of native woody plants in woodland planting schemes or native seed mixtures for meadow-type habitat creation. Most English-language horticultural reference literature makes reference to only the most basic information about plants: sun/part shade/shade, good drainage or high moisture requirements, hardiness and calcareous or acid soil preferences. Spread (the potential diameter, or horizontal growth ability of a plant), a very useful piece of information for planning any kind planting, EBPS especially, is rarely given for herbaceous species. Thomas (1976) is one of the few standard reference texts that does so do. Rates of growth are very occasionally given for woody plants (e.g. Davis 1987), but never for perennials. Ferguson's 'Right Plant, Right Place' (1986) established a new benchmark in associating the ecological requirements of plants with species commonly used in gardens and public landscapes, but one which few following books have aspired to follow. Whilst native wildflowers and their ecological requirements are addressed in a number of publications (e.g. Luscombe and Scott 1994) this knowledge was not applied to non-native species. 'The New Perennial Garden' (Kingsbury 1996) was the first book in English that attempted to relate the more systematic linking of habitat with species, and was followed by several more, of which the turn of the well-known 'conventional' garden designer Penelope Hobhouse (1997) towards an awareness of ecological issues is particularly noteworthy

Literature orientated towards the landscape professional tends to deal only superficially with questions of ecology. Robinson (1992) makes passing references to the work of Hansen (see below) and 'wild gardening' but as with most landscape professionals his focus is almost exclusively on woody material. Lisney and Fieldhouse (1990) mention the CSR model, but make no practical application of it, nor indeed make any particular applications of plant ecology. 'Herbaceous Perennials for Landscape Planting', a manual produced by the UK Joint Council for Landscape Industries (CPSE 1994)., whilst not relating plant use to ecological principles particularly, nevertheless sets a new standard in the amount of detail given, particularly about plant performance Much of the information included should be of considerable value to those engaged in EBPS. Hitchmough is one of the very few who has related the CSR model to horticultural practice, listing a small number of common ornamental perennials under C, S-T, S, etc. headings (for example see Hitchmough 1994) but not undertaking a systematic classification.

1.2.3 An overview of plant selection in the current practice of ecological design

1.2.3.1 Dynamic communities and persistence – criteria for 'success'

The dynamic quality of EBPS is one of its key features. Ecological processes result in a constant ebb and flow in the abundance of species. Often this results in species loss from a planting. Clearly, in visual terms, this can be regarded as a failure. In other circumstances one or two species may come to dominate a planting – again this may be regarded as a failure in design and functional terms, by reducing diversity, and therefore the long term ability of the planting to cope with changes in the environment and its support for bio-diversity (Dunnett 2003a). A central issue then in an assessment of plant selection, is plant persistence. Ideally plant diversity will survive through the fluctuations in species abundance always to be found in plant communities. Longer term, i.e. successional change, has an inevitable quality to it, and indeed one of the roles of maintenance is to prevent undesired successional changes, e.g. the growth of light-excluding woody plants. A key aspect of 'success' for an EBPS is that it is *relatively* stable, i.e. fluctuations in species abundance are part and parcel of its dynamism, and may even be aesthetically desirable, but successional, i.e., one-way change, must be slow, and therefore easy to manage.

1.2.3.2 Classifying and describing planting styles -'Meadow -style' and 'Open border' plantings

Contemporary EBPS design covers a wide range of different working practices and philosophies. One way of making sense of these different design philosophies is to analyse them on a grid, where one axis represents the degree to which plant species native to the area are used and the other a gradient that goes from 'art' to 'nature' (Kingsbury 2003a). The extreme 'art' position is represented by much conventional horticultural practice, where plants are placed exactly, and maintained in a particular way, which is entirely focused on aesthetic criteria, and 'nature' where the planting is focused on the creation and development of a functioning ecosystem with as little human intervention as possible.

Whilst a grid is a good way of making sense of a variety of EBPS styles through looking at plantings from a variety of perspectives, it may be reduced to a simple gradient for the purpose of an ecological analysis - the laws of nature operate on plants regardless of whether or not they are regional natives. Simplifying further, it might be argued that EBPS plantings fall into two distinct camps:

'Meadow'	**'Open Border'** α
High plant density	Low plant density
Created by direct sowing	Created by planting
Usually native plants, but recent work Dunnett and Hitchmough β shows the possibility of using non-native mixtures.	Non-native taxa often used
A matrix of grasses often,but not necessarily, a part of the scheme.	Matrix plants not generally used
Very naturalistic 'meadow' aesthetic	Aesthetic more like an expansive herbaceous border
Extensive management	May be extensive, but more likely to be semi-extensive or intensive

[α] Kingsbury 1996

[β] Dunnett and Hitchmough 2003a and 2003b

EBPS plantings of both categories have been used for both stressful environments, chiefly dry 'steppe' type habitats (Hertle 1994), and competitive ones. In both cases, the management of the former is in many ways easier than the latter, as a higher level of plant diversity can be maintained, whereas in productive environments competition for resources usually results in a loss of diversity over time. This is why the identification of plant characteristics for EBPS is particularly relevant for productive environments, and thus is

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intended to be the focus for this research. Whether the same plant characteristics are relevant for both meadow and open border styles is not clear. A comparison between the two could be an objective of long-term research.

Broadly speaking the two philosophies that dominate ecological planting design largely correspond to the two positions outlined above; the one, habitat creation, of which the 'meadow' style described above is driven by a concern with ecology, the other, e.g. the 'open border' style, is primarily concerned with aesthetics.

1.2.3.3 Habitat Creation

Here the aim is the creation of natural habitats, using locally native species. The benefits of this planting style are expressed in overwhelmingly ecological terms, i.e. that it creates a habitat for wildlife, especially valuable in urban areas. Meadows and prairies are the habitats most popular for creation, generally created with a seed mix that aims at establishing a matrix of grasses, with the forbs as a minority element. Woodland created by tree planting programmes however pays little or no attention to the ground layer. Wetland, using native species, can be regarded as an increasingly important habitat for both functional purposes (e.g. swales for water capture) and amenity purposes (Kingsbury 2003a).

1.2.3.4 Open Border Plantings - primarily aesthetic ecological plantings

In contrast to these high-density plantings, it is also possible to create EBPS which are much lower density, through direct planting. In many ways these schemes are much like conventional herbaceous border plantings, but with a distinctly naturalistic aesthetic, and the application of more rigorous ecologically based selection criteria.

German practitioners have worked with a style that chooses and arranges plants in a way that is radically different to that of conventional planting styles, and very much inspired by the way that they would grow in natural plant communities. Working largely within public space, they have also aimed at an effect with a strongly visual appeal for the public, but also with an awareness of the potential value of the planting for local wildlife. The role this planting style plays is almost entirely one for relatively small areas of high visibility: notably frequently used areas of public parks. There is definitely more need for maintenance, particularly in the face of weed infiltration, than with habitat creation type plantings. This greater need for maintenance also indicates that these planting schemes are very often less ecologically stable than those which rely heavily on native plant communities.

Of all the ecological planting styles, the work that has been done by Hansen and Stahl, and their followers (*Lebensbereich*), represents perhaps the most sophisticated balancing point between nature and art, and one that carries very little ideological baggage or preconceived ideas about what is natural (Kuhn 1999). It also has an immense amount of research work behind it, much carried out over several decades at the Weihenstephan Institute in Freising in Bavaria. *Lebensbereich* means 'living space' and refers to the close matching between the ecological conditions of the site and the ecological preferences of the species used, which is crucial to the success of the planting schemes carried out. The results are undoubtedly spectacular in visual terms, with sweeping masses of perennials flowering in flushes from spring through to autumn.

Hansen and Stahl's work is summarised in 'Perennials in their Garden Habitats' (1993), a horticultural reference work qualitatively different to any other in the rigour of its argument from ecological principles, as can be appreciated by a statement in the preface to the German edition, 'the detailed classification of garden habitats has sometimes made it necessary to list species that are almost unobtainable in the trade but could nevertheless play a useful role in colonising difficult areas of the garden'. The authors identify a large number of garden habitats, often in relationship to natural habitats, classifying them and listing taxa that are appropriate for each one.

Hansen and Stahl in passing recognise 'two broad strategies' of plant survival, 'characterised as specialisation on the one hand and adaptability on the other'. In a discussion of plant longevity, Hansen and Stahl recognise the importance of long-lived as opposed to ruderal strategies. Simply in recognising that herbaceous perennials have variable lifespans is a great advance over any English-language work, which recognises only annuals, biennials and perennials, with an occasional reference to monocarps (e.g. Brickell 1996). Hansen and Stahl point out how 'dependent ... a plant community must be on the patchwork of tiny niches that results from the life and death of its short and long-lived constituents' and that an ecological planting too will consist of species endlessly changing their populations and their relationships to each other through such changes. Although this dynamism is recognised there is very little systematic discussion of longevity, or the roles that plants of different longevities can play, in the habitat and plant listings. However, in a section headed 'long-term performance' the authors list some particularly long-lived species under various headings related to the way they are grown or increased (e.g. 'planted in small clusters' or 'long-lived companion plants that have spread through self-seeding'), and each plant is cross-referenced to its particular habitat classification. This listing, although somewhat incomplete, nevertheless offers information of considerable import for planning. The role of competition on longevity is recognised by Hansen and Stahl, as they point out how dense planting tends to reduce the lifespan of some components of a planting, which they put down to increased competition.

Plant selection in the Hansen and Stahl system

Hansen and Stahl discuss five categories based on their needs and use:

1) ***Border perennials*** they define as those taxa that need intensive and regular maintenance for successful cultivation, including many of the genera which are highly hybridised, e.g. delphiniums and chrysanthemums – these are clearly not suitable for any kind of ecological planting.

2) Wild perennials with border character are selections that maintain their natural aesthetic and robust character e.g. the various cultivars of *Salvia nemorosa* such as 'Mainacht' and 'Ostfriesland'.

3) ***Exotic wild perennials*** are true species not native to central Europe, and which if matched to the appropriate environment, can be used for a low maintenance ecological planting style.
4) ***Native wild perennials*** are central European natives with enough of a decorative character to be suitable for ecological planting.
5) ***Specimen perennials*** are those such as the herbaceous aralias, that are so large and imposing that in design terms they can almost be treated as shrubs (Hansen and Stahl 1993).

In practical terms, unless the planting is to be a self-consciously native planting, an EBPS needs make no distinction between the selection of plants from 2-5, as they are all robust enough for planting in the appropriate habitat. The usefulness of Hansen and Stahl's schema lies perhaps in its focussing the attention of practitioners on the following issues of plant selection:

Group 1. The clear distinction made between taxa robust enough for ecological planting work and this group, which are suitable only for traditional hi-maintenance garden situations.
Group 2. The importance of a naturalistic aesthetic amongst cultivars. This is a very subjective matter, but it is a crucial question in the selection of taxa for ecological design, whether the original species concerned is native or not.
Group 3. This group is potentially enormous, comprising any species of perennial hardy in the region where it is to be used. There are some major issues in the selection of appropriate exotic taxa, which Hansen and Stahl hardly touch upon:

- Issues concerning potential invasiveness
- Issues of visual ecology

Instead the authors concentrate on identifying the appropriate habitat for exotic taxa, and the compatibility of taxa within each habitat category.
Group 4. Native species are often overlooked, and yet they have considerable aesthetic appeal. There may well be additional reasons as to why their use in combination with non-natives is appropriate:

- In the appropriate habitat their ability to thrive is tested beyond doubt
- The importance of some species to wildlife
- A possible role in establishing a stable plant community.

Group 5. 'Architectural' plants have considerable public appeal, and are thus important elements for inclusion.
'Group x'. In addition Hansen and Stahl recognise the importance of the more modest plants in design schemes in a discussion of the ecological integrity of planting combinations, drawing attention to 'the significance of mutual competition or tolerance' between taxa used in plantings, and the importance of recognising that 'it is not just the showy plants but also more modest ones whose contribution is important to the whole' (Hansen and Stahl 1993). This concept is not returned to, and is not recognised as a group as with the above, but indicates a potentially valuable area for further research.

Hansen and Stahl's work has faced criticism for a variety of reasons. One is that although they discuss what they describe as a crucial connection between aesthetics and ecology, in discussing how the appearance of plant species is not chance but an expression of adaptations to particular habitats, they never return to this connection. Their whole approach is arguably very much only about an aesthetic-functional application of ecologically determined plant character, with little appreciation of a more purely aesthetic element, such as colour or form combinations.

Hansen and Stahl and those who have worked within their Lebensbereich system apply a 'naturalistic aesthetic' to the way they group plants. This relies heavily on a concept of 'sociability', which suggests planting species in groups of varying sizes, in order to fulfil various aesthetic criteria as well as, in some cases, attempting to group plants as they would be found in the wild, a reflection of their growth habits (Hansen and Stahl 1993, Plenk 1998). The results look more naturalistic than a traditional border but it can be argued that they do nothing to make a planting inherently necessarily more stable over time or diverse – in other words they arguably perform no ecological function. In any case such a schematic system is all too liable to ossify into dogmatism. Dunnett (2003a) points out that the patterns plants adopt in nature may be quite short-lived and in any case are a reflection of underlying factors in the environment. Laying out plantings in groups in imitation of how they occur in nature, thinking that this somehow makes them 'ecological', is mistaking cause for effect.

Walser, former director of the Hermannshof trial garden in Weinheim, and one of the most experienced and artistic practitioners of Lebensbereich, recognises its dynamic nature, but feels that successful long-term development is hampered by standard maintenance procedures, which are aimed at keeping a static picture, not recognising the dynamic element. He sees that a key problem in working with long-term dynamics is that designers are paid to design a planting and then walk away, whereas those plantings that are maintained by staff with ecological knowledge and artistic skill can have the dynamic of change directed over time, often by small-scale and subtle management. This is most important in productive environments where the competition between dominants most often results in a loss of diversity over time (Walser 1998).

Hansen and Stahl's work is based on research conducted in Bavaria, and it can be readily appreciated that the further one moves from the particular climatic conditions off this area, the less relevant will be their findings, so that even within Germany, their work can seem inflexible. There is little understanding of the need for a more fundamental approach to plant selection – the need for an analysis of the underlying factors which dictate whether a plant will succeed or not in a given environment. It is to look at these factors that this research aims to do, so that practitioners may have a greater ability to *predict* plant performance.

Despite the use of *Lebensbereich* style plantings at a number of high-profile locations, and despite extensive enquiries, it does not appear as if anyone has done any research on these plantings to look at their long-term development and dynamics. At the most heavily managed and closely researched location, the trials garden at Weinheim originally established by Walser, there are only very limited long-term records of the plantings (Schmidt 2003).

1.2.3.5 Other research using perennials in central Europe

Recent developments in perennial use in Germany have focused on addressing some of the problems inherent in the application of complex planting schemes. In what is termed 'Mixed Perennial Planting' researchers have focused on the development of a plant list, with specified numbers of plants of various taxa and equal planting distances. The planting combination is carefully researched, with relatively similar levels of competitiveness being especially important. Exact plant positions end up by being pretty much random, making it possible to create an attractive planting without involving a plan or a designer (and their attendant fees) to specify the location of each plant. Kircher and Messer at Bernburg, and Kolb and Schönfeld at Veitschöchheim have both worked with a number of mixtures, all suitable for relatively dry situations, and have evaluated their work using panels, who meet monthly, comprising practicing amateur gardeners and non-gardeners. Comparisons with monoculture plantings have been very favourable. (Messer 2003)

Some short-lived species are included, which are intended to die out as the mixture develops, but according to Schönfeld, even after 8 years, an equilibrium is not established and the plant mixture remains dynamic (Schönfeld (2000). The Kircher trials are still young, and it is too early to see how they will develop long term.

Similar is the 'integrated plant system', where perennials, geophytes and annuals are assembled (Bächtiger et al 2001). The inclusion of annuals is a recognition of the aesthetic planting being in some way a succession, although the species selected were somewhat problematic (Föhn 2002).

Post-industrial areas develop their own vegetation through natural processes, which can be managed creatively for aesthetic results (Hientz *et al* 1999 and Eckhardt *et al* 1999). Such vegetation has also been the inspiration behind some trials of mixtures of species chosen for their visual characteristics, and their tolerance of drought and heat (Kuhn 2000).

1.2.4 Non-native meadow style plantings

The middle ground between habitat creation and open border style plantings involves the development of dense plant communities using species chosen on ecological and aesthetic grounds but not on the basis of being regional natives. Hitchmough's work with attempting to establish robust non-native forbs in a matrix of meadow grass through planting illustrates the potential but also some of the problems in trying to achieve this (Hitchmough and Woudstra 1999). Even if successful, large numbers of plants are needed to create visual impact, with obvious cost implications. Other workers have experienced similar limited results (Kingsbury 1997). Introduced forbs may survive, but competition reduces their size considerably, and many do not spread appreciably over time, nor propagate themselves through sowing. In such a competitive environment, those species which do survive can be regarded as models of persistence (e.g. *Euphorbia palustris)*, and consequently their growth characteristics need investigation (Dunnett and Hitchmough 2003a). A key characteristic for fitness seems to be the ability of the forb's foliage to shade out surrounding grasses (Kingsbury 2002).

Work by Dunnett and Hitchmough illustrates how it is possible to combine a range of non-native forb species in meadow-style plantings through direct sowing (Dunnett and Hitchmough 2003b). The species used combine British natives, North American prairie species and mainland European natives. Species selection is on the basis of established reputations for persistence in cultivation, adaptability to both productive and relatively unproductive soils, readiness to germinate without vernalisation together with flower colour and length of flowering, mixtures being created around distinct colour themes (Pictorial Meadows 2002, Dunnett 2003b).

The use of ornamental plants in such environments as rough meadow grass or in close conjunction with others is radically different to other types of horticultural planting; by allowing plants to compete with each other it is allowing ecological processes to take over – an understanding of plant ecology now becomes vital at both the design stage (i.e. selecting plants) and for ongoing management (Hitchmough & Dunnett 2003). Whilst this type of planting represents an extreme in terms of allowing a relatively free rein to ecological processes, the need to understand the ecology of ornamental herbaceous species is important for all plantings where there is an element of the 'naturalistic'; indeed it could be argued that all horticulture and planting design would benefit from a great ability to understand plants as ecological beings, and in particular to predict plant performance.

1.3 ECOLOGICAL PRINCIPLES IN PLANT SELECTION – A REVIEW OF LITERATURE

The aim for a review of the literature on plant ecology is to seek insights into how plant characteristics can be identified that will further the selection of suitable herbaceous ornamentals for EBPS.

Objectives for a literature review:

To gain a better understanding of:

- What makes a species an effective competitor
- What promotes floristic diversity
- What promotes species persistence in a community

1.3.1 The CSR model and horticultural practice

The work of Grime (2001) on plant survival strategies and plant functional types has proved one of the most fruitful areas for discussion amongst plant ecologists.. Grime and co-workers (eg. Grime 1988) have advanced the idea that the survival strategies which plants pursue can be broken down into three key variables, which are effectively co-ordinates: C – competitive, S – stress tolerant, and R – ruderal. Species may show a predominant character of one type (e.g. C types) or may show more than one (e.g. C-S, C-S-R) ..

Competitive species are those with a physiology that allows them to fully utilise high levels of inputs: nutrients, moisture, light, and a morphology that tends towards physical over-reaching of neighbours and their suppression. Rapid growth, height, large leaves, and reduced investment in tissue are characteristic.

Stress-tolerant species have a physiology that maximises scarce resources and favours conservation of resources, typical of environments where shortages of water, nutrients and light inhibit growth. They are typically slow growing, often evergreen, and show morphological adaptations that favour resource conservation and defence mechanisms against predators.

Ruderals have a lifespan that minimises the time between germination and the production of plentiful seed; they are opportunists that need to maximise the availability of resources in environments that are essentially temporary. Their survival as species depends upon the production of large quantities of seed, which often dominates seed banks. They typically grow and mature fast, and put high levels of resources into seed, and comparatively little into vegetative spread.

Grime's work, to be referred to as CSR theory from now on, has potentially major implications for horticulture and landscape practice. It helps to explain, in ecological terms, much of the practices of conventional horticulture. It also raises issues that tend to be seen as paradoxes within the paradigm of conventional practice. One paradox is that Grime (2001) shows how unproductive or stressful environments are often more species-diverse than productive one – essentially, stress limits growth, so allowing for more co-existence.. The experience of many practitioners working with the establishment of British native wildflowers illustrates this – that floristic diversity is more or less dependent upon low fertility substrates (Luscombe & Scott 1994)

Given that stressful environments are often effectively easier to manage with EBPS, the focus for research needs to concentrate on what factors would allow long-term visually attractive plantings to be developed in more productive horticultural environments. Many, if not most, ornamental borders are installed on soils with plentiful moisture, a high level of nutrient resources, and in the case of locations in the north-west of Europe, a long growing season. These conditions favour competitive species which can utilise the high level of available resources, however competition can be so intense that species diversity is gradually reduced, with the most competitive suppressing others (Grime 2001). In practice, this may mean the triumph of unwanted weed species. Grime (2001) also shows that environments that are occasionally disturbed may often have more species diversity than undisturbed ones, as disturbance reduces the ability of competitive species to completely dominate space and provides habitat for ruderal seedlings to establish

Many studies have shown that over time, i.e. in succession in productive conditions, the role of competition increases, whilst that of ruderality decreases, e.g. the meta-study of Pywel et al. 2003. The development of EBPS for productive conditions is the focus of this study; partly because the creation of bio-diverse and visually complex plantings for such conditions is inherently more difficult because of the 'winner takes all' end result of much competition in such circumstances, and thus arguably more deserving of research effort, and because many planting potential environments for EBPS are notably productive e.g. old-established urban parks in Britain. Pywel notes that vegetative spread to be the dominant form of regeneration in closed communities, with a general decline in time of importance of traits linked to colonising ability. However he notes that it is well established that competitive ability is very difficult to characterise.

Many public environments are prone to disturbance through a variety of factors, including dog digging and various anti-social activities. There is thus scope for species with a distinctly ruderal character. In addition, many plants with a ruderal component are visually attractive and have an important aesthetic role to play. In addition, low levels of maintenance mean that plants in public EBPS may not receive the care that plants in other horticultural environments may get, and thus be subject to a greater and more intense variety of stresses e.g. lack of irrigation, lack of soil nutrient replacement etc.

The insights of CSR theory would appear to have a lot to offer landscape and horticulture practitioners, both in terms of guiding practices and in plant selection. The starting point of this research is to attempt to evaluate CSR theory, to see if the application of CSR ordination which has been applied to the British flora (Grime et al. 1989) can be applied to species used in horticulture and provide useful or predictive insights, particularly with regard to EBPS.

1.3.1.1 C strategists

Grime (2001)stresses that competitive ability is related not just to large shoot mass and height, but also leaf design and dynamics, with those species able to form a dense carpet of leaves achieve dominance through leaf design and phenology rather than height. The 'dominance index' concept explored by Grime has shown the relationship between certain morphological characteristics: growth rate, height, litter production and morphology and levels of diversity, i.e. high levels of dominance reduce diversity.

According to Grime, tall perennial herbaceous species often do dominate in productive habitats where there is little disturbance. In some cases, their dominance is assisted not only because of their ability to shade out competitors from early in the season, but also because they can produce dense litter, which inhibits the growth of rival species. In competition, Hutchings (1997) points out how larger plants have a greater adverse effect on smaller plants than vice versa, this asymmetric competition effect increasing over time. Morphology, he points out, is a major factor in how strongly competition develops, e.g. species that cast greater shade suppress surrounding species more strongly. In terms of horticultural plantings, the competition effect can be used to advantage to compete with weeds, or can be detrimental to diversity if one or two species are able to exclude others (Kingsbury 2002).

For EBPS, species with a competitive strategy are particularly useful for public environments where:

- Moisture and nutrient resources are high
- Occasional disturbance is possible
- Weed infiltration either from the seed bank or from local weed populations is likely.

1.3.1.2 C-S-R strategists

C-S-R strategists include many species of relatively stable habitats. There is considerable overlap, both in terms of the species and their visual character, with the more stress-tolerant vegetation characteristic of meadow-style habitat creation, the relatively unproductive nature of the soil being the underlying common factor. Public situations where the identification of this strategy may be important include situations where:

- Moderately high nutrient resources may become reduced through time through cutting and removal of dead herbaceous growth.
- There is occasional drought
- Weed infiltration is likely to be low
- Disturbance is unlikely.

It is worth noting that Grime (2001) identifies the C-S-R strategy as being the one most clearly associated with herbaceous perennials.)

1.3.1.3 C-S strategists

Whilst there will be a major overlap with stress-tolerant meadow-style EBPS, there may well be herbaceous species that combine these strategies which could be combined with others as a major part of EBPS. Various morphologies and phenologies characteristic of such plants may have value in the appropriateness of plant species for particular public environments, e.g. persistence amongst more competitive dominant species, or have particular visual features, e.g. are evergreen.

1.3.2 Succession

Succession in an EBPS is inevitable, as Luken (1990) points out, in stressing that no plant community is completely stable, and that management only modifies the 'rate and direction' of succession rather than preserving a plant community in stasis. What management aims to achieve will depend considerably on a number of factors, and in many cases, certainly for the less floristically diverse EBPS it may well be possible to maintain a plant community that keeps its original character over a long period. Just how much succession changes the composition of the planting over time will depend on many factors, and identification of pertinent plant characteristics could play a major part in understanding and predicting how succession will develop.

Regeneration of species within a community through seeding is part of the ongoing dynamism of EBPS. But, unlike in a traditional planting, this dynamic process inevitably involves changes in species composition. Luken discusses how as the availability of resources changes, so the survival rate of seedlings of different species changes, thus resulting in some species replacing others.He discusses a variety of models of succession that seek to explain the varying trajectories of succession that can be taken by plant communities. One, of particular pertinence to those engaged in horticulture, is 'inhibition', where species which establish early in the succession process effectively stabilise the process, inhibiting its progression. It is conceivable that a similar result could be achieved through the use of appropriate competitive herbaceous ornamentals, to inhibit undesirable herbaceous and woody growth. To achieve this it would be necessary to identify those plant characteristics which would enable a species to compete most strongly with a variety of species regarded as undesirable. Grime (2001) identifies lateral spread, rapid growth and copious litter production as being key factors in the inhibition of woody plant seedlings.

1.3.3 Competition, persistence and regeneration

Competition theory shows how it is possible for any number of competing species to exist in a given area, depending upon the level and kind of interspecific trade-offs between them. In particular Tilman (1997) draws attention to the fact that co-existence requires a species A that is an inferior competitor be a superior coloniser of vacant space or more long-lived if it is to co-exist with a superior competitor, species B. Species with good colonising ability, for example relatively ruderal species with high levels of seed production, are always going to have plenty of opportunities for growth in situations where there is vacant ground for some of the year. It is also possible that certain ornamental perennials that are notably long-lived may also show persistence in situations where more competitive, but shorter-lived species, grow in a cycle of expansion and contraction.

Floristic diversity depends partly then on the ability of species within the community to colonise new areas, indeed this is vital for long-term species survival, at least for those species which do not form very long-lived clonal clumps. Moderate disturbance promotes the regeneration of species from seed by providing potential seedbeds (Hutchings 1997). However the eventual outcome of this process will depend upon the ability of seedlings to compete, and thus become adults (Burrows 1990). The shorter the lifespan of the plant, the more important it is that seedlings are able to compete, if the species is to continue to be present, thus for shorter-lived species survival depends upon not just the ability to produce plentiful seedlings, but also on the competitive ability of those seedlings.

Austin (1990) suggests that community structure is the result not just of the outcomes of competition between plants, but the whole process of senescence and disturbance, leading to the creation of areas for regeneration. In other words, diversity depends to a certain extent upon disturbance, the development of a varied, and therefore visually interesting vegetation might require occasional disturbance.

1.3.4 Vegetative regeneration

Whilst the study of regeneration through seeding has been extensively studied, Luken (1990) points out how in contrast there has been relatively little research into regeneration through vegetative growth. In a great many EBPS, especially those derived from planting rather than sowing, vegetative regeneration may be the dominant, and indeed the only means of regeneration. Luken contrasts regeneration from seed, where new individuals have to take their chances on resources existing at their site of germination, and vegetative, where ramets are still attached to the parent plant and are thus able to transfer resources from parent to young ramet, and indeed vica versa. He states that vegetative regeneration is particularly important and successful in the later stages of succession where there is little scope for regeneration from seed owing to a lack of suitable sites for successful seedling growth. This has important implications for plant selection for EBPS. Grime (2001) stresses the importance of vegetative regeneration for C-strategists, allowing them the possibility of rapid lateral expansion and pre-emptive occupation of resources.

In discussing species longevity Luken (1990) discusses the existence of extremely long-lived clones, and the 'absence of complete senescence', which he suggests is can be seen as an adaptation for 'perpetual site occupation'. Clonal plants, he suggests, are thus ideal for the creation of very stable plant communities. Clonal plants vary considerably in the morphology of their ramet formation however. A number of authors have recognised the difference in modular growth amongst herbaceous plants, with two clear 'end of spectrum' strategies, 'phalanx' and 'guerrilla' (Crawley 1997a). Just how the younger modules spread out into new territory is however recognised as being very dependent upon resource availability, i.e. greater success will be made by spreading into vacant spaces (Hutchings 1997). The guerrilla strategy is commonly seen in some of the most problematic and persistent weeds of ornamental plantings, e.g. *Ranunculus repens* and *Agropyron repens,* but more rarely amongst ornamentals. In theory, ornamental species with a robust guerrilla strategy may perform well in some situations, i.e. where there are gaps that can be readily occupied. However, the solid onward march of phalanx strategies may better ensure long-term stability.

The importance of a better understanding of vegetative strategies is illustrated in work discussed by Bazzaz (1990), regarding competition between *Aster pilosus* and *Solidago canadensis* and *S.altissima* in abandoned fields, the solidago eventually replacing the aster, partly because of a better integration of solidago ramets with the parent, allowing establishment in more unfavourable sites.

1.3.4.1 C-R strategists

Grime (2001) regards the guerrilla activities of species such as *Ranunculus repens* as examples of what he terms 'ruderal-perennial herbs', with a competitive-ruderal strategy, an extreme example of the plasticity of growth characteristic of the competitive strategy Whilst species with this strategy are clearly unsuitable and inappropriate to be dominants, either ecologically or aesthetically, they could play an important subsidiary role in EBPS.

1.3.5 Species Diversity

Diversity is regarded as 'a good thing' for a variety of reasons, summarised by Dunnett (2003a), amongst which the fact that higher levels of diversity make a planting more resilient to changes in the environment and therefore contribute to its success as a low-maintenance feature in designed landscapes, is a particularly important one. Floristic diversity also contributes to faunal diversity and to greater visual complexity and interest. Diversity though is generally reduced on productive sites through a few particularly competitive species becoming dominant. Yodzis (1986) suggests that where there is spatial competition, i.e. that based on obtaining all the resources from an area, community structure develops through dominance relationships.

In a study of plant functional types across the western USA, Paruelo and Lauernroth (1996) found that the abundance of forb species had no clear relationship with geographic variables. This suggests that evolution can proceed in a wide variety of environments and still come up with floristic diversity, and that levels of diversity are dependent upon variables at a lower spatial level than that studied, and/or that diverse communities need time to develop, i.e. that low levels of floristic diversity are primarily a reflection of 'young' habitats.

Whilst an individual plant species may be described as 'competitive', in reality its degree of competitiveness is dependent entirely on the environment and the other species present. Crawley (1997b), who somewhat unusually for a writer on ecology draws on common garden lore to point out that many plants can be grown in situations quite different to their natural habitat because they are freed from competition. Crawley, and also Burrows (1990), discusses the distinction between 'fundamental' and 'realized' niches. Most herbaceous ornamentals are notably 'generalist' in Crawley's terms, thriving under a range of conditions, i.e. a wide range of realized niches. Hutchings (1997) discusses how the theory of niche separation attempts to explain how a number of species may co-exist in a plant community, diversity being the result of each species having a different niche. However he points out that niche specialisation, and with it the opportunity for relatively high levels of diversity appears more likely to occur in extreme environmental conditions.

Grubb (1996) recognises four component niches in which a plant species may exist:

- Habitat niche. Variation in microhabitat will vary considerably less in herbaceous plant communities than in communities that occupy more physical space such as forest.
- Life Form Niche. Morphological differences may enable a variety of plant species to co-exist.
- Phenological niche. Exploitation of resources at different times of year, largely driven by the ability (or otherwise) to exploit light.
- Regeneration niche. Species in a community may be differentiated with regard to how they regenerate, with different species able to exploit different possibilities.

Niche differentiation can be expected to be important between species of high abundance within a community, but not necessarily between species of low abundance.

There appear to be trade-offs between the abilities of plants to forage on coarse and fine scales – subordinates are more likely to be ' precise' foragers The hypothesis suggested is that by increasing productivity higher growth rate is linked with higher morphological plasticity and a greater degree of active foraging; subordinates will have adaptations that limit their ability to monopolise but will be able to forage more thoroughly in small areas or at different times of year; dominants and subordinates in other words(Campbell et al. 1991).

Management techniques involving disturbance to top-growth, can limit the growth of dominants, and arguably open more niches, or reduce the tendency of a limited range of species to occupy a limited range of niches. Grime (2001) developed the 'hump-backed model' whereby the greatest floristic diversity is to be found mid-way along a gradient with extreme stress or disturbance at one end and an increasing standing crop and litter at the other. The implications for the maintenance of EBPS are thus considerable, yet the ideal maintenance levels are not always practicable in public spaces, especially if staff skill levels and funding are both low. Many EBPS may have to survive with as little as one or two maintenance sessions (e.g. weeding or cutting) per year. Hence identification of means by which maximum diversity can develop in the absence of an 'ideal' level of management has an important role.

Diversity in natural and semi-natural plant communities is often the result of localised disturbance events, such as trampling and animal soil turnover, leading to species, often those with a more ruderal character, exploiting the gaps. (Grime 2001) In public space these factors also occur: trampling by children/youths and dog digging are notorious. The plant community thus needs to include species with a regeneration strategy which allows them to rapidly occupy the spaces created by damage; even though these disturbances are regarded as undesirable, they may play a role in maintaining the presence of shorter lived ruderal species. 'Disturbance-induced competition release' is a proposed mechanism whereby weak competitors are able to become more dominant in more disturbed areas, where stronger competitors are less able to dominate (Lenssen 2004). It is predicted that there is a trade-off between a species ability to tolerate disturbance and the ability to survive competition and suppression by other species

Goldberg (1990), surveying a number of studies, speculates that species which are more highly effective at extracting resources (moisture and nutrients) will dominate in situations where persistence is determined by size-symmetric competition – early in succession or in gaps. Conversely species which tolerate lower resource levels, i.e. those with effective competitive response, will dominate where persistence is dominated by size-asymmetric competition, e.g. seedlings in mature vegetation, and perhaps by extension all species in dense mature communities. The former situations offers habitat for R- or C-R strategists, the later C-strategists or C-S.

Even in communities dominated by a very few species there are usually several other species which occur in small quantities. The presence of non-dominant 'minor species' in many natural and semi-natural habitats is often a key part of their visual appeal; it is the minority forbs in a wildflower meadow that make it attractive not the overwhelmingly dominant biomass of grasses. (Grime 2001).

Examples of monocultures or near monocultures among herbaceous plant communities are rare; personal observation in the British Isles, central Europe and North America, suggests that near monocultures are most likely to occur in either densely shaded habitats or highly productive, but at least partially shaded tall-herb communities. Givnish (1982) suggests that 'altruistic' reduction of leaf height, and thus a reduction in competition, is likely to occur in situations where intra- rather than inter-specific competition dominates, citing *Aster macrophyllus* in North American woodland, where the costs of constructing stems in a dense herb community are avoided, as the species is able to dominate its environment through the use of allelopathic compounds.

In resource-rich undisturbed environments with dense vegetation, one way in which plants minimise competition is through the occupation of different spaces within vegetation (Burrows 1990); in some cases it may be possible to identify a variety of 'microhabitats' (Grime 2001). A suggestion is made by Bazzaz 1990 that there is greater co-existence, and therefore diversity in communities that are in the later phases of succession, because there is 'higher species packing' as a result of greater specialisation in exploiting various niches. This may explain the extraordinarily high diversity of some habitats, e.g. in Ukrainian steppe where up to 80 species per square metre may be found (Londo 1995). It is the experience of many who work with artificially created native wildflower meadow habitats that species counts go up over the years, Londo for example finding that even after 25 years, new species continue to arrive . The lesson for EBPS practitioners is that if a relatively stable community can be created, natural processes may proceed to build high levels of diversity over many years.

Diversity in plant communities is to some extent a result of there being a patchwork of different micro-habitats, where competition will operate differently owing to different conditions, Keddy (1990) suggesting that this is best understood with a 'centrifugal' model, whereby all species are found in a 'core' habitat, but that some are better able to compete in a variety of peripheral habitats, which may differ from the core through different soil moisture levels, pH etc. The implication for EBPS perhaps is that over time, community dynamics will increasingly allow species to 'sort' themselves into a complex, and visually interesting, patchworks, as is seen in any semi-natural habitat.

Several studies concur in rejecting resource partitioning this as a major factor in species co-existence (Goldberg and Fleetwood 1987, Goldberg and Landa 1991). There is also little evidence for a clear development of within-community niche specialisation, particularly within herbaceous-dominated ones (Aarssen 1983). A fundamental paradox of plant ecology is that the immobility of plants forces them to make what are essentially the same demands for resources on their environment – they must therefore be similar, and yet widespread co-existence can be observed. Aarssen argues that Gause's principal of competitive exclusion must be looked at with suspicion, and proposes that co-existence is possible because of the enormous number of different combinations of the biological attributes which favour competition, and which are constantly adjusted in an on-going process of fine-tuning within plant communities.

Part of the discussion about co-existence concerns the issue of whether communities become saturated with species through a process of 'niche saturation' or alternatively that there is no real limit on the number of species able to exploit resources - 'diversity begets diversity'. Work by Palmer and Maurer (1997) provides experimental evidence that the latter is more likely, although the precise nature of the mechanisms involved remain obscure.

Species which are rare, or which are sparse in the communities in which they are found, are not necessarily uncompetitive, indeed they may be very effective competitors, and be rare for other reasons; in the communities in which they are found their competitiveness may be quite marked, and may be an evolutionary mechanism which offsets the hazards of low density. Experimental evidence shows that they can grow best when surrounded by many individuals of common species (Rabinowitz & Rapp 1984). Hitchmough et al. (2005)discusses work which suggests that a variety of species diversity and plant architecture increases community stability, largely through resistance to weed incursion, and increases the value of a planting to faunal bio-diversity.

Diversity can also be promoted by species with a variety of phenological characteristics, so that species that are able to grow during the time when the dominants are either dormant or of reduced size, reducing their rate of growth dramatically when the surrounding vegetation overshadows them (Hutchings 1997).

1.3.6 Competition

The understanding of competition is a major component of plant ecology studies, and there is no shortage of material in the literature. However as Goldberg (1997) notes, there are many obstacles to examining relationships between plant traits and competitive ability, of which she focuses on three: differing definitions of competition, the contingent nature of competition, and the logistical problems of measuring it, compared to many other plant traits.

Grime's definition of competition is the one used here: "the tendency of neighbouring plants to utilise the same quantum of light, ion of mineral nutrient, molecule of water or volume of space" (Grime 2002, p.12). This definition, Grime stresses, emphasises mechanisms rather than effects. It is mechanisms that this study is looking at – effects will inevitably vary from place to place; the diversity and variability of competitive abilities amongst herbaceous vegetation from place to place is a distinctive feature of the field.

Broadly speaking, there have been two approaches to explaining how competitive performance is related to environment: one that performance is highly dependent upon the environment in which plants are competing, the other that relative competition is largely independent of the environment, the former position largely associated with Tilman, the latter with Grime (Keddy et al. 2002). The sense that this is a major academic dispute is one that comes across strongly in the literature.

1.3.6.1 Competitive hierarchies

Testing the Grime and Tilman hypotheses, Keddy et al. (2002) found that relative competitive performance under relatively stressed and unstressed conditions were strongly correlated and that competitive hierarchies are largely independent of environment. There is indeed growing evidence that plant species are arranged in hierarchies of relative competitive performance (Keddy & Shipley 1989), with at least one study suggesting that competitive effect rankings are constant across environments (at least those environments in which the species being tested might be found) but that competitive response rankings are not (Keddy et al. 1994), possibly suggesting that response is more closely linked to changes in environment than effect, i.e. effect is more an intrinsic feature of plant traits. Rösch et al. (1997) found that competitive hierarchies were constant across different nutrient levels. If such hierarchies do exist, it is clearly important for EBPS to understand the means by which they are enforced.

Weiher at al. (1999) note that competitive abilities can vary along environmental gradients, therefore it cannot be assumed that a given trait will confer effective competition in all situations. The traits which most convincingly suggest competitive ability are relative growth rate, seed mass and plant height (Weiher at al. 1999, Hodgson et al.1999, Goldberg and Landa 1991, Gaudet and Keddy 1988). The former can be represented by specific leaf area (SLA) (Weiher at al. 1999); seed mass is not a part of this study, although the collection of a list of seed weights of ornamental herbaceous species would be a relatively straightforward exercise.

Several studies indicate that competitive hierarchies change over time, as plant communities change their composition (Goldberg and Landa 1991).

1.3.7 Plant traits and competitive ability

It is assumed that 'natural selection favours species whose form tends to maximise net carbon gain' (Givnish 1982). This is generally regarded as being related to total biomass and/or surface area of organs for resource exploitation, although total biomass does not account for all differences between species in their ability to compete (Goldberg and Landa 1991). No one factor makes a plant species competitive, instead competitive ability needs to be understood in terms of a combination of factors (Grime 2001).

Gaudet and Keddy (1988) found strong links between plant traits and competitive ability, with biomass accounting for 63% of the variation in competitive ability, with plant height, canopy diameter, canopy area and leaf shape accounting for most of the rest. In doing so, they see themselves adding to a considerable body of evidence that size-related variables are key indicators of competitive dominance in herbaceous plant communities, and that competitive ability is a key determinant of the patterns developed by plant communities (see also Keddy 1992). They suggest that guilds of plants with similar competitive ability occur along a continuum of increasing biomass. Within the guilds (of plants of similar biomass) factors other than biomass become important. They suggest that biomass may simply integrate a number of other traits, largely concerned with resource capture. At high resource levels, it is competition for light which they consider may be the critical factor, and that the traits they have identified may be primarily linked with competition for light. Keddy and Shipley (1989) consider it more difficult to measure competitive outcomes the more similar species are . This clearly has implications for plant selection in EBPS.

Competitive ability is composed of two aspects: the ability to grow at the expense of neighbour, so reducing their growth – effect, and the ability to perform in the presence of competing neighbours – response (Goldberg and Fleetwood 1987). High eventual plant mass has the strongest per-plant competitive effect, but those with the highest growth rate have the stronger per-gram effect (Goldberg and Landa 1991). Species with the best competitive response are more likely to be those with lower maximum growth rates (Goldberg and Landa 1991). This fits in with the Grime C-S gradient, with C-strategists staking survival on effect, those species with a higher S-component on response, i.e. tolerance of difficult conditions.

Estimates of competitive effect are a good predictor of distribution in the field (Gaudet 1993). Pausas and Lavorel (2003) consider that response is more relevant to post-disturbance situations where re-sprouting is an important response and where vegetation builds to a continuous canopy, effect to situations where disturbance leads to an intense struggle to dominate space, and where species which re-sprout are uncommon.

Effect and response are not necessarily correlated, and evidence from studies does seem to be contradictory, Goldberg and Landa (1991) finding that there is no evidence of correlation, whereas Goldberg and Fleetwood (1987) found a positive relationship. The two components may well be related to different traits (Goldberg and Landa 1991). Keddy et al., in a relatively large study stresses that it is not possible to generalise from effect to response (Keddy et al. 1994).

Aarssen and Keogh (2002) critique much work on competition for its concentration on growth, which they argue is only one aspect of competition. Furthermore they point out that most studies ignore competition over time and the role of reproduction in maintaining species presence over time. They argue that competition involves three components:

- Growth – the ability to deny resources to competitors,
- Survival – the ability to survive suppression
- Reproduction – the ability to maximise fecundity

Growth may be such that the ability of a plant to deplete resources locally is so effective that competitors are negatively affected – 'exploitation competition' in Aarssen's words', or less seriously - the ability to interfere with competitors ability to access resources – 'interference competition' (Aarssen 1983).

Competitive ability may depend upon competitive response, i.e. the ability to withstand competition. Mechanisms may include storage organs, avoidance of competition through seasonal dormancy or various adaptive mechanisms, e.g. shade tolerance.

Aarssen (1989) discusses reproduction/allocation to fecundity of resources in relation to seed production, which may be regarded as potentially of considerable importance to species with a ruderal aspect. However it could be extended to the ability to reproduce clonally. Resources maximised by a plant can be allocated to reproduction, and the more effective it is at producing successful offspring, the more the species can dominate.

These various factors can often be seen as overlapping through positive feedback loops. For example a successful competitor may garner resources and in so doing physically extend itself, therefore shading out and therefore denying resources to a competitor, and then divert resources into a) storage tissues, thus enabling it to survive competition from neighbours, and b) into clonal material, enabling it to further spread.

Aarssen discusses a number of traits involved in competitive ability, covering both reproduction and the occupation of physical space. Since this study concentrates on vegetative rather than reproductive aspects of competition, only the ones relevant are listed, those most relevant to this study are indicated (*). 'Secondary traits' are physical traits which determine 'primary traits' which are those factors which describe how the ability of a plant to compete.

PRIMARY TRAIT		*SECONDARY TRAIT*
greater depletion rate of water greater depletion of mineral nutrient	<<<<<<<<<<	greater root density greater lateral extension of roots faster uptake into root hairs greater density of root hairs
greater depletion of light	<<<<<<<<<<<	greater plant height larger leaf area more effective leaf orientation

1.3.8 Which traits favour competitive ability?

1.3.8.1 Size as primary factor in competitive effect

A large number studies show that size is crucial in giving a plant competitive advantage, both in height and biomass (Mahmoud & Grime 1976; Keddy et al. 1998; Keddy et al. 2002; Aarssen & Keogh 2002; Pausas & Lavorel 2003). Rösch et al. show how both total plant and shoot mass are both correlated with a strong competitive effect, along with stem mass (Rösch et al. 1997). This study also showed significant correlations with SLA, vegetative height x diameter and leaf area ratio. Simple plant height or diameter, did not, however, significantly correlate. DISC.

Weight is only one measure of size; total leaf surface area may be more important, if competition for light is the crucial factor in an environment, which is possibly why grasses are such effective competitors; in other situations other factors may be the most important. Rösch et al. (1997) count total leaf surface area as a significant factor. In practical terms, height may be the crucial aspect of size; it is surmised that the most important effect of a species having its leaves at a greater height than its neighbours is that it enables it to intercept light at the expense of the neighbours (Givnish 1982, Keddy 1989). Even small differences in height may have a major impact (Keddy and Shipley 1989).

There may not be a simple relationship between large plant and leaf size and competitive advantage; large plants may simply be better at capturing resources below and above ground through being more physiologically active, and the increased area which results allows them to be more effective – a cycle of positive re-enforcement, but a 'chicken and egg situation' in terms of explanation (Keddy et al. 2002).

1.3.8.2 Size and competitive response

It is to be expected that overall size makes a species an effective competitor, but also that it contributes to effective competitive response. Trial-based research sometimes throws up examples of species where there is no clear reason for a species being as effective as it is, e.g. *Chenopodium album* in one trail was far more effective as a competitor than would have been expected from its size and its seed weight (Goldberg and Fleetwood 1987). It is also noted that several very large herbaceous perennial genera, e.g. macleaya and rheum appear to be ineffective competitors, being out competed by smaller surrounding species – an apparent anomaly.

Goldberg and Fleetwood (1987) argue that competitive effects are more likely to be related to similar traits than response.

1.3.8.3 Growth rate

Grime indicates that rapid growth rate is correlated to competitive ability (Grime 2001), but this is not supported by all studies, for example Rösch et al. finding that there is not significant relationship (Rösch et al. 1997). Fast growth has been linked to competitiveness, and correlated to SLA (Pausas & Lavorel 2003)

1.3.8.4 Leaf size and shape

Shading has long been recognised as a means of establishing dominance. This is stressed by Salisbury (1929), with *Pteridium aquilinum* as an example of a species that effectively suppresses competitors.

Leaf area is generally correlated with rapid growth (Keddy et al. 2002). Leaf length to width ratio is regarded by Keddy as offering the best predictor of competitive performance, but different results are reported for different nutrient levels, with forbs with rounded leaves being better competitors in pots with no nutrient stress, and those with linear leaves better in low-nutrient compost. DISC. There is no known relationship between degree of leaf dissection and competition. (Keddy et al. 2002).

In a study of North American terrestrial orchids Givnish (1982) found that leaf height above ground related to habitat productivity, consistent with a previous study of solidago; species growing in relatively low-density low-productivity environments had lower leaves than those in high-density, highly productive ones.

1.3.8.5 Above and below ground competitive ability

Work by Mahmoud and Grime (1976) suggests that above and below ground competitive ability are interdependent, and that effective above ground competition for light may be pre-determined by effective belowground garnering of nutrient resources. They suggest that all competitive abilities are linked, as part of a family of genetic characteristics to maximise production. Gerry and Wilson (1995) suggest that, at least in their study, competition was primarily below ground.

Rösch et al. (1997), recorded there is no significant correlation noticed between competitive ability and root mass, but this has to be seen in the context of the trial lasting for only one growing season, and in containers. In another trial (also lasting one summer), Gerry and Wilson (1995), in which transplants were introduced into an established sward of grass, it was suggested that competition was primarily below ground. Grime, in a review of evidence on belowground competition concludes that competition for mineral nutrients has a major role to play in the interactions between species on fertile soils (Grime 1994).

Wilson (1988) reviewed 17 root and shoot competition studies and concluded that the total competitive effect is a linear combination of root and shoot interactions, which could in theory lead to species developing trade-offs between root and shoot abilities, enabling competition to be symmetrical, so that one could be a superior competitor for nutrients below ground and another a superior interceptor of light.

1.3.8.6 Ramets and competition

Trials by Mahmoud and Grime (1976) suggest that stolons give plants a competitive ability, as do massive shoots bases impenetrably by other species. Aarssen (1989) regards stolons and other similar features as being useful in competition because they enable nutrients to be effectively transferred between individuals.

Species with over ground plagiotropic shoots appear to be at an advantage over those with underground ones, e.g. *Galeobdolon luteum*, (Salisbury 1929) the garden variegated forms of which are commonly observed to spread rapidly in shaded habitats when discarded from gardens. Their effective spread may be limited however by variations in the efficiency with which they can penetrate leaf litter (Salisbury 1929), or indeed existing live vegetative cover. Aboveground runners appear to be an advantage in competing in flood-prone sites (Lenssen et al. 2004).

Forbs in low-resource environments will be limited in the quantity of resources which can be allocated to increasing growth in response to environmental conditions; geophytes are a clear example, where the annual production of shoots and leaves is limited by the amount of nutrients stored in the storage organ, and by the need to replenish those reserves during a relatively short growing season. Those species living in more productive environments can afford to, and need to, exhibit greater responsiveness to prevailing conditions, and hence show greater plasticity of growth. There is thus considerable population variation in leaf height (Givnish 1982); similarly it may be assumed that there is also considerable variety in ramet production and age, and possibly in leaf size.

According to work by Grime (1994), plasticity is not related to a capacity for dominance per se, at least in fertile soils; instead, he considers dominance to be related to high growth rate and massive above ground structures. Weiher at al. (1999) suggest that plasticity is related to relative growth rate , and therefore specific leaf area. Plasticity per se is very difficult to measure, but could well be related to traits which affect the distribution of clones, such as the distance between ramets, and the rate of ramet production.

It is suggested that clonal plants are more likely to be found in habitats where, in general, possibilities for successful pollination or seedling recruitment are reduced, or where resources are spatially irregular or where growing periods are short (Van Groendael et al. 1987). In particular, research indicates the following: wet habitats, low light conditions, low-nutrient, low mean temperatures, that non-persistent, splitting systems are more likely to be found in nutrient-rich or low-light conditions and that capacity to spread is generally stronger in wet or nutrient-rich habitats (Van Groendael et al. 1987). More precisely, splitting systems, linked to effective clonal spread, are more likely to be found in habitats which combine high nutrient and low light conditions and/or high nutrient and high moisture levels, while persistent systems which are linked to reduced spread and spatial consolidation, are more likely to be found in conditions with low nutrients and high light and/or low nutrient and low moisture.

1.3.8.7 Phenological advantage

Getting a head start is known to be a key element in competition, early emerging species able to grow in cooler conditions being at an advantage over later-emerging ones which need more warmth (Rabinowitz & Rapp 1984, Salisbury 1929). Aarssen established that earlier emergence confers a competitive advantage, although competition trials have generally worked with seedlings (Aarssen 1989).

1.3.9 Natural habitats and horticultural habitats

The relationship between fundamental niche and realized niches is perhaps part of the key to explaining why a study of plants in their native habitat can only provide us with a limited amount of useful information about their possible performance in cultivation. Horticultural reference literature is often extremely vague as to geographical origin and native habitat. Since plants in cultivation very often originate from one genepool, i.e., from a single provenance with a particular habitat, knowledge of geographical and habitat origins of the species as a whole may be little help in guiding practitioners in selecting suitable planting habitats. More broadly however, knowledge of the climate zone of a plant is from may be of help, as Hitchmough does in classifying a limited number of herbaceous ornamentals under climate categories and discussing how this knowledge might be used by planting designers (Hitchmough 1994).

Plants in the wild will be growing in a realised niche, in standard horticultural conditions they will very often be in conditions somewhat closer to their fundamental niche. In EBPS, potentially in competition with a wide range of other species, and positioned with usually scanty knowledge of their home growing conditions, they may be growing anywhere along a gradient between their fundamental and realised niches.

The difference between growing a plant specimen in isolation in cultivation and putting it into competition with neighbours is supported by trials which show that there is a large decrease in growth due to having any neighbours and a smaller decrease as more neighbours are added, i.e. the increasing effect of competition is strongly non-linear (Goldberg and Fleetwood 1987). The competitive ability of a plant species is often independent of the neighbouring species with which it is in competition (Goldberg and Fleetwood 1987).

1.3.10 Are there 'facilitator' species?

One possibility is that there may be plant species that effectively stabilise a plant community, reducing the infiltration of unwanted weedy species but at the same time not providing major competition for the ornamental forbs. Such species are here termed 'facilitator species'. Certain annuals perform this role as 'nurse crops' for wildflower meadow seed mixtures (Luscombe and Scott 1994), and have been shown to be beneficial in the establishment of forb-only seed mixtures (Dunnett and Hitchmough 2003b), by reducing the opportunities for unwanted species to develop through competition. It is possible that some species may perform this role on a more long-term basis. Such plants might perform the following functions:

- Filling in gaps between individuals of other species, thus protecting the soil against erosion during heavy rain,
- Competing with notably competitive weedy species (e.g. unwanted turf grasses), and so reducing their rate of growth, and so increasing diversity.

  Theoretically the following might be characteristics of such species:
    - Evergreen or semi-evergreen foliage, to compete with weed seedlings during the late winter and early spring period when the majority of weed seed germination takes place, and to limit leaching and erosion.
    - A spreading habit that enables the plant to fill the spaces between larger forbs, as do turf grasses. A guerrilla habit would do this most effectively.
    - Low stature, to reduce light competition with larger forbs.
    - An ability to withstand the intense competition for light and nutrients with larger forbs. Evergreen foliage is clearly an advantage here.

The issue of such species in designed vegetation needs to be seen in the context of Grime's distinction between three categories of species functioning within ecosystems: dominant, subordinate and transient (Grime 1998). Grime suggests that functional differences between dominants can have major impacts on the ecosystem as a whole, e.g. in levels of species diversity, but that subordinates may possibly exert a 'filter effect' on the recruitment of dominants, e.g. by a foliage canopy suppressing seedlings.

1.3.11 Intraspecific diversity

Grime points out how survival strategies may be affected by higher levels of genetic variation, his research showing how mixtures of species descended from clones show less species diversity over time than do those descended from seed raised plants (Grime 2001). Given how many species in horticulture are descended from a narrow genetic base, this has obvious implications for EBPS, indeed it could be argued that the genetic impoverishment resulting from relying on clonal vegetative propagation reduces the ability of a plant community to adapt and survive long-term, therefore reducing its 'ecological' as well as functional content and value.

1.3.12 Conclusions

A review of the relevant literature on plant ecology leads to the following conclusions regarding appropriate characteristics of plants in EBPS for productive sites.

EBPS on highly productive sites where ongoing maintenance is a particular problem can perhaps be most successful if an attempt is made to select species that are particularly effective competitors, which can effectively prevent the incursion of other, unwanted species. Diversity is likely to be low because competition will result in a limited number of species, some of which will establish large clonal patches.

Such species will be able to compete through:

- An ability to make early season rapid growth
- Shading out surrounding plants
- Inhibiting of other species through litter production
- Persistence/longevity
- A phalanx spreading habit

It is to be expected that species with C, C-S-R and C-S strategies will be most useful in this regard.

EBPS on productive sites which are liable to experience some disturbance or which are likely to receive a higher level of maintenance can rely less on sheer competitive ability but must be able to adapt to changing conditions through flexibility and rapid response to changes in local conditions.

In addition to having some of the characteristics of strongly competitive plants, as outlined above, such species will be able to fill vacant patches through:

- Successful self-seeding
- A far-reaching guerrilla spreading habit

It is to be expected that species with C-S-R or C-R strategies will be most useful in these situations.

Diversity can be difficult to maintain in productive environments, but the following characteristics are typical of species which show some ability to co-exist with dominants:

- Main period of active growth outside the growing season of dominants
- Growth habits that allow for the occupancy of physical space not occupied by dominants
- The maintenance of genetic diversity through reproduction by seed. Taxa of clonal origin or which cannot reproduce sexually, i.e. cultivars and many hybrids, can thus be regarded as less useful.

1.4 THE NEED FOR RESEARCH METHODOLOGY

Goldberg (1987) argues that there is little between detailed long-term studies of a few species and broad and observational surveys; there is a need for short-term experiments which provide inferential links between observed traits and competitive ability but which can be applied to large numbers of species. This study is aimed at working within this middle ground. In particular this study aims at developing a methodology that can be used by practitioners: the nursery trade, garden and landscape designers, horticulture professionals, etc. to evaluate and analyse the competitive abilities of herbaceous plants. Whilst the time scale of the study precludes the establishment and evaluation of long-term projects, it does concentrate on the analysis of relatively large numbers of species, as well as some analysis of vegetations that have existed for some years.

Exploring this 'middle ground' of research is important as there is a major gap between academic researchers and practitioners in the field of landscape and horticulture with regard to issues of plant ecology, and it might be argued, with many other aspects of plant growth too. The work of those in the field of restoration ecology does appear to be better informed by research. Practitioners tend to build up extensive knowledge of the plant material they work with, based on observation, but only rarely undertake any systematic controlled trials, or, unless they write semi-professionally, record these observations. There is no reason why practitioners should not be able to set up simple controlled trials in order to learn more about the material they work with. The corporate horticulture industry already does this, not as part of the wider world of academic research (i.e. not peer-reviewed or published), but for use within the company (Davis 2002). There is no reason why this practice should not become more widespread, and be undertaken by smaller businesses, or indeed by amateurs. Research may not be as rigorous as that undertaken by academics, but could still be of considerable use. A long-established example of this 'informal research' within an amateur or semi-professional area are the 'annual experiments' undertaken every year by members of the Henry Doubleday Research Association (now re-branded as 'Grow Organic'), in the development of techniques in the organic production of edible crops. It is one of the aims of this research to examine and assess techniques that could be used by practitioners in 'informal research'.

Gaudet and Keddy (1988) describe the observational type of study of interspecific competition as 'largely phenomological and non-predictive'. Keddy argues that functional ecology assesses traits measured on a large number of species, as only large sample sizes can create statistically significant correlations, pointing towards general patterns rather than the peculiarities of individual species; these patterns can then be used as a guide towards a refinement with new studies based on other traits suggested by the earlier studies. Vegetation studies, he suggests, are full of observations of links between plant traits and environment, but very little quantitative support for these (Keddy 1992). He also notes how our intellectual heritage tends to force us towards the analysis of smaller and smaller problems. This is another way of saying that 'reductionism' is often the only way that science actually solves problems, but the results are often little help for practitioners seeking to understand the wider issues (Keddy 1990).

Competition studies can be criticised by those involved in practice as often being short-term (often taking place only within one growing season), bearing little relationship to reality (nearly always in containers) and dealing with only a few species. The intention here is to use a broader brush approach, with both simple trials based on the kind of trials often used in plant ecology and some schematic observation.

Since little formal experimental work has so far been carried out on the competitive abilities, or indeed any ecological characteristics, of ornamental herbaceous plants, these trials were inevitably also part of the process of evaluating how such experimental work could be carried out, in particular the feasibility of running them for practitioners with limited resources and experience of scientific method.

Furthermore, the attitude is taken that there is such a gap between the very systematic and reductionist nature of scientific work on plant ecology and the almost completely unsystematic and anecdotal nature of plant knowledge (at least in the UK) that *any* attempt at improving systems of data collection and establishing relatively crude trialling methods is to be welcomed. Trials and data collection, as undertaken by those working within scientific ecology are time-consuming and often involved expensive equipment (or staff or student time), and as such are seen by those outside science as being irrelevant to their needs. Consequently, methodologies which may be seen as overly crude or inaccurate by those within the scientific community are here accepted as being an improvement on the - arguably amateurish approach taken to plant evaluation and trailing by horticultural practitioners and commentators in the UK, where evaluation is, at best, carried out only for visual appearance or usage within conventional horticultural management schemes.

2

THE CSR MODEL OF PLANT FUNCTIONAL TYPES – AN EVALUATION OF ITS VALUE IN ECOLOGICALLY-BASED ORNAMENTAL HORTICULTURE

THE CSR MODEL OF PLANT FUNCTIONAL TYPES – AN EVALUATION OF ITS VALUE IN ECOLOGICALLY-BASED ORNAMENTAL HORTICULTURE

2.1 INTRODUCTION

The Grime CSR model has been discussed (see *1. Introduction 3.1)*. Here the intention is to attempt to assess whether the CSR model has real value for practitioners in ornamental horticulture and planting design. CSR theory is a useful source of ideas about the role of particular species or management practices for those in horticulture or landscape management, but there is a need for a more rigorous analysis. In particular there is a need to assess whether the model has any value in helping the predicting plant performance and the compatibility of plant species in EBPS. Given the focus of this study, the predicting of competitive performance of horticultural species is a particular interest. Competitive performance has major implications for the planning and management of plantings with regard to the long-term compatibility of the species included, important for the maintenance of biodiversity and visual interest, and with regard to the possibility of achieving suppression of unwanted weedy or alien species.

2.1.2 Aims

- To undertake CSR ordination for a representative sample of ornamental herbaceous plant species suitable for productive sites.
- To assess whether a knowledge of CSR ordinations might be of any use in guiding plant selection for horticultural situations and EBPS.

2.2 CSR THEORY AND ORNAMENTAL HORTICULTURAL VEGETATION

Grime's *Competitor, Stress tolerator, Ruderal* (CSR) model for the understanding of plant functional types has had considerable impact, but by no means complete acceptance amongst plant ecologists.

Part of the rationale behind CSR theory it that by enabling ecologists to have a better understanding of survival strategies it is possible to adopt a more predictive approach to the behaviour of plants in wide range of habitats and geographic and climatic regions (Grime 2001). Evidence that a set of plant traits can be measured and conclusions drawn with meaningful results for a variety of habitats and geographic regions has been produced by Diaz et al; although CSR ordination was not included in this study, the traits measured by CSR were (Diaz et al. 2004). Other studies have found the CSR model useful in understanding vegetation dynamics outside Britain (Caccianiga et al 2006). Others have found it less useful, with limited validity as a predictive tool, but with some value as simply the only coherent model for plant community ecology (Bastow Wilson & Lee 2000).

Van der Werf et al. 1998 reported that trial evidence suggested the identification of plant functional types (e.g. CSR) may be limited in predicting vegetation dynamics in succession, and furthermore that relative growth rate and associated trits may not play a crucial role in competition between species in succession either.

An obvious application might be to horticulture, and indeed the last few years have seen an increasing consideration of the applicability of CSR. An assessment needs to be made of how useful an understanding might be of the CSR ordination of horticultural plants for their management in garden and other created vegetations, in particular for how useful the predictive aspects of CSR theory may be in assembling sustainable and low-maintenance plantings. There appear to have been no attempts at measuring the CSR value of ornamental plant species, although suggestions have been made that is should be possible to categorise ornamental herbaceous species in this way (Hitchmough 2004). Therefore, it is suggested that the first step in assessing whether the model has any value, is to undertake a CSR ordination of a number of well-known species and then to see if the results are in any way meaningful to established garden practice, and existing knowledge of plant use and performance.

The most determined efforts to argue the applicability of CSR theory to horticulture has been made by Schmidt and Hofmannn (2003), who relate the three basic survival strategies to maintenance regimes. They describe C-concept, S-concept and R-concept plantings, each one suitable for a particular category of environment, and requiring a different level and type of maintenance. C-concept plantings are those for situations were there are high levels of resources (light, moisture, nutrients), S-concept for those where there are limiting factors (e.g. drought, low soil fertility, waterlogging) and R-concept for where there is regular disturbance. In practice, this latter concept is used to describe the kind of border plantings which have historically been the mainstay of conventional horticulture, using annuals and other short-lived (and thus ruderal) species; the maintenance requirement is high, which reflects the ephemeral nature of ruderal plant communities - they need a lot of input to maintain what is in fact a relatively unstable combination of species. In a further paper, Schmidt (2006a), spells out that a knowledge of the CSR model can be seen as an addition to and expansion of Hansen and Stahl's work on ornamental plant communities.

Schmidt and Hofmann's work makes sense intuitively to those involved in plant management, and is useful for producing a set of categories which integrates knowledge of the natural habitat of many species in cultivation, their behaviour in cultivation and thus provides guidance towards the development of an appropriate management regime, and even aspects of their visual qualities. The often-difficult task of combining ornamental plant species can thus be simplified. However no CSR ordinations of plant species have been carried out, and the application of CSR theory and language is applied intuitively rather than being based on objective data. Schmidt (2006a) draws attention to the fact that practitioner intuition about plant morphology is generally a good guide to species ecological requirements and functional type.

2.2.1 Methodology

The soft CSR tests, developed by Grime and his collaborators to simplify the original laboratory-based tests, involve the measurement of data in the field, and the application of a number of simple tests (Hodgson et al. 1999, Grime 2001). Results are run through a Microsoft Excel™ spreadsheet, one for forbs, and a different one for grasses (Hunt et al. 2004). Species were selected primarily as being known to be useful and commonly used, robust and vigorous herbaceous perennials, suitable for use in the public landscape. A number of other common garden species were included for comparison, mostly as examples of less clearly vigorous perennials (at least in the British garden environment). The remainder included were species with little history of cultivation, but which have characteristics which lend themselves to use in public landscapes.

Specimens of the species tested were growing mostly in one of two gardens in the English west Midlands, the remainder in gardens or public parks in the south-west (see Appendix Research Locations). There is little climatic difference between the locations. Soil types varied but all were relatively fertile, with average moisture conditions. In each case there were at least three specimens of the plants in the garden, and often many more, so a brief examination was able to determine that the individuals measured were typical. In addition, all plants had been planted and maintained either the author, or a colleague, so their history was known. Plants were generally at least three years old, and in most cases five to six.

Leaf dry weight, leaf area, and specific leaf area (SLA) were measured by procedures carried out on at least five of the largest, fully hydrated, leaves. They were scanned with a Hewlett Packard scanning programme on a desktop flatbed scanner, and the surface area measured using a leaf surface area measurement programme (Askew n.d.). Scans were done at 600dpi except for some of the grass and carex species, where leaf laminas ended in very fine points, where 1200dpi was used. Further measurement of small leaves was attempted at 1200dpi, but was not pursued as it was very time-consuming, and sometimes the leaf surface area measurement programme gave wildly inaccurate results, which necessitates scanning twice, once at a lower resolution to give a rough figure in order to establish an outline parameter. In some cases leaves had light patches which are not registered by the scanner. Where this was the case, the leaves were photocopied, and any light patches which still persisted on the photocopy were touched up with black felt pen. Differences between originals (touched up with felt pen to remove light areas) and photocopies were measured, and were small enough to be regarded as not significant: *Urtica dioica* photocopies were 95% of the original, *Lunaria rediviva* and *Geranium x oxonianum* were both 99%. In the case of species where leaves which cast enough shadow to possibly affect results, e.g. urtica where deeply toothed leaf edges can create a considerable length of 1mm wide shadow, the leaves are pressed first.

The leaves being tested were weighed fresh, immediately after picking, and were later dried in an oven at 80°C until crisp, then weighed again, and the dry matter content calculated.

An attempt to evaluate the accuracy of the test was carried out, by performing the soft test on a number of British natives and comparing the results with those to be found in Grime, et al. 1989 – on the table of results (see 2. Appendix 2), these are termed 'calibration species'.

	result		Grime
Alliaria petiolata	C/CR		CR
Geum urbanum	S/SC		S/CSR
Leucanthemum vulgaris (x 15 leaves)	SC		CSR/CR
Urtica dioica	C/CSR		C

(8.May.2004)

Table 2.1. CSR Ordinations of Calibration Species for Soft Test

Clearly the soft test as applied here gives a broadly similar, but not identical result, with no clear and obvious bias towards any of the three extremes.

According to Thompson et al. (1999, 2004) the issue of whether to include petioles in evaluation of SLA has never been satisfactorily resolved. The argument for inclusion is that of functional equivalence between leaves without petioles whose lamina structure supports itself and leaves with petioles to perform this function, a position Thompson supports. However he suggests that in plants, such as in petasites, where the stem is horizontal at ground level the petiole acts as a functional stem, and should not be included. Apart from species such as this, the definition of a leaf is taken to be the point of abscission. In those species where leaves are strongly decurrent and no clear abscission takes place (as in some *Cirsium* species), the decurrent section of the leaf is cut away from the stem and included as leaf.

In those species where there is a majority of basal leaves supported by long petioles originating from a stem at ground level, but also a proportion of leaves with shorter petioles which emerge from a vertical flowering stem (as is the case with many species of geranium), it is not clear whether the length of petiole may affect results. In order to throw light on this, stem and basal leaves of *Geranium phaeum* 'Lily Lovell' were measured, with and without petioles.

	% dry matter	SLA	CSR
Geranium phaeum 'Lily Lovell'			
stem leaf	17	35	C/CR
basal leaf	13	19	C/CR

(May 2004)

Table 2.2. Comparison of data for basal and stem leaves for *Geranium phaeum* 'Lily Lovell' The differences between the two leaf types do not seem significant.

2.3 RESULTS

Results of the CSR ordination of the species tested is given in the table *CSR ordinations of 48 ornamental herbaceous perennials not native to the British Isles* (2.6.2 Appendix 2), together with a broad indication of the climatic zone and typical habitat of the species in the wild.

Anyone with practical experience in the management of herbaceous perennial examining the results will find confirmation of their, generally subjective, assessment of the growth habits and management requirements of the species under consideration. The majority of those species with C-character will be known as vigorous plants in most horticultural situations. However only the most broad indications as to plant traits are given, for example, both *Aqulegia vulgaris* and *Geranium endressii* are CR, yet the former forms only a tight clump with no development of potentially independent ramets, whilst the latter forms a strongly-spreading clump through rapid ramet production. As expected, since the majority of species examined are those which are known to perform well in standard horticultural situations, C- traits predominate. All those which show some S-character are clearly visually different, being smaller species, often slower growing, or having foliage which is evergreen, physically tough or grey through having a coating of minute hairs – all of these being typical characteristics of plants which originate in environments which expose plants to stress. In horticulture, these are species which are often grown in situations where growth conditions are less than ideal: e.g. *Vinca minor* is shade-tolerant, *Nepeta x faassenii* drought-tolerant and *Euphorbia myrsinites* is often grown in rockeries, steep slopes and other dry and infertile environments.

There are some obvious anomalies. Three similar plants stand out: *Bergenia 'Abendglut', Helleborus x hybridus,* and *Liriope muscari.* All are functionally evergreen, with leathery foliage, and are generally regarded as being shade-tolerant (Rice 2006). Intuition would give them some S-character, yet they give results with clear C-character. To investigate this further, the CSR test was applied to helleborus with and without the large petiole:

	% dry matter	SLA	CSR
Helleborus x hybridus			
lamina and petiole	21	7	C
lamina only	25	10	C

(May 2004)

Table 2.3. Comparison of data between usage of lamina and petiole and lamina only of *Helleborus x hybridus.*

This appears to have made no difference. The liriope was tested twice, once in June and once in August, the first producing a 'CR' result, the second a 'C/CR'. Thompson notes that CSR prediction worked with least sensitivity in woodland habitats (Thompson et al. 1999). Another clear anomaly is *Artemisia* cf. *cana*, a native of dry prairie in the Great Plains of North America.

2.4 DISCUSSION

Indication of C-character indicates that a species can at least be expected to be competitive in its natural habitat. In a horticultural situation, of necessity an artificial one, this cannot be assumed. Experience suggests that many of the species shown here to share C-character cannot all be planted together and be expected to be compatible. Knowledge of the natural habitats of many of the species listed suggests that species with C-character can originate in a wide variety of habitats, including some which are notably stressful, e.g. dry meadows.

Plant traits relating to growth habit and phenology can be observed to play a vitally important role in determining how species will perform in horticultural conditions. Indication of C character does not by itself give a good indication of horticultural performance; even less does it of performance in EBPS. For example, shoots of *Eupatorium maculatum* do not emerge until May in British garden conditions, reaching a height of 2-3 m by late August, yet spreading sideways through ramets only very slowly, whilst *Geranium endressii* grows almost continuously through the winter at any temperature above freezing, and spreads rapidly through ramet production. If grown in competition with grasses, the former is reduced considerably in height, whilst the latter is only slightly, and continues to spread (see *Investigating the growth of ornamental herbaceous perennials in grass swards* 4.2.1). I t could be argued that knowledge of the CSR character of plant species adds little to our comprehension of competition without a wider understanding of plant traits and how these affect competition.

A point strongly made by Hodgson et al. (1999) is that competitiveness does not always coincide with dominance. They point out that C-character indicates high levels of resource capture and re-investment, whereas dominance only that a high biomass relative to other species has been attained, and that C-character makes no distinction between large fast-growing species and large species which grow slowly but are long-lived. This is important to understand in the context of a number of species which in horticulture are known to be slow to establish, but are long-lived, and resilient, in that they show an ability to survive suppression by more vigorously growing species, at least when established; *Dictamnus albus* (C) and *Baptisia australis* (C/CR) are two good examples. This might also apply to *Iris sibirica* (C). For our purposes these might be seen *slow competitors*.

The CSR system is meant to be applied to a range of habitats and vegetation types. Consequently species which are classified as competitive in one habitat may not be in another. The example above, of a eupatorium and a geranium, indicate this particularly clearly, and highlight one of the central issues in ecological planting design, that of selecting traits which are used as a basis for choosing plants to be grown together. *Eupatorium maculatum* is from a very strongly continental climate and a member of what could loosely be described as 'prairie flora' and exhibits the classic growth habit of prairie forbs, of having strongly upright stems (Ladd 1995). The latter is from moist and woodland edge habitats with a maritime climate (Tutin et al. 1968), and could be described as belonging to the 'tall herb flora' characteristic of highly productive sites often associated with woodland edge habitats in mountain areas (Kuhn 2001). Like many species from these areas, the geranium exhibits rapid growth early in the year and strongly horizontally spreading tendencies. *Eupatorium maculatum* appears to be able to make very rapid growth in a short period, thus enabling it to respond to the relatively short but intense growing season of a strongly continental climate, whereas the geranium has a phenological response to a climate which offers a longer but cooler growing season. The greater ability of plants from maritime regions and tall-herb floras to spread sideways could possibly be related to the need to compete for different resources using different physical means – the investigation of this could be an area for further research (Kingsbury 2004).

Several of the species tested were of European (including Asian Turkey) dry meadow origin. All of the following exhibited some C character, but no S: *Dianthus carthusianorum* (CR), *Eryngium bourgatii* (CR), *Knautia macedonica* (CR), *Papaver orientale* (C/CR) and *Salvia nemorosa* (CR). According to the conception of Schmidt and Hofmann, it might be expected that these species would exhibit some S-character, as they are commonly planted in the drought-tolerant 'steppe' style planting in public parks in Germany, and there is no doubting their ability to survive testing conditions (Schmidt and Hofmann 2003), Kingsbury 1996). However, these could be best described as 'stress avoiders', as they grow and flower early in the year, when post-winter moisture levels are high, tending to become dormant later. In the case of *Papaver orientale* (C/CR) this can be seen quite dramatically, as foliage emerges in late winter in British gardens, and the plants die back in mid-summer. Other species from these habitats, such as those listed above, will die back in drought, but in British garden conditions, summer moisture conditions are usually sufficiently high for them to continue to stay green, and in some cases (notably *Knautia macedonica*) to continue to flower for several months. The only short-grass prairie/Great Plains species tested, *Artemisia cana,* has a CR rating, and a similar argument may apply here.

Competition in the brief spring of the wild habitat of dry meadow forbs may be expected to be intense, but of short duration while conditions conducive to growth are good, ceasing rapidly once the soil begins to dry out (see fig.2.1 – 1.). For much of the year, competition can be expected to be minimal, as there are insufficient resources to fuel it (Bavkon 2005). In the very different conditions of horticulture in a maritime climate, the competitive character of these plant species is overlooked, as on the one hand, those involved in growing them make inevitable comparisons with much larger and more rapidly-growing species of prairie and tall-herb floras and on the other, are rarely given the opportunity to appreciate their 'stress-avoidance' strategy (see fig.2.1 – 2.).. Those managing these plants in the relatively continental climates of central Europe may make the first miss-evaluation, but will appreciate their ability to survive drought by slowing down their growth or becoming dormant – however to see them as 'stress-tolerators' in the context of the CSR model is clearly incorrect.

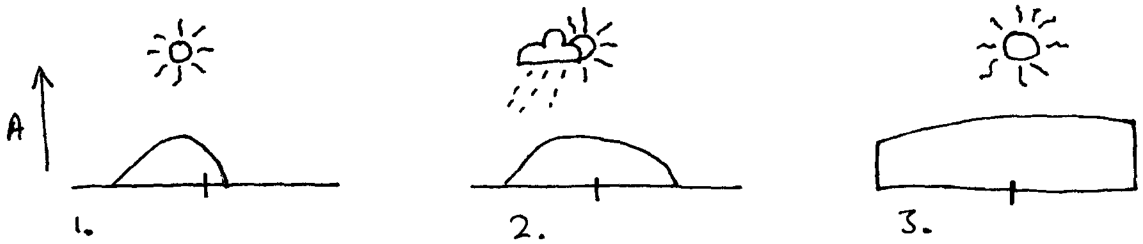


Fig. 2.1. Stress tolerators, and stress avoiders in dry summer climates (see below for explanation).

Many competitive plants survive low moisture stress by dormancy during dry periods. These diagrams represent above ground living biomass (*y* axis), from the beginning to the end of the year (*x* axis).

1. In a continental climate with a hot dry summer a competitive species which operates as a facultative stress avoider builds to a maximum in late spring and declines to total dormancy by mid-summer. During its period of maximum growth it is able to dominate neighbours – its competitive character is obvious from a visual examination of the vegetation community in which it occurs.
2. In a maritime climate with a cool moist summer, the same species maintains biomass until autumn since as a facultative stress avoider it is able to respond to relatively high moisture levels and so continue to grow. However it may not be able to maintain dominance as other species may be able to make better use of the available resources – so its competitive character is masked. Examples might be Central European dry meadow species like *Saliva nemorosa* and *Dianthus carthusianorum* growing in the west of Britain.
3. A true stress-tolerant species often conserves resources through accumulation, i.e. through being evergreen.

In addition, the R-character of the above dry-meadow habitat species needs to be put in context. The most extreme form of stress-avoidance is the kamikaze one - the parent dies but leaves behind seeds to start off the next generation. In particularly severe droughts, the ruderal character of these species clearly has a role to play – again this is unlikely to be appreciated in the conditions provided for the plants in horticultural situations in the British Isles.

Hitchmough (n.d) suggests that CSR theory is only a helpful guide to species performance in the context of a plant's natural habitat, as species will only occur in environments to which they are broadly fitted; looking at CSR in isolation will not necessarily provide any useful explanation of the performance of a particular species in cultivation alongside species with which it is not found in nature in a climate and soil regime which may be very different to that in which it is normally found, let alone have any predictive power (Hitchmough n.d). CSR in other words is not a quality which is integral to a species, but instead a quality which is contextualised by environment and by relationships with other species.

It would appear that the usefulness of the CSR model in predicting performance in horticulture and even in ecological planting design, where there is a higher level of competition, appears to be very limited. It could be argued that an understanding of competition is more important for contemporary ecological planting work, but given that as we have seen, the nature of competition varies considerably from one habitat and climate zone to another, it is necessary to have a much deeper understanding of how plant growth form and phenology affect competition.

2.5 CONCLUSIONS

Since the plant traits that affect competition in different habitats and climate zones appear to be different, more useful than a narrow focus on applying the CSR model to horticultural vegetation, might be a focus instead on 'suites' or ensembles of plant species from roughly similar habitats and as well as on individual traits and how these determine competitive, or other behaviours, in different habitats. An attempt at relating plant traits and their phenological aspects to different environmental conditions would be very useful in building up lists of species suitable for particular conditions and climates. Knowledge of the ecology of plant species in their natural habitat may have something to contribute, particularly in relating phenological response to climate, but it is more important to gather information on plant traits and how these contribute to competitive ability in the context of the climate zone in which they are to be grown – it may be possible to 'mix and match' plants from different climate zones and habitats to some extent.

The idea of suites of plants brings the discussion back to the Schmidt and Hofmann conceptualisation of C-, S- and R-based planting schemes. These have been developed on a pragmatic basis, on what works in the context of the situation in which the authors are working, and the lack of any testing of species for their place in the CSR model appears to be relatively unimportant to the undoubted success of the plantings which they manage and the coherence of their management schemes. Instead the idea of C, S, R planting concepts appears to be an extremely useful tool in putting together suites of plants which can be expected to co-exist and which can be managed in similar ways. Further research into plant traits and competitiveness could do worse than to work within this model. However, the usefulness of the CSR model to Schmidt, begs the question – how is it decided whether a plant taxon should be allocated to a C-type, S-type or R-type planting scheme?

However, to avoid confusion with the Grime CSR model, it is suggested that the Schmidt and Hofmann use of terms such as competitive, stress-tolerant and ruderal be qualified; their use of the terms 'C-concept, S-concept and R-concept' could perhaps be used to the exclusion of the terms used by Grime and his colleagues – so making it clear where the inspiration comes from, but that this is a different model, serving the world of horticulture rather than ecological science.

This study will now abandon any further use of the CSR model, and concentrate on the 'real world' of the garden, and in particular on an analysis of plant morphological and phenological traits and how these relate to competitiveness.

2.6 Appendices

2.6.1 Appendix 1. Variables used in the CSR ordination

Variables used in the CSR ordination (Hunt et al. 2004).

Variable	Definition			
CanopyHeight	Six-point classification:		1	1- 49 mm
			2	50 - 99 mm
			3	100 - 299 mm
			4	300 - 599 mm
			5	600 - 999 mm
			6	> 999 mm
DryMatterContent	Mean of percent dry matter content in the largest, fully hydrated, fully expanded leaves (%)			
FloweringPeriod	Normal duration of flowering period (months)			
FloweringStart	Six-point classification:		1	First flowering in March or earlier
			2	in April
			3	in May
			4	in June
			5	in July
			6	in August or later, or before leaves in spring
LateralSpread	Six-point classification:		1	Plant short-lived
		(in graminoids)	2	Loosely tufted ramets radiating about a single axis, no thickened rootstock
		(in non-graminoids)	2	Compactly tufted about a single axis, no thickened rootstock
		(in graminoids)	3	Compactly tufted ramets appressed to each other at base
		(in non-graminoids)	3	Compactly tufted about a single axis, thickened rootstock present
			4	Shortly creeping, <40 mm between ramets
			5	Creeping, 40-79 mm between ramets
			6	Widely creeping, >79 mm between ramets
LeafDryWeight	Mean dry weight in the largest, fully hydrated, fully expanded leaves (mg)			
SpecificLeaf Area	Mean of area/dry weight quotient in the largest, fully hydrated, fully expanded leaves (mm sq / mg)			

2.6.2 Appendix 2. CSR ordinations of 48 ornamental herbaceous perennials not native to the British Isles

	CSR	Canopy height,category	% dry matter	Single leaf dry wt., mg	Specific Leaf Area	Flowering start	FloweringPeriod	Lateral Spread
Aquilegia vulgaris	CR	4	24	820	18	2	2	3
Amsonia orientalis	C/CR	4	28	54	13	4	1	4
Artemesia cf.cana	CR	3	19	20	15	6	1	3
Artemesia lactiflora 'Rosenschleier'	C/CR	6	17	134	27	4	2	4
Aster cordifolius 'Little Carlow'	CR	4	14	68	15	6	2	4
Aster puniceus	C/CR	6	23	126	23	6	2	4
Aster umbellatus	C	6	38	78	16	6	1	5
Astrantia major	CR	4	15	544	37	3	4	3
Bergenia 'Abendglut'	C	3	24	1708	6	1	1	5
Calamagrostis x acutiflora 'Karl Foerster'	C-R	5	62	208	13	4	1	4
Calamintha grandiflora	CR	4	21	54	32	6	2	4
Carex dipsacacea	SC	3	44	80	3	4	1	4
Cirsium canum	CR	4	12	1066	19	6	1	4
Dianthus carthusianorum	CR	3	19	30	19	6	2	4
Dictamnus albus	C	5	28	104	19	3	1	3
Eryngium bourgatii	CR	4	17	504	8	6	1	4
Eupatorium maculatum ssp.purpureum	C/CR	6	20	232	12	6	1	4
Euphorbia cyparissus	CR	4	18	1	31	3	1	6
Euphorbia myrsinites	SC	2	24	21	11	1	1	4
Euphorbia palustris	C/CR	5	24	34	27	3	1	3
Filipendula rubra 'Venusta'	C	6	33	3982	13	5	1	6
Geranium asphodeloides	C/CR	3	20	178	9	4	2	6
Geranium endressii	CR	4	37	620	15	4	5	4
Geranium phaeum	C/CR	4	19	436	24	3	2	5
Geranium x oxonianum 'Claridge Druce'	CR	4	18	260	19	4	5	4
Helianthus 'Lemon Queen	C/CR	6	22	116	5	6	2	4
Helleborus orientalis hyb.	C	4	26	7342	6	1	1	3
Iris sibirica	C	5	30	646	11	3	1	4
Knautia macedonica	CR	3	21	90	16	4	4	3
Liriope muscari	CR	3	12	460	8	6	2	4
Lunaria rediviva	C/CR	5	18	632	23	2	2	4
Lysimachia ciliata 'Firecracker'	CR	6	24	163	26	6	1	5
Macleaya cordata	C	6	21	5227	14	6	2	6
Miscanthus sinensis	C-R	6	33	778	14	6	1	4
Nepeta x faassenii	C/SC	4	31	19	25	3	2	4
Ophiopogon bodinieri	C/SC	3	35	80	10	6	1	6
Papaver orientale	C/CR	4	14	684	11	3	1	3
Persicaria amplexicaule	C/CR	5	20	826	17	6	2	5

	CSR	Canopy height,category	% dry matter	Single leaf dry wt., mg	Specific Leaf Area	Flowering start	FloweringPeriod	Lateral Spread
Phlomis russelliana	C	4	33	2230	12	4	1	4
Rudbeckia fulgida 'Goldsturm'	C	4	34	962	12	6	2	5
Salvia nemorosa	CR	4	24	34	23	3	2	3
Solidago rugosa 'Feuerwerke'	C/CR	6	24	34	27	6	2	4
Stipa arundinacea	S/SC	5	72	84	13	6	1	3
Stipa gigantea	S/SC	4	38	300	5	4	1	3
Thermopsis caroliniana	C/CR	5	15	313	29	3	1	6
Veronica incana	C/SC	2	26	51	12	2	1	6
Veronicastrum virginicum	C	6	29	220	18	4	1	3
Vinca minor	SC	3	46	50	9	2	1	6
Native species for calibration.								
Alliaria petiolata x 5 leave	**C/SC**	5	20	1,005	8	1	2	1
x 10 "	**C/CR**		23	3,754	31			
x 15 large "	**C/CR**		27	6,005	23			
Geum urbanum x5 "	**C/SC**	3	7	806	7	2	3	2
x 10 "	**S/SC**		13	1,482	12			
x 15 large "	**SC/CSR**		13	5,386	25			
Hyacinthoides non-scripta	**C/CR**	3	13	3,187	23	1	2	3
Leucanthemum vulgaris x	**SC**	4	19	537	15	2		3
Ranunculus repens x 5 "	**SC**	2	23	734	5	1	3	6
Urtica dioica x5 "	**C/SC**	5	23	1,544	17			
x 10	**C/CSR**		27	2,528	26	1	4	6

3

USE OF TRANSECTS TO INVESTIGATE ESTABLISHED ECOLOGICALLY-BASED PLANTINGS

USE OF TRANSECTS TO INVESTIGATE ESTABLISHED ECOLOGICALLY-BASED PLANTINGS

3.1 INTRODUCTION

The use of plans and transects is well established in plant ecology. In theory it should be useful for the analysis of vegetation in designed plantings too. No published studies of deliberately planted herbaceous vegetation are known which use any mapping element whatsoever, although mapping exercises of plantings are undertaken by students at some Germany universities (Schmidt 2004).

EBPS, given that they involve plant species in a constant state of flux, will over time see the movement of plant species and individuals from their initial planting or sowing positions, and the development of an increasingly complex structure at ground level. As time goes on, this structure will increasingly reflect natural processes rather than human design; although maintenance operations or other periodic human interventions will modify the naturally developing pattern to a greater or lesser extent. As an example, the following natural processes have been observed in two author-created plantings over 9-10 year periods (Cowley Manor, and Elmtree Cottage):

1. Seeding of species planted, which is observed to vary enormously in quantity between species.
    - Development of seedlings through to maturity is observed to vary too, with the following patterns observed:
        - i) Mass germination resulting in dense seedling mats, from which only a small proportion of individuals develop to maturity, the rest becoming stunted and eventually disappearing, e.g. *Digitalis purpurea, Verbascum bombyciferum*
        - ii) Occasional seedlings, a high proportion of which develop to maturity, the rest disappearing, e.g. *Aquilegia vulgaris, Geranium sylvaticum.*
        - iii) Very occasional seedlings, of which nearly all develop to maturity, e.g. *Helleborus foetidus, Lunaria rediviva.*
        - iv) Mass or at large-scale germination, of which only a small quantity develop to maturity, the rest remaining as healthy-looking individuals but which do not develop. It is not clear whether these individuals are replaced every year by fresh seed or whether they survive from year to year, but a 'reserve stock' of juvenile plants seems to exist, presumably ready to develop further if local competition is reduced, e.g. *Filipendula ulmaria, Thalictrum polygamum.*

i)-iii) can be related to seed size; high seed weight has been shown to relate positively to ability to establish and compete (Goldberg and Fleetwood 1987, Grime 2001).

2. Spread of clumps of species planted, through a variety of clonal mechanisms.
3. Breaking up of clumps, either through patterns of clonal growth or disturbance.
4. Disappearance of individuals and species.
5. Intermingling and close association of species planted.
6. Appearance of species which were not part of the original plan, either species from elsewhere in the garden concerned or wild species from outside the garden.

3.1.1 Validity and appropriateness of mapping as a means of assessing plant competitiveness

It may be argued that mapping only describes the situation of one set of plants in one place (with its own peculiarities of climate, soil, management history etc) at one time, and that general conclusions cannot be drawn from such an exercise. However, mapping does record what is going on, in a real life situation. Information about plant performance gained from mapping from one site may be compared with less detailed information from another; the former may elucidate the latter, or the latter may validate or invalidate the former – but gradually a picture can be built up of typical plant performance.

In this instance, the value of the mapping exercise is seen as looking at issues of real life competition, in particular at examples of competitive and associated processes (re-generation and senescence) which can then be used to inform discussions of plant morphological and phenological characteristics, trial results etc, as well as providing a guide to suggestions for further research.

3.1.2 Aims

To use transects to evaluate the following aspects of well-established planting schemes for which plant content and an outline record of management are both known:

1. To record the position of planted species, measure their movement, and their gains and losses over time – very crudely, gains could be seen as the result of greater competitive ability, in the given environment, relative to species which have gained less.
2. To distinguish between species which are increasing through clonal spread and recruitment through seed, i.e. between competitive ability in the strict sense, and colonising ability, or degree of ruderality.
3. To assess how effectively weeds, or non-intentional but benign species are able to colonise plantings.
4. To assess floristic diversity, and level of integration of species, after a given period of time.

5. To assess the use of transects as a methodology to record the status and development of plants in herbaceous borders and other planting schemes.

3.2 SELECTION OF SITES AND METHODOLOGY

Transects, rather than area mapping, was selected as the most appropriate method, as it allows a more extensive area to be examined, including a wide range of plant individuals and allows habitat gradients to be included (Kent & Coker 1992). Also, it seemed the easiest solution to what is a formidable practical problem, that of mapping a complex mass of vegetation where there is considerable interweaving of foliage; in particular it is necessary to distinguish between and to record the canopy of an individual and its base, and the two may occupy very different areas, which is considerably more problematic to record on a plan than in a transect – which by its nature as a sectional view enables this distinction to be shown.

A major problem with selecting sites for mapping is that there is very little documentation of EBPS sites, or indeed of any herbaceous plantings. Specifically:

1. Relatively few sites have detailed and quantified plant lists of what was originally planted
2. Almost none have planting plans
3. There is no documentation of management or other interventions such as thinning, the introduction of new taxa or re-planting.

In addition, sites need to be chosen where plantings are large enough to include multiples of individuals of a reasonable number of taxa, in order that something like a functioning inter-species balance might evolve.

Only two sites could be found which approached these criteria:

Cowley Manor, Gloucestershire, England (see Appendix 2. Research Locations)

Plantings of several hundred square metres, created by the author during 1995-6, and where the author either supervised maintenance or was informed about maintenance procedures between planting and 2004. During this time, the planting received very little maintenance from 1999-2004, with no weed removal or thinning of planted species – this enhanced the value of the site, as natural processes clearly dominated.

Hermannshof, Weinheim an der Bergstraße, Baden-Wurttemburg, Germany (see Appendix 2. Research Locations)

Little documentation is known to exist of plantings prior to the appointment of Cassian Schmidt in 1998, although detailed verbal reports were given to him by the founding director (Urs Walser) regarding original plantings, made from 1982 onwards and their subsequent modification. Some plans, made by students, have also been made at various times which show what has been planted. There are several plantings in the garden which are known to have been relatively untouched for a period of 20 years – it is these which have been examined here.

3.2.1 Details of Methodology

1. A site is selected and a transect made on the basis of cutting across a representative swathe of vegetation, including a habitat gradient if present. A flexible tape measure is used to describe the transect.
2. The following are noted, for all plants present:
    - i) Plant height
    - ii) Edge of base of clump at ground level, i.e. where stem growth connects to root growth
    - iii) Edge of foliage at its maximum horizontal spread
    - iv) Position of seedlings
    - v) Position of any additional factors affecting habitat, e.g. tree canopy.
3. A diagram is drawn illustrating the above, using abbreviated plant names and a series of stylistic devices to convey, as simply as possible, the location of plant growth along the transect.

3.3 RESULTS

Transect diagrams, explanation of symbols and abbreviations – see 3 Appendix.

3.3.1 Cowley Transects

3.3.1.1 Site History

All borders were made from lawn grass, sprayed off with glyphosate, and planting was made through the dead turf with no soil preparation or provision of additional nutrient, or mulching. There was little apparent germination from a seed bank.

3.3.1.2 Observations of Cowley Transects

Transects carried out1.June.2004

Central Bed, T1

Planted in spring of 1996, this border on reasonably deep soil, slightly calcareous, incorporated a range of species chosen for a reputation for thriving on moist soil. There is no problem with drainage. Minimal afternoon shading of this area from nearby tilia sp.

During 1996-1998, spring hoeing removed surface weeds. During 1999-2001, this ceased, but during June/July the bed was hand weeded, pulling primarily chamaenerion, urtica, rumex and convolvulus. In 2002 an attempt was made to limit convolvulus by painting with glyphosate and wallpaper paste. Since then there has been no maintenance apart from some weeding around the edges and an annual winter cutting back and removal of deal herbaceous growth.

From 1998, the spread of *Filipendula ulmaria* through self-sowing and vegetative spread has been noted, along with considerable numbers of seedlings of Thalictrum aquilegifolium. Indeed whilst taking the transect, large numbers of seedlings of both of these were found on many areas of bare soil, approaching 100% soil coverage in places.

An overall visual evaluation of this planting is that it is of very high quality, with good diversity and high levels of species complexity, with apparently comparable levels of competition between *Geranium x oxonianum* forms, *Filipendula ulmaria*, *Persicaria bistorta* 'Superbum', all of which are frequently intricately mixed together.

This bed is illustrated in 3. *Illustrations. 3.1*

Thalictrum aquilegifolium/T.polygamum

Appears to produce vast numbers of seedlings, but few of these grow on to become adult plants. The presence of one plant in the middle of and *Iris sibirica* clump (where the latter's ramets have moved away) indicates the plants ruderal potential.

It should be noted that two species of thalictrum were planted here and both are noted as having spread; seedlings could be of either.

Filipendula ulmaria

Has spread considerably through phalanx spread of clumps and through seeding. Although it can form large monocultural blocs, it does not appear to be able to be able to totally out-compete *Iris sibirica*, geraniums spp, aster spp., *Tanacetum vulgare Persicaria bistorta*

See 3 *Illustrations 3.2*

Iris sibirica

is present in steadily expanding clumps. Its foliage is notably higher than competitors.

Tanacetum vulgare

was not part of the original planting mix, but has formed one or two large clumps, which exclude other species, and it also appears to self-sow.

Persicaria bistorta 'Superbum'

has formed extensive clumps, but these do not tend to exclude other species. Foliage is notably lower than competitors.

See 3 *Illustrations 3.3, 3.4*

Geranium x oxonianum and Geranium x oxonianum 'Claridge Druce'

are present in considerable numbers but have not self-sown as much as has sometimes been observed in plantings of this kind. No seedlings were observed taking this transect.

Geranium phaeum

One young plant, clearly self-sown.

Unintentional species:

Chamaenerion angustifolium

is present as isolated specimens, with none of the almost monocultural stands which this species commonly forms.

Galium aparine

is present as seedlings and rather weak young plants.

Wall Bed. T1

Planted in spring of 1996, this border is on reasonably deep soil, slightly calcareous, slightly east facing. Full sun.

During 1996-1998, spring hoeing removed surface weeds. During 1999-2001, this ceased, but during June/July the bed was hand weeded, pulling primarily chamaenerion, urtica, rumex and convolvulus. In 2002 an attempt was made to limit convolvulus by painting with glyphosate and wallpaper paste. Some larger aster clumps were thinned out during winter 2002/3. Since then there has been no maintenance apart from some weeding around the edges and an annual winter cutting back and removal of dead herbaceous growth.

Aster novi-belgii forms or hybrids

forms dense and extensive stands. It does not completely exclude other species however.

Echinops ritro.

has formed a very dense clump, clearly spreading.

Geranium psilostemon.

appears as a large plant.

Helianthus 'Lemon Queen'.

forms a dense clump, having clearly spread considerably.

Lysimachia ciliata 'Fireworks'

behaves as does Aster novae-belgi, fills in gaps between species with more solid clumps.

See 3 *Illustrations 3.5*

Unintentional species:

Aegopodium podagraria.

I present as several dense stands towards the rear of the planting, which is where some was present at the base of a wall when the border was installed. It is not clear if it has displaced other species.

Chamaenerion angustifolium

is present as isolated specimens.

Galium aparine

is present as seedlings and rather weak young plants.

Poacaea (grasses) unidentified

present, growing weakly beneath some of the herbaceous canopy.

Heracleum spondylium

is present as occasional seedlings and adult plants, which are able to penetrate the canopy formed by other species.

Wall Bed T2

Euphorbia palustris.

appears to have the ability to dominate space at the canopy level whilst occupying comparatively little at the basal.

Centaurea cf.phrygia

was found in a clump of *Aster novae-belgi* indicating an ability to self-sow in competitive situations.

Thalictrum aquilegifolium/T.polygamum

was not originally included in this planting, but its presence, assumed to be self-sown from the neighbouring central bed, indicates a ruderal character.

Geranium pratense

was not originally planted here, although several shorter hybrids of it were. Several plants, assumed to be of seedling origin, were found in the transect, with considerable occupancy of the canopy level.

Serratula gmelinii.

appears to be able to create a broad head of foliage above competitors from a limited, but dense basal clump.

Also found as occasional seedlings were geranium sp. possibly *Geranium psilostemon and Echinops ritro*

Unintentional species:

Heracleum spondylium

see Wall T1

Urtica dioica.

is present as isolated plants, including stems inside clumps of As.nb.

Wall Bed, T3

Aster umbellatus

has formed a dense, slowly spreading clump.

Geranium pheaum

is present as large dense clumps with a clear early dominance in height over competitors.

Unintentional species:

Cirsium arvense.

is present as small seedlings/ramets (not sure which). Nearby several taller plants were seen.

Gingko bed, T1

Planted in 1996, with the others in this area, it received the same level of maintenance as them until 2000, when the presence of considerable quantities of *Agropyron repens* and *Calystegia sepia* became a cause for concern. All plants were removed in spring 2000, the area covered in black plastic until winter, when the plastic was removed and the area replanted with propagules from the plants removed, and a thick bark mulch applied.

Soil – same as areas above. Some shading from gingko, but reduced by narrow canopy.

Geranium x oxonianum 'Claridge Druce'.

has covered considerable areas, apparently out-competing *Doronicum pardalianches* which originally occupied much of this area. It forms a dense canopy from relatively little ground coverage.

Geranium pratense

has self-sown.

Phlomis russelliana.

has covered considerable areas of ground with dense basal as well as canopy cover.

Valeriana alliariafolia

has an extensive canopy with little basal coverage. Elsewhere (ie, not in this transect) considerable *Calystegia sepia* ramet penetration of the canopy was noted. Little self-seeding happens beneath this canopy.

Unintentional species:

Chamaenerion angustifolium

is present as larger clumps than in other beds in this area, possibly because of bare patches, or possibly because relatively little of the ground here is taken up with the basal growth of perennials.

Calystegia sepia

is still clearly a problem, with ramets emerging at the top of herbaceous clumps at the time of observation, including the normally weed-suppressing *Phlomis russelliana*.

3.3.1.3 Additional data on plant survival

Whilst a detailed plant population survey of the whole site was not carried out, it was possible to compare the original planting lists with a visual survey of the planted areas at Cowley. The following were noted:

- Virtual disappearance of monarda hybrids, which had thrived and spread in the first three years after planting,
- Failure of several aster taxa to spread much beyond the clump size established in their first three years; none are known to show the spreading ability of A.novi-belgii hybrids; asters have been noted as being vulnerable to slug predation elsewhere (Elmtree Cottage)
- Disappearance of *Macleaya cordata;* despite its reputation for forming vigorous clumps in more conventional border situations
- Major reduction (<75%) in height, spread and leaf size of *Rheum palmatum var. tanguticum;* widespread competition of *Filipendula ulmaria,* geranium spp., thalictrum spp., was noted, with these plants growing right up against rheum crowns.
- *Iris sibirica.* Despite not having growth which does not effectively shade competitors, this iris species has formed extensive clumps at Cowley, with seedlings of neighbouring species establishing in the empty centres of the clumps. Foliage canopy was observed to be above that of competitors until late June.
- Behaviour of *Geranium x oxonianum* group, *Persicaria amplexicaule.* Foliage of ramets of individuals of this species group are able to penetrate or stretch over the canopies of other species, showing a tendency to not only co-exist effectively with other species but also possibly to compete effectively with them.

3.3.2 Hermannshof Transects

Carried out 15.June.2004

Woodland Edge (known as 'Caucasus corner')

Dappled shade from prunus canopy and yew hedge covers the entire area of this border. Bark mulch present. Large areas of bare ground. Laid out at least 15 years ago, According to Schmidt this area has gradually become less diverse over time.

See *3.Illustrations. 3.6*

Aconitum x arendsii

forms large monocultural blocks, through vegetative spread.

Astrantia maxima

appears to be able to survive and regenerate through seeding under *Telekia speciosa* canopy.

Carex pendula

dominates large areas from a relatively small basal coverage, spreading through seeding. In this transect however its coverage is patchy, appearing to be young plants.

Dryopteris felix-mas

dominates large areas from a relatively small basal coverage.

Geranium phaeum

One plant in transect penetrates dense canopy, illustrating a habit seen elsewhere in this and other borders at Hermannshof.

Lamium orvala

forms large monocultural blocks. It is thought to have spread through seeding here. (Schmidt 2004)

Ligularia 'Zepter'

dominates large blocks, not seen in transect, spread vegetatively.

Lysimachia punctata

has gradually spread vegetatively over the years, largely displacing *Senecio tanguticus*. (Schmidt 2004)

Pulmonaria mollis or *Pulmonaria saccharata*

appear to be able to survive under telekia canopy.

Senecio tanguticus

See note above re. *Lysimachia punctata*, this is despite its greater height. Vegetative spread.

Tanacetum macrophyllum

forms large monocultural blocks, vegetative spreading.

Telekia speciosa

Much of area was dominated by Telekia speciosa, which had spread by seed but this died during 2004, possibly adversely affected by heat/drought or perhaps because it is a short-lived species anyway. (Schmidt 2004) Considerable numbers of telekia seedlings are present. The canopy can spread considerably beyond basal coverage.

Valeriana officianalis

Despite erect growth tends to flop.

Delphinium Bed, west side

Some light shading, basically open. Thought to be 12-15 years old.

Alchemilla mollis

is present here as small plants, apparently self-sown

Brunnera macrophylla

does not form monocultural blocks but intermingles with taller, and later developing species.

Geranium 'Johnson's Blue'

dominates large areas from a relatively small basal coverage, largely through falling over of stems.

Lysimachia ciliata

Forms clumps with infiltration of guerrillas into other groups of plants, e.g. of *Tanacetum parthenium*. Schmidt regards it as invasive and hopes to remove it.

Tanacetum parthenium

forms large stands as a result of self-sowing, and dominates through bushy growth habit rather than by basal coverage.

Delphinium Bed, East side

Astrantia maxima

dominates quite large areas from a relatively small basal coverage. Presence of seedlings indicates vigorous self-sowing. Possibly achieves some dominance over shorter species through height.

Hemerocallis cvs.

dominates relatively large areas from a small basal coverage, although *Astrantia maxima* appears to be gaining dominance in clump at right of transect.

Blue cedar bed, north side

Light shade, increasing with time. Thought to be between 10-12 years old.

Alchemilla mollis

forms clumps with tight dense growth.

Chelone obliqua

appears able to dominate very large areas through a mass of basal shoots.

Hosta sieboldiana

dominates large areas from a relatively small basal coverage.

Thalictrum flavum subsp. *glaucum*

is able to penetrate lower vegetation.Tendency for growth to fall over.

Unintentional species

some *Equisetum arvense*

(Old) Prairie Border

Established approximately twenty years, species composition according to Schmidt, has achieved a high level of integration and balance between competing species and those which self-seed (*Silphium perfoliatum* and *Persicaria amplexicaule*) and those which spread vegetatively (*Spartina pectinata* 'Variegata'). This planting is adjacent to a pool but only the extreme western end could be described as appreciably damper than elsewhere in the garden. (Schmidt 2004).

In overall appearance and to some extent in species composition (*Spartina pectinata* 'Variegata', *Coreopsis tripteris*, *Silphium perfoliatum*) Schmidt reports that he says it is very similar to areas of moist prairie he has seen in Minnesota.

North Side

Eupatorium rugosum

is present as seedlings, self-sown from a planting in a neighbouring bed.

Geranium palustre

is present, with several seedlings or plants of self-sown origin.

Iris sibirica

forms clumps of varying sizes.

Leucanthemella serotina

is present as isolated stems and small clumps.

Origanum vulgare

is present as self-sown plants.

Persicaria amplexicaule

is present as small clumps in areas where sp.pe does not predominate, in some cases with a canopy which spreads some distance from the base.In areas dominated by *Spartina pectinata* 'Variegata' there are plants with a few stems which penetrate and appear to be physically supported by the *Spartina pectinata* 'Variegata'. Also many seedlings.

Silphium perfoliatum

occasional seedlings are present as well as full-grown plants.

Spartina pectinata 'Variegata'

forms a dense basal layer and canopy,but which does not appear to exclude other species or prevent their regeneration through seeding.

Symphytum ibericum

dominates under prunus canopy forming monoculture.

Uniola latifolia

shows some sign of self-seeding.

Vemonia crinita

forms large solid clumps which appear to dominate surrounding vegetation.

Veronica longifolia

is present as seedlings, although not a part of original planting scheme.

Veronicastrum virginicum

forms clumps of varying sizes. Some of these may be self-sown, but Schmidt does not think so [CS ibid].

South side

Aster novae-angliae

forms small clumps

Coreopsis tripteris

forms clumps of varying sizes, with seedlings and clear regeneration.

Heliopsis helianthoides

forms clumps of varying sizes

Iris sibirica

dominates the moister area at left, adjacent to pond, closely intermingled with *Spartina pectinata* 'Variegata'.

Persicaria amplexicaule

forms clumps of varying sizes. no seedlings present here.

Polemonium species

is present and apparently is a visually dominant feature earlier in the year. [CS]

Primula vulgaris

is present.

Silphium perfoliatum

forms a strong clump in this transect. According to Schmidt it self-sows.

Spartina pectinata 'Variegata'

forms a clear matrix but not dense, with clear co-existence with other species present.

Thalictrum minus

is present and appears to be self-seeding.

Veronica longifolia

is present, apparently self-sown.

3.4 DISCUSSION

3.4.1 Levels of weed penetration.

Given the concern over weed control in any ornamental planting, the level of weed penetration in these plantings is an issue of major practical interest. Since Hermannshof is very highly maintained, it was not expected that there would be much weed penetration there – and there is not. At Cowley though, with a history of low levels of management, there is an opportunity to gain a more realistic insight.

This is a subjective statement, but the overall impression of the Cowley plantings is that weed levels are very low, compared to what would be expected of a much less dense, conventionally planted area of herbaceous planting which had had similarly low levels of management. This is supported by the relatively low levels of weed found in the transects. Weed seedlings (chiefly *Galium aparine* and various grasses) were limited in number, extent and seriously limited in vigour. It is suggested that this is related to the dense foliage canopy achieved by May and maintained until November. It is also suggested that a high level of species integration is achieved, with physical space having higher multiple species occupancy than is conventional in herbaceous plantings. This effectively means that a variety of niches (as defined by physical volume) are being occupied; it might be expected that such multiple occupancy would minimise opportunities for weed infiltration.

Weeds which grow from ramets are more noticeable. *Chamaenerion angustifolium*, which is normally notorious for forming monocultural stands, is certainly present, but only as interconnected individuals emerging occasionally from the canopy of the planted perennials. *Calystegia sepia* was the known to be the most widespread at Cowley, although few examples showed up in these transects. Interestingly the transects show the strongest concentration amongst *Valeriana alliarifolia*, which has a wide leaf canopy but little ramet spread, and leaves relatively large areas of bare soil beneath it. This species was the only perennial at Cowley which did not participate in the production of a dense intermingled 'sward', instead forming a light-excluding canopy which appeared to inhibit the growth of anything (other than *calystegia* beneath it. However in some areas (not mapped) adventitious shoots of pasture grasses were seen making inroads into the areas covered by the valeriana's foliage.

3.4.2 Self-sowing of perennial species

It is clear that several species planted at both locations have been able to reproduce themselves through seeding:

Cowley:
Filipendula ulmaria
Geranium phaeum

Geranium pratense
Thalictrum aquilegifolium/T.polygamum

Hermannshof:

Astrantia maxima
Coreopsis tripteris
Eupatorium rugosum
Geranium palustre
Lamium orvala
Origanum vulgare
Persicaria amplexicaule
Silphium perfoliatum
Telekia speciosa
Thalictrum minus
Uniola latifolia
Veronica longifolia

The following observations were made:

I) Given that many cultivated species are derived from very limited genepools, it might be expected that the ability of out-breeding species to reproduce by seed would be low. In the case of Cowley, for example, all asters taxa were grown from vegetative material, which may account for a lack of seedlings, yet thalictrum species (unclear which) were present as large numbers of seedlings – this being a genus which does not have a reputation for self-seeding in gardens; one of the thalictrums present (*T.aquilegifolium*) was grown from seed and planted originally in large numbers which is different to the isolated specimens usually encountered in horticultural situations. It might be expected that self-seeding will be greater in EBPS where taxa are grown from seed, which may be a factor in a greater ability of these planting schemes to regenerate and develop a self-sustaining dynamic.

ii) However it is interesting to note that the *Geranium endressii/G.versicolor/G. x oxonianum* complex has not produced many seedlings, in contrast to other situations observed (e.g. Elmtree Cottage). Self-sowing of ornamental herbaceous species is noted as being very unpredictable; this is clearly an area where further research would be valuable.

iii) At Cowley, large numbers of *Thalictrum* (unclear which species) and *Filipendula* were noted, yet few plants of a size intermediate between them and mature plants. This could be an example of a seedling bank (Grime 2001) where large number of seedlings can exist for many years, not growing any larger until conditions are right. The presence of the filipendula as a seedling bank may indicate that this species could in future come to completely dominate this planting (see below).

iv) It is possible that some species, particularly those with a ruderal strategy, establish themselves, dominate a site or community, die out at the end of their lifespan, and then (only possibly) regenerate. Such a possibility is indicated by the behaviour of *Telekia speciosa* at Hermannshof. There is very little in the literature of either plant ecology or horticulture on the lifespan of short-lived (as opposed to biennial or monocarpic) perennials, although Hansen and Stahl have made long-term studies of some, generally long-lived, perennials (Hansen and Stahl 1993); this is clearly an area for further research.

3.4.3 Intermingling of species as opposed to development of monocultures

What is distinctive about the Cowley planting is the level of intermingling of species; in this respect this is an illustration of what appears to be a very successful example of EBPS. The planting is much closer to a non-cultivated plant community in its degree of interpenetration of species than a conventional herbaceous border. It is debatable however how long term this will be; there are indications: seeding of filipendula discussed above and a brief visual observation made in summer of 2005, that point to a possible future domination by *Filipendula ulmaria*.

A similar level of interpenetration is noted in *some* of the Hermannshof plantings, in particular the old prairie bed, which it is also worth noting where the largest amount of self-sowing seems to be happening. Despite the reputation of *Spartina pectinata* 'Variegata' as being a strongly spreading species (Grounds 1989, Greenlee 1992), it has not led to a situation of competitive exclusion in this border.

The opposite situation is that of species which develop almost monocultural stands. This is comparatively infrequent in non-cultivated temperate zone plant communities, and is most likely to be observed in undisturbed highly productive habitats (Grime 2001), e.g. tall-herb communities (Ellenberg 1988). Of these two locations, only Hermannshof is arguably long established enough to offer a long enough period of lack of disturbance to see a dominance effect, although it is noted that *Valeriana alliariafolia* at Cowley was possibly showing this effect. At Hermannshof, this monocultural effect has been observed primarily in the woodland edge area.

See *3.Illustrations. 3.8*

3.4.3.1 Species forming large monocultural stands at Hermannshof.

The region of origin, native habitat and means and extent of vegetative spread is noted – for referenes see Appendix 1, Region and Habitat of Origin.

A..... through vegetative, i.e. clonal spread:

Chelone obliqua	E N. America	swamps	extensive runner production
Hosta sieboldiana	Japan	?****	densely clumped ramets
Lamium orvala	N.Balkans	woodland	densely clumped ramets
Ligularia 'Zepter'	China	wet places, (original species)	loosely clumped ramets
Lysimachia punctata	C & SE Europe	tall herb flora, damp places	very long and extensive runner production
Senecio tanguticus	China	moist meadows	extensive runner production
Tanacetum macrophyllum	Balkans	moist woods	extensive short runner production

B.....through extensive spread of foliage low enough to create dense ground-level shading, plants may or may not have self-seeded extensively.

Astrantia maxima (self-seeded)	Europe	moist, fertile woodland, tall-herb	tight clumps, slow rate ramet production
Carex pendula (self-seeded)	Europe	moist woods	extensive clumps tightly packed ramets
Dryopteris felix-mas	Europe	woodland, including dry	doubtfully clonal
Geranium 'Johnson's Blue'	Eurasia/Himalaya	scrub and open country (parents)	extensive clumps of ramets, high rate ramet production

Of the species dominating shaded or partially shaded areas at Hermannshof, a distinction can be made between those which do this through underground ramet growth (A above) and those which have less extensively spreading clumps but extensive foliage canopy (B above). The geranium is best described as occupying an intermediate category, as it does form large clumps with extensive ramet formation. Amongst the species forming monocultural blocks, there are a variety of strategies of spread; widely spreading ramets are not, it would appear, necessary for the formation of monocultural blocks.

As can be seen from the table, these species are all from productive habitats, and/or high rainfall regions.

The distinction between areas of intermingling and monoculture is possibly due to the difference in species spread through seeding and vegetative spread. Areas at Cowley and Hermannshof where there appears to be considerable intermingling are where there is a distinct level of self-seeding; species which might possibly form monocultural stands through vegetative growth alone (and in many gardens are often observed to form extensive clumps) such as *Persicaria bistorta* or *Geranium x oxonianum* group, grow in company with seedlings of many of the species represented in the planting. The woodland edge and other areas at Hermannshof that have both areas with self-seeding and areas of monocultural stands; it appears as if some of the species forming these stands are more effective at excluding competition – there is no shortage of species in the vicinity which are effective at spreading through seeding. The spread of *Aconitum carmichaelii, Ligularia* 'Zepter, '*Lysimachia punctata, Senecio tanguticus, Tanacetum macrophyllum* must be assumed to be because they are very effective at establishing dominance. From a superficial examination, confirmed by Schmidt 2004 it appears as if not all these species do form stable, long-lived, blocks, but that there are 'winners and losers', with the lysimachia and tanacetum appearing to overwhelm others. It is noted that all are species of tall-herb or other very productive habitats.

It is suggested that there is a gradient between species which have traits which, in some circumstances, are highly effective at creating monocultural blocks, and those which are never able to do so. Whether they are able to do so, is dependent not only on abiotic conditions at the site, but also the presence of competitors in the broad sense. These competitors may be species which spread vegetatively or by seed. It is possible that the presence of competitors with a high rate of recruitment through seed is more likely to result in a diverse vegetation, with seedlings establishing themselves at the edges of clumps of vegetatively-spreading species able to reduce the rate at which the latter spread.

3.4.4 Disappearance of *Macleaya cordata* and *Rheum palmatum*

Finally, it needs to be noted that two species which intuition suggests might be very competitive either disappeared at Cowley (the *macleaya*), or became very much smaller with competition (the *rheum*).

The large foliage and apparent vigour of both these species, and the extensive ramets of the *macleaya,* do not appear to guarantee long-term survival. It is noted in *Investigating the growth of ornamental herbaceous perennials in grass swards*, that both of these two species were not able to compete effectively with meadow management grass.

The following factors may account for this:

A tendency for young foliage to be severely damaged by light frosts, unlike virtually all other plants in this study.

They are ineffective belowground competitors.

3.5 CONCLUSIONS

This survey has shown that transects have the potential to be a useful tool for exploring a number of issues concerning long-term performance of perennials in borders. In particular the following points can be made regarding the performance of the species in the border studied.

- The formation of a vegetation which is able to minimise weed infiltration is enhanced by the presence of species with dense foliage from early in the growing season.
- It is possible that the presence of a canopy of foliage composed of species with a multiplicity of species with a high level of spatial integration reduces weed establishment through inhibition of seedling establishment and restriction of their vegetative spread.
- Alternatively, some species appear to be able to dominate space, and restrict weed infiltration through forming monocultural stands.
- There appears to be a gradient between species which are able to form monocultural stands and those which are more likely to develop integrated and species diverse communities. This has major implications for both the practical and aesthetic aspects of planting design.
- Species which form monocultural blocks may do so through a variety of patterns of vegetative spread and/or through the production of extensive ground-shading foliage.
- Recruitment through seeding of ornamental perennials is very variable; some appear to be potentially capable of very effective recruitment.
- Species which seed extensively rather than spread vegetatively may be more likely to form integrated communities.
- Species which form monocultural blocks may do so through a variety of patterns of vegetative spread and/or through the production of extensive ground-shading foliage.

3.5.1 Transects as a methodology to study ornamental plant performance

Transects do appear to give a very informative 'snapshot in time' overview of plant growth in a border, particularly with regard to plant spread, relationship of foliage spread and location of basal growth, location and spread of self-sown seedlings and weeds, and degrees of interpenetration of species vis a vis monoculture.

Their use as a tool is severely limited by the fact that only rarely is there information about original planting schemes, and almost never any systematic record of work, such as replanting done since installation

3.6 APPENDIX – TRANSECT DIAGRAMS

Contents:

1. Explanation of symbols

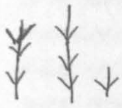
2. Abbreviations used in transect diagrams

3. Transect Diagrams:

3.6.1. Explanation of symbols

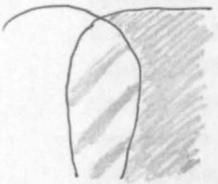
TRANSECT LEGEND

indicates presence of foliage in transect, contact with base off line of transect



individual young plants or seedlings

sparse foliage present in transect



indicates intermingling of foliage of two species

indicates growth hanging over line of transect, i.e. connection to base off transect

3.6.2. Abbreviations used in transect diagrams

sdlgs.	seedlings
Ac.ar.	Aconitum x arendsii
Ac.br.	Achnatherum brachytricha
Ae.po.	Aegopodium podagaria
Al.mo.	Alchemilla mollis
Aq.	Aquilegia sp. Probably A.vulgaris
Ar.la.	Artemesia lactiflora
Ar.di.	Aruncus dioicus
As.	Aster sp.poss.novi-belgii x laevis
As.na	Aster novae-angliae
As.nb.	Aster novi-belgii form,
As.pu.	Aster puniceus
As.um.	Aster umbellatus
As.ma.	Astrantia major
As.sp	Aster sp.
Bo.as	Boltonia asteroides
Br.ma	Brunneral macrophylla
Ca.	Camassia sp.
Ca.pe	Carex pendula
Ca.se	Calystegia sepium
Ce.ph.	Centaurea cf.phrygia
Ch.an.	Chamaenerion angustifolium
Ch.ob.	Chelone obliqua
Ci.ar.	Cirsium arvense
Co.tr.	Coreopsis tripteris
Do.pa.	Doronicum pardalianches
Dr.fm.	Dryopteris felix-mas
Ec.ri.	Echinops ritro
Eq.ar.	Equisetum arvense
Eu.du.	Euphorbia dulcis ex. 'Chameleon'
Eu.pa.	Euphorbia palustris
Eu.ru.	Eupatorium rugosum
Fi.ul.	Filipendula ulmaria
Ga.ap.	Galium aparine
Ge.pa	Geranium palustre
Ge.CD	Geranium x oxonianum 'Claridge Druce' + seedlings
Ge.JB	Geranium 'Johnson's Blue'
Ge.ox	Geranium x oxonianum group
Ge,ph.	Geranium phaeum
Ge.ph.dk	Geranium phaeum 'Dark Form'
Ge.pr.	Geranium pratense or hybrids

Ge.ps.	Geranium psilostemon
Ge.sy.	Geranium sylvaticum
Ge.ve.	Geranium versicolor
He.cv./He.var	Hemerocallis cvs.
He.LQ	Helianthus 'Lemon Queen'
He.he	Heliopsis helianthoides
He.sp.	Heracleum sphondylium
Ho.si.	Hosta sieboldiana
Ir.si.	Iris sibirica
La.or.	Lamium orvala
Le.se	Leucanthemella serotina
Li.Ze.	Ligularia 'Zepter'
Ly.ci.	Lysimachia ciliata
Ly.ci.F	Lysimachia ciliata 'Firecracker'
Ly.pu.	Lysimachia punctata
Ly.sa.	Lythrum salicaria
Me.ca.	Meconopsis cambrica
Mi.si	Miscanthus sinensis cv.
Na.	Narcissus cvs.
Or.vu	Origanum vulgare
Pe.am	Persicaria amplexicaule
Pe.bi.	Persicaria bistorta 'Superba' + seedlings
Ph.ru.	Phlomis russelliana
Po.sp	Polemonium species
Po.mu.	Polygonatum multiflorum (or P. hybridum)
Pr.vu.	Primula vulgaris
Pu.mo.	Pulmonaria mollis
Pu.sa.	Pulmonaria saccharata
Sa.ob.	Sanguisorba obtusa
Se.gm	Serratula gmelinii
Se.ta.	Senecio tanguticus
Si.pe	Silphium perfoliatum
Sp.pe.	Spartina pectinata 'Variegata'
Sy.ib.	Symphytum ibericum
Ta.ma.	Tanacetum macrophyllum
Ta.pa.	Tanacetum parthenium
Ta.vu.	Tanacetum vulgare
Te.gr.	Tellima grandiflora
Te.sp.	Telekia speciosa
Th.	Thalictrum sp. seedlings
Th.aq.	Thalictrum aquilegifolium
Th.fl.gl	Thalictrum flavum glaucum
Th.mi	Thalictrum minus
Tr.	Tradescantia cv.
Un.la	Uniola latifolia
Ur.di	Urtica diocia
Va.al.	Valeriana alliarifolia

Va.of.	Valeriana officianalis
Ve.cr.	Vernonia crinita
Ve.lo	Veronica longifolia
Ve.vi	Veronicastrum virginicum
Vi.sp.	Viola sp.

3.6.3 Transect diagrams

Central Bed, T1

Wall Bed. T1 Wall Bed T2

Wall Bed, T3

Gingko bed, T1

Delphinium Bed, west side

Delphinium Bed, East side

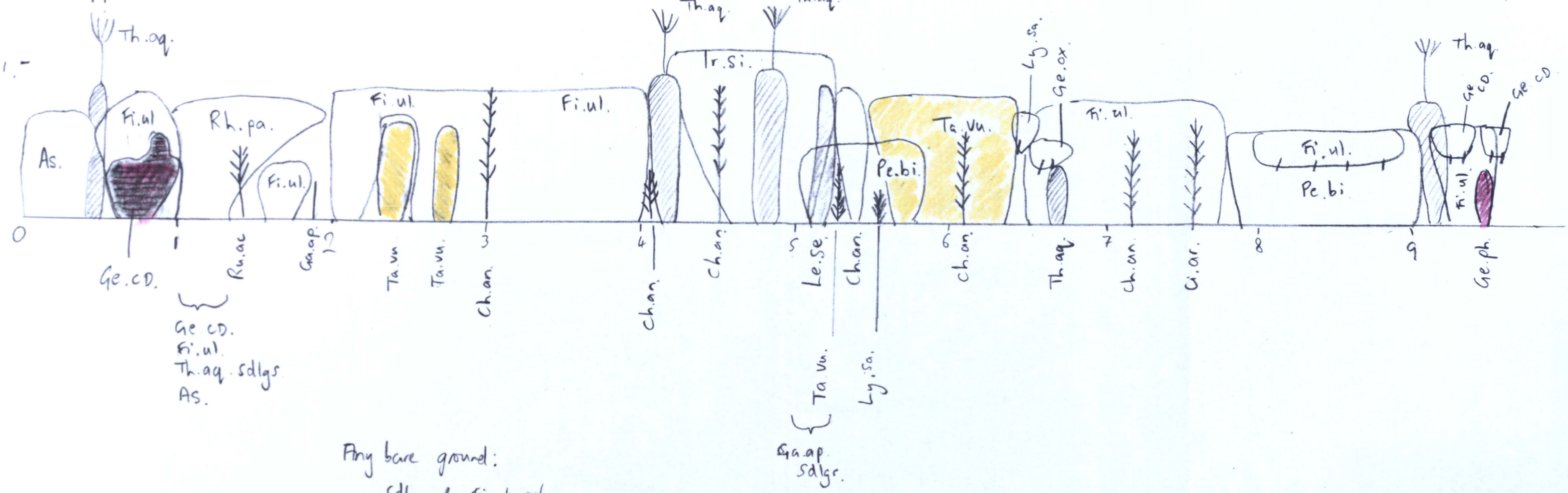
Blue cedar bed, north side

(Old) Prairie Border

North Side

South side

Cowley Manor,
Central Bed
T1

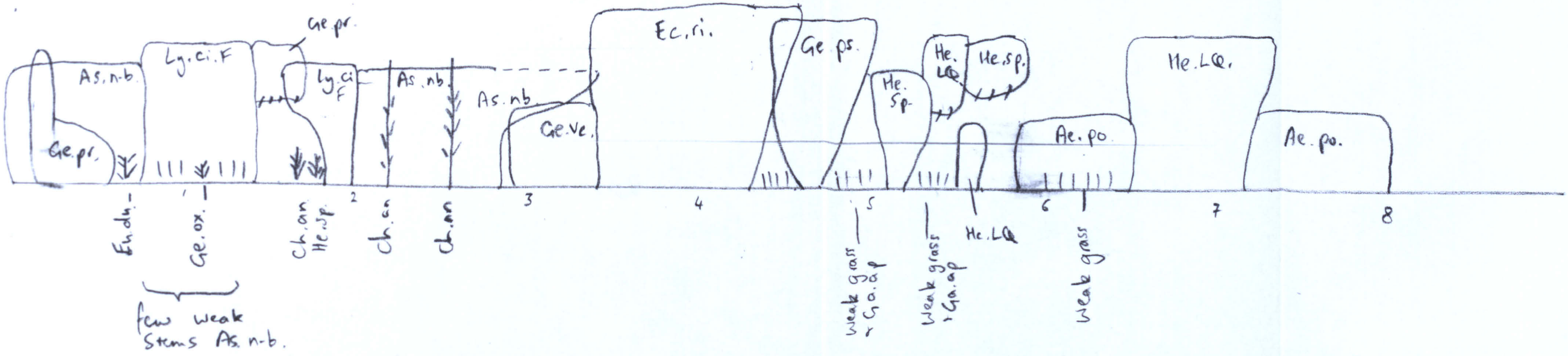


Any bare ground:
sdlgs. of Fi.ul., Th.aq.

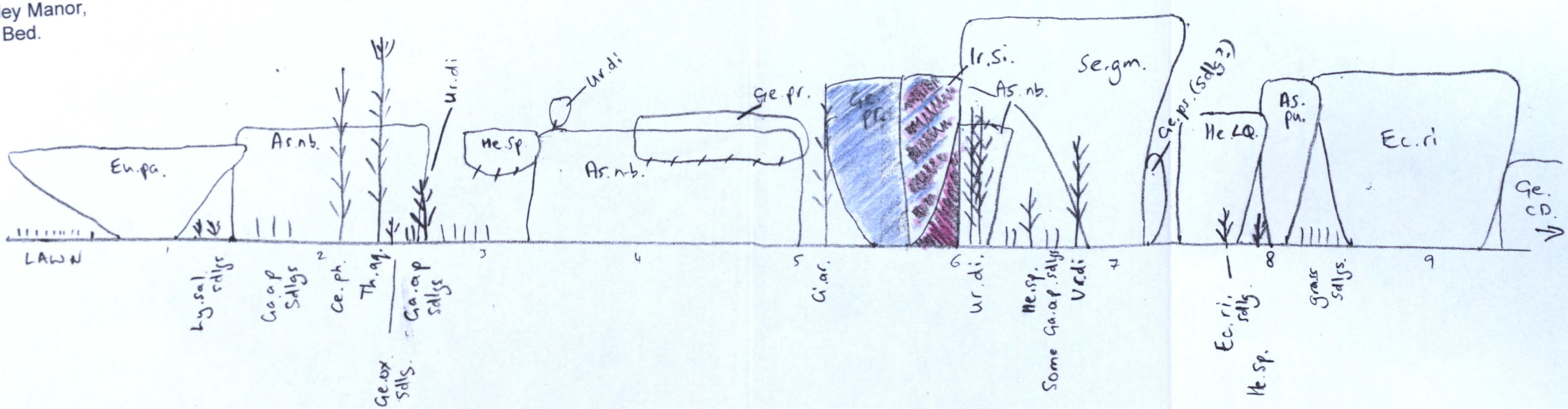
Cowley Manor
West Lawn. Central Bed
Transect 1. 1. June 2004

Wall bed 1. 1. June 04

Cowley Manor,
Wall Bed.
T1



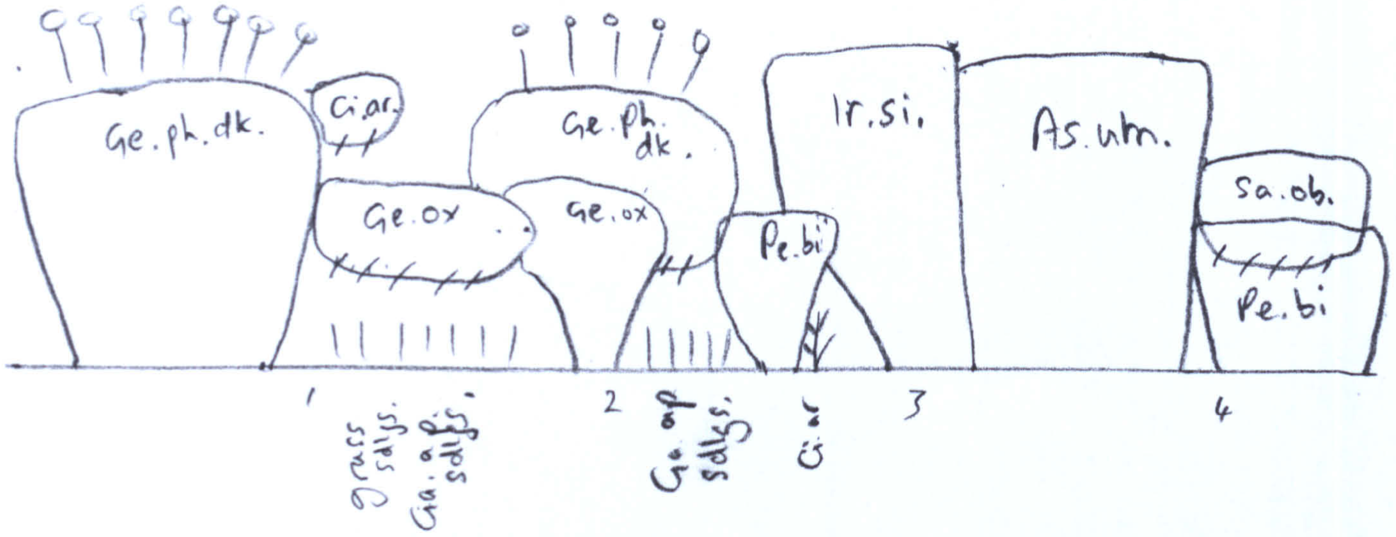
Cowley Manor,
Wall Bed.
T2



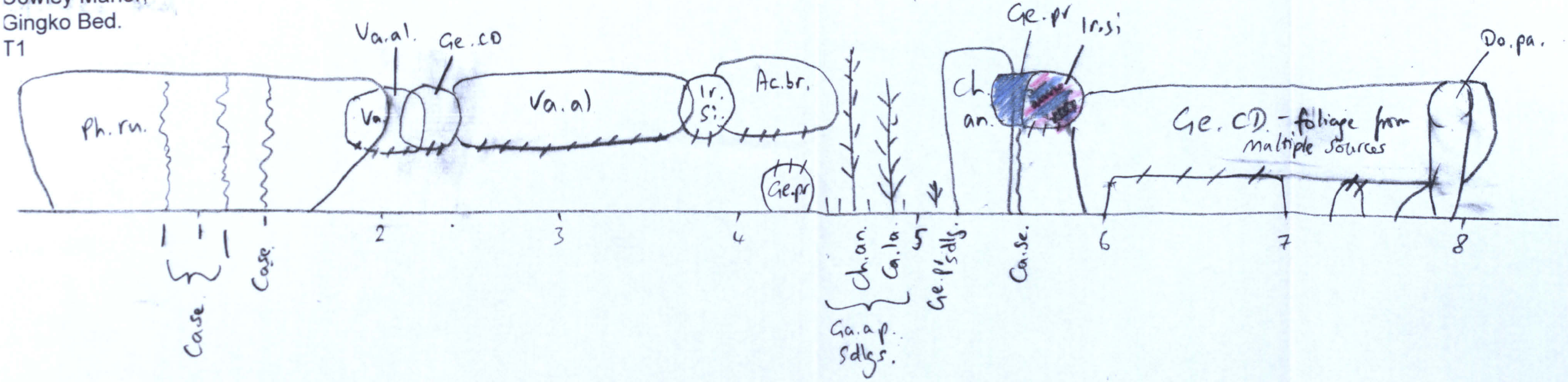
Cowley Manor,
Wall Bed.
T3

Bed 3.

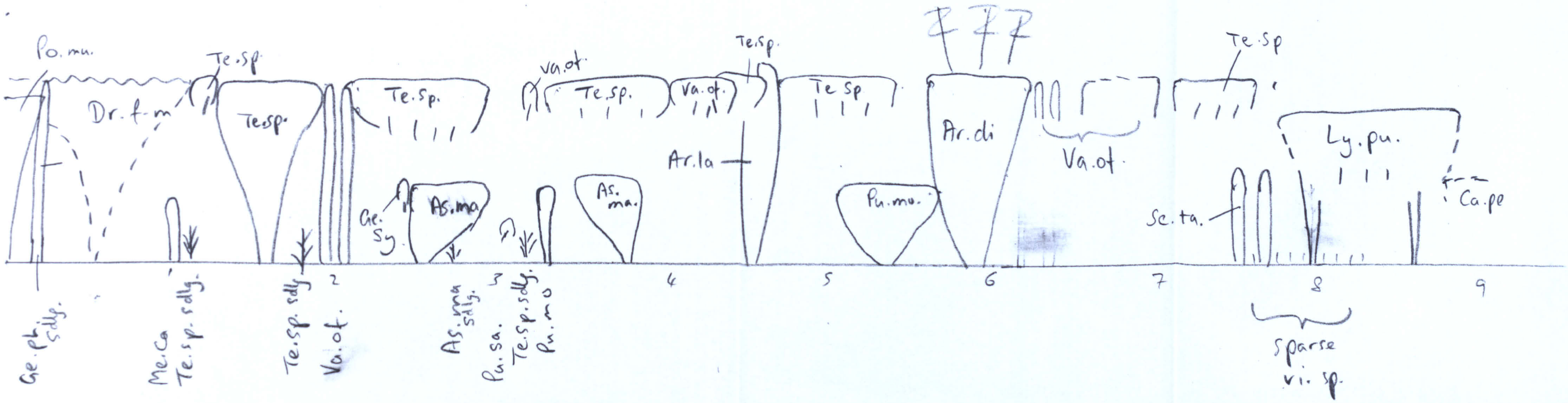
1. June. 04

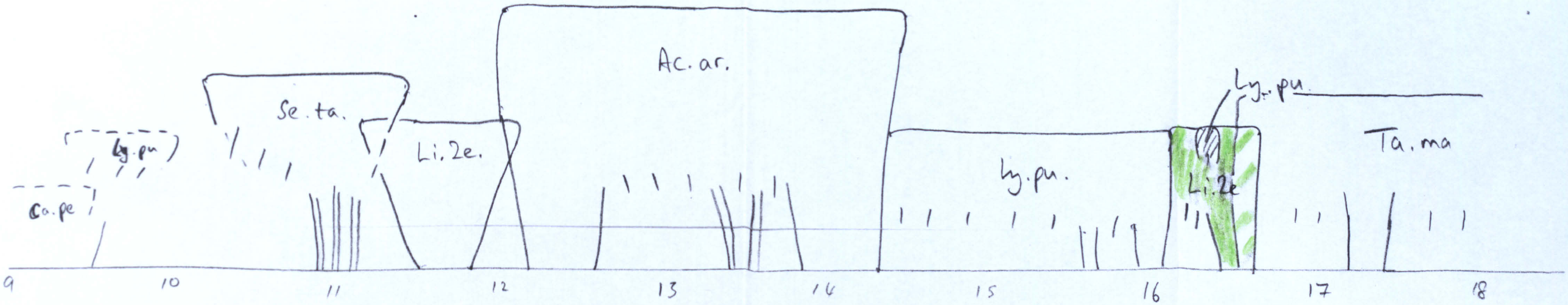


Cowley Manor,
Gingko Bed.
T1

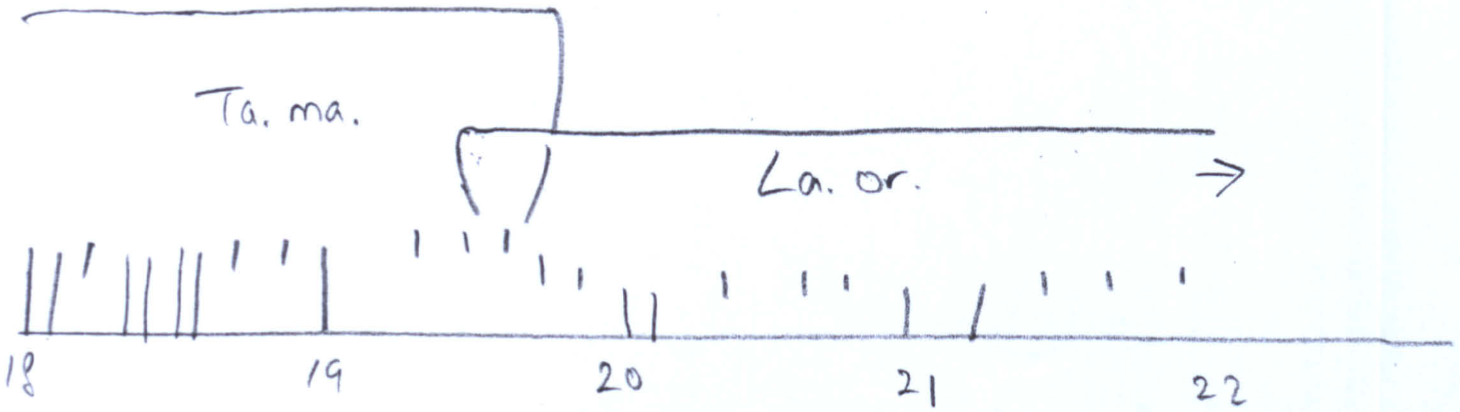


Hermannshof
Woodland Edge

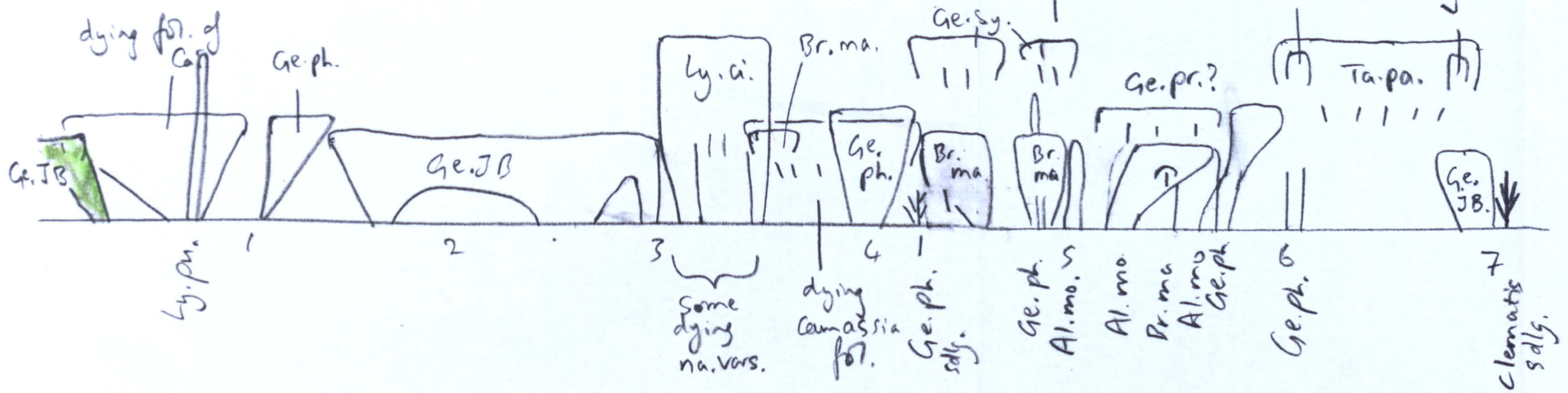




Hermannshof Woodland edge. Cont.

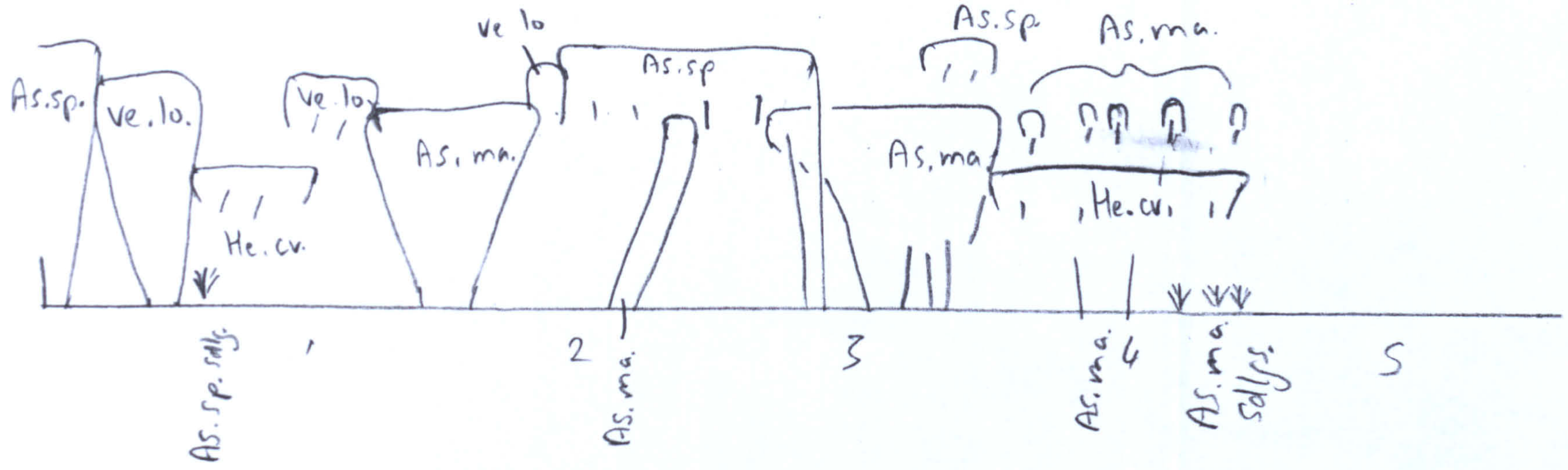


Hermannshof
Delphinium Bed, West side



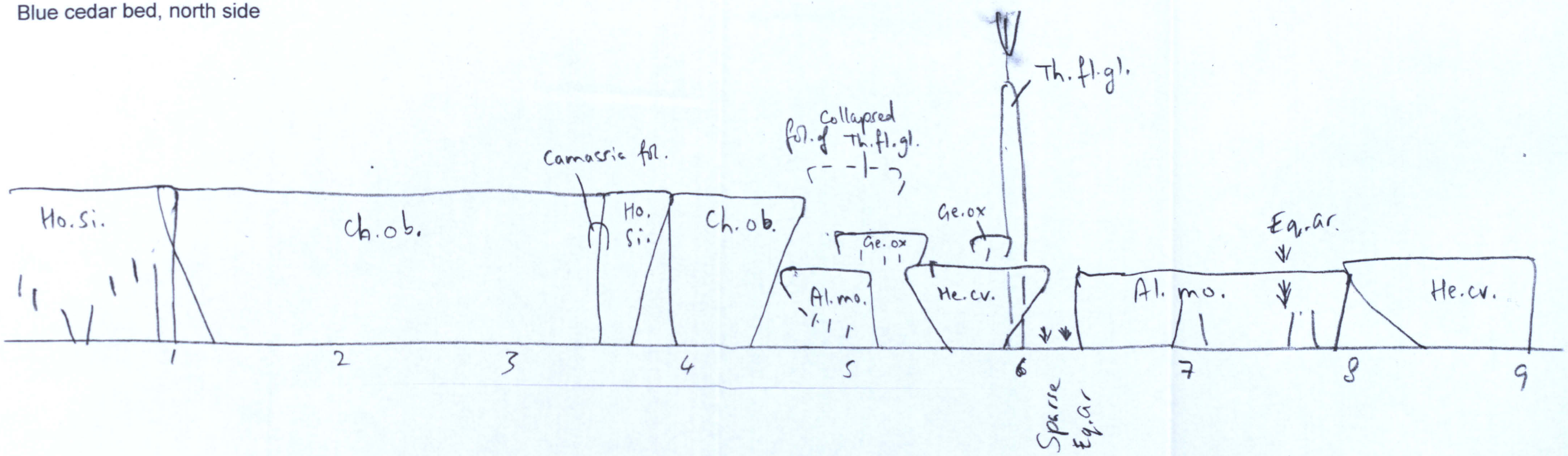
Hermannshof
Delphinium Bed, East side

d. East end.



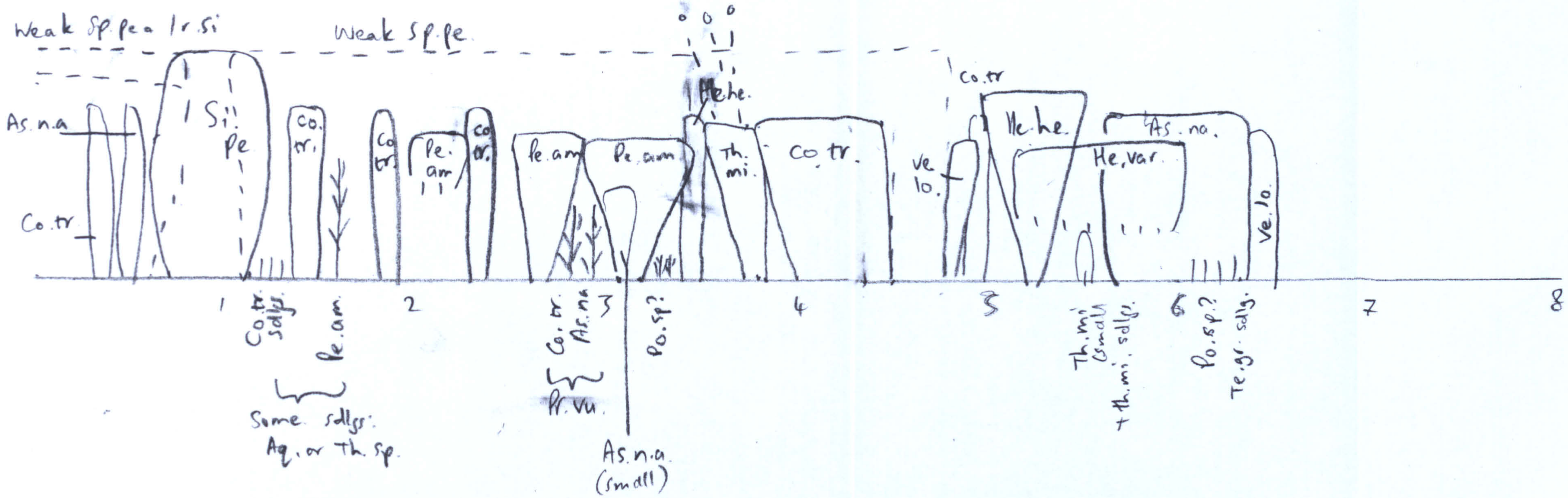
Hermannshof
Blue cedar bed, north side

d.



Hermannshof
(Old) Prairie Border
South Side

border. S. side transect 0.4-0.6 m from path.

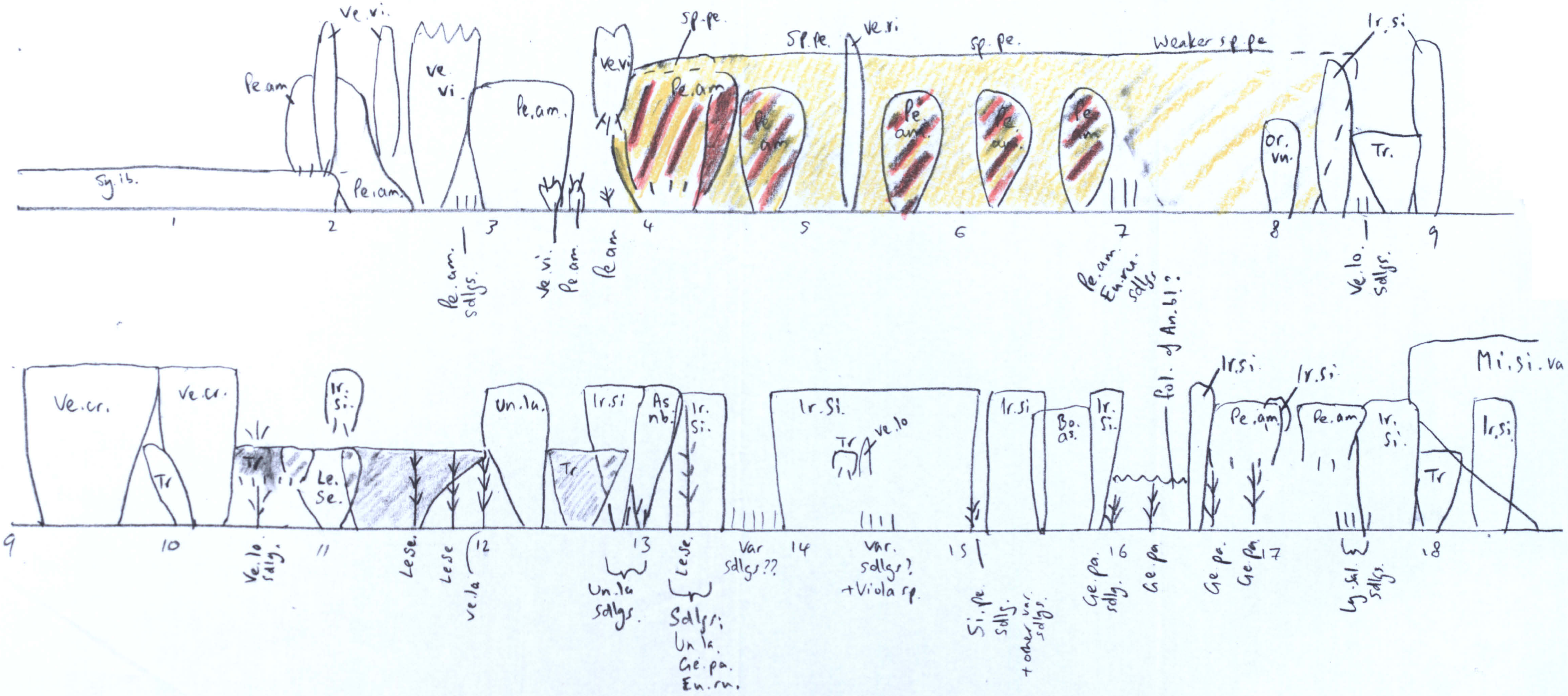


Hermannshof
(Old) Prairie Border
North Side

order N. side. transect 0.4-0.7m from path.

← edge of prunus canopy — — — →

Ir.Si. is var 'Caesar's Brother'



3.1.

Cowley Manor, West Lawn. Central Bed.

An example of an 'open border' style planting of forbs with no grass. June 2003

3.2.

***Geranium x oxonianum* group with *Filipendula ulmaria*.**

April 2004. Cowley.

3.3

***Geranium x oxonianum* group with *Persicaria bistorta* 'Superbum' at Cowley Manor.** Note clump interpenetration. Feathery foliage is *Aconitum napellus*.April 2004. Cowley.

3.4

Iris sibirica co-existing with *Persicaria bistorta* 'Superbum'.April 2004. Cowley

3.5

***Geranium* taxa, various. with *Lysimachia ciliata* 'Firecracker'.** The lysimachia guerilla strategy allows for penetration of spaces between geranium clumps, which are classic vanguard spreaders.
April 2004. Cowley

3.6.
Hermannshof, (old) prairie border
Species visible include *Spartina pectinata* 'Variegata', *Coreopsis tripteris*, *Aster novae-angliae*, and *Silphium perfoliatum.* June 2004.

3.7.

Hermannshof, Woodland Edge. *Telekia speciosa, Carex pendula, Dryopteris felix-mas, Valeriana officinalis.* June 2004.

3.8.

Hermannshof, Woodland edge, species forming monocultural blocks.
Aconitum x arendsii (rear), *Tanacetum macrophyllum* (right, front), *Lysimachia punctata.* June 2004.

4

INVESTIGATING THE GROWTH OF ORNAMENTAL HERBACEOUS PERENNIALS IN GRASS SWARDS.

INVESTIGATING THE GROWTH OF ORNAMENTAL HERBACEOUS PERENNIALS IN GRASS SWARDS.

4.1 INTRODUCTION

Despite the suggestion that non-native forbs be naturalised in grass sward as an ornamental features by Robinson, relatively few examples are seen (Robinson 1870). Examples of forb species used in ornamental horticulture naturalised in grass-dominated environments are also rare, and very few species have become established; solidago taxa (primarily derived from *S.canadensis*) and *Aster novae-angliae* are notable examples, but these are have spread little beyond their original points of naturalisation and appear commonly only on sloping or disturbed ground, generally in urban areas. The comparative rarity of naturalised forbs suggests that British grass sward is simply too competitive a habitat for successful naturalisation – the corollary would be that it is difficult to establish ornamental forbs into grass. This is supported by Goldberg and Fleetwood (1987) who state that the dominance of grasses across many temperate (and indeed other climate) zones suggests that they are highly effective competitors; this is based on competition trials which suggesting that the competitive effect of grasses can be much greater than that of forbs.

Examples of naturalised perennials have been surveyed by Hitchmough and Woudstra (1999); trials have been undertaken by Hitchmough (2000). European and Asian species dominate the list. Hitchmough suggests that a scandent habit, as found in the geraniums, was one of the features, which enhanced survival, along with tall leafy canopies or above average shade tolerance. Hitchmough trials (2007) indicate that a grass sward is a hostile one for many non-native forbs, with decrease in end of season dry weight for many of the species trialled or even total disappearance by the end of the second or third year.

It is interesting to note that one species notable for widely-spreading ramets, and which is observed to have naturalised in peri-urban locations is not mentioned in Hitchmough and Woudstra's 1999 survey - *Lysimachia punctata* and *Thermopsis montana*, with very long-ranging ramets has also been noted as spreading into grasses (personal observation – Somerset 2003). Ornamental forbs with such strongly spreading ramets are however rare.

A number of small-scale informal qualitative trials were carried out, before the current research was initiated. Assessments of plant growth were qualitative and evaluative.

4.1.1 Aims

- To use evidence gathered on the performance of a selection of herbaceous grown in a grass sward to indicate possible factors which accounts for species survival or disappearance.

4.2 METHODOLOGY

4.2.1 Cowley Manor – 1996-2004.

An informal trial was carried out by planting upwards of 6 individual plants (at 9cm pot size, or divisions suitable for planting into 9cm pots) in spring 1996 of 23 ornamental herbaceous perennials. Circles of turf some 400mm diameter were cut out and removed, with test plants planted in the centre of the resulting bare soil. The grass was a lawn, known to have been established some 100 years previously, with a varied grass flora, including vigorous species such as *Holcus lanatus* and *Arrhenatherium elatium*. Soil was a reasonable depth over oolitic limestone; summer drought was only occasionally severe enough to brown grass). The aspect was open and east facing.

Following the planting, the management of the lawn was reduced to two annual cuts, one in autumn and one in winter. It can thus be described as 'meadow management'.

All species trialled were also present in several border plantings nearby, with very similar soil type, and managed without any grass matrix. These acted as controls.

4.2.2 Elmtree Cottage – 1997-2003

In spring of 1997, 6 individuals of four taxa of ornamental grasses were grown in rough grass on a steeply sloping east-facing open site, on a deep and fertile sandy clay loam. Summer drought sufficient to brown grass was unknown during the period of the trial; moisture levels could be high enough during winter to cause pooling in the ground immediately at the bottom of the slope. Grass, both matrix and ornamental test subjects, were cut once a year – in February.

All three taxa were also growing in the garden without a grass matrix.

4.3 RESULTS

See 4. Appendix, which illustrates the results, based on a visual assessment of plant status made in early autumn. Individuals of subject plants grown in nearby borders without grass competition and relatively low competition of surrounding plants acted as a control – they all flourished, and formed clumps consistent with what would be regarded as average growth in horticultural conditions.

The following was noted.

- Of the upright-growing North American species, only two survived and continued to expand (the *Helianthus* and the *Rudbeckia* studied), the *Aster species* did well initially but then disappeared – possibly due to slug predation in a wet spring (2001).
- Of the species which survived: two were North American (the helianthus and a rudbeckia), one Asian, of uncertain natural habitat (*Inula* cf.*racemosa*), the remainder European, of meadow or other open habitats.
- Three species, which are observed to grow very large in border situations: *Cephalaria gigantea, Macleaya cordata* and *Rheum palmatum*, had very poor survival rates and were dramatically reduced in size, both height and leaf size. *Persicaria amplexicaule* is also noted as a vigorous border plant but performed poorly.

4.4 DISCUSSION

Survivors:

- Tended to be early emergers, showing strong new growth during March, if not earlier; helianthus, rudbeckia and inula emerged later; aster species, were until their sudden disappearance, are also noted as early emergers.
- Survivors tended to have large basal (or apparently basal) leaves, which shade out an area of grass around them; of those which do not, one (*Rudbeckia* 'Juligold') has wide-spreading leaves on emergence, but which only effectively shade the ground for less than a month. The performance of this species, which in terms of ability to project shade over the ground surface, as measured by the Ground Coverage +Shading Effectiveness (GC+SE) measurement (see 7. *An analysis of plant traits and characteristics*) scored the lowest of all the taxa studied, is remarkable – suggesting that highly effective root competition is its main means of competing with grasses.
- *Euphorbia cyparissias*, a survivor, is of markedly different appearance to the others, with narrow, almost linear foliage, and a strong tendency to extensive guerrilla ramet formation; it is known as a common element in meadows on limestone in central Europe.

It is noted that in rough grass, its pattern of ramet distribution is far sparser than in the conventional border, i.e. it is spatially integrated with the grass,

- *Iris sibirica*, also a survivor, is of markedly different appearance, with almost vertical linear foliage. Hitchmough 2007 has it increasing in his trial.
- Of the grass species which survived and expanded, both were tillering, with clear production of new growth before April at the latest.

Of the species which did not survive (apart from aster):

- Three are noted for their apparent vigour as border plants: *Macleaya cordata, , Rheum palmatum Persicaria amplexicaulis* – they also have large outwardly-pointing leaves; intuitively one might have expected them to survive
- Hemerocallis taxa are known to have successfully naturalised in Germany in several locations (Simon 1994),
- One to be a moderately vigorously-spreading plant in border situations (*Rudbeckia fulgida*),
- The knautia is a native of dry meadow habitats in the Balkans; it grew well during the first two summers, 1997,1998, (notably dry), poorly later.
- The *Eupatorium maculatum*, which makes very vigorous upwards growth in border situations, does not form strongly spreading clumps, and emerges late (May).
- Of the grasses which did not survive, both formed caespitose clumps, and began to make growth only in April.

Vigour in conventional border situations is clearly not necessarily a guide to good performance in grass, indeed neither is ability to spread, as indicated by the case of *Macleaya cordata*, which is renowned as spreading strongly through underground ramets. Height, generally regarded as of major importance in competition (Grime 2001), does not in itself guarantee effective competition

The disappearance of the aster species, after initial good establishment and increase, suggests that mollusc predation may be a major factor. Hitchmough (2000) suggests that the unpalatability of geranium foliage may be a major factor in the survival of species of this genus .

Eurasian species of meadow and other open habitats strongly dominate the list of survivors; they have presumably co-evolved with turf-forming grasses – some are indeed known to be closely associated with them throughout much of their range (*Cirsium canum* Adler 1994), *Geranium phaeum* (Ellenberg 1988), G.psilostemon (Gough 2005) (also noted as increasing in a grass sward by Hitchmough 2007), *Echinops ritro, Euphorbia cyparissias, Iris sibirica, Symphytum asperrimum* (Ellenberg 1988). North American species would have co-evolved with clump-forming grasses. Habitat information in any detail is lacking for *Cephalaria gigantea, Persicaria amplexicaulis, Macleaya cordata* and *Rheum palmatum*. It should be pointed out that the young growth of the latter two species is frequently damaged by frost, which would put them at a considerable competitive disadvantage.

4.5 CONCLUSIONS

The fact that survival of Eurasian meadow-habitat species appears to be higher in a grass sward is consistent with the survey of naturalised perennials in Britain carried out by Hitchmough and Woudstra (1999), and a trial run by Hitchmough (2000), in which only *Geranium x magnificum, G. x oxonianum, Iris sibirica* and *Lychnis chalcedonica* increased in size over time . Other work by Hitchmough indicates biomass, as a combination of height and extensive side branches, as in *Aruncus dioicus* and *Euphorbia palustris*

It is suggested that the key factors in survival are early emergence and/or the presence of a widely spreading leaf canopy on the lower part of the stem; both of these factors would enable forbs to shade out grass competition from around their base early in the growing season. Widely running ramets may in some cases also help in naturalisation. Vigour as a border plant is no reliable guide to performance in a grass sward, and neither is height. Caespitose grasses would appear to be disadvantaged in a matrix of tillering grasses.

There is also some indication that resistance to mollusc predation is an important factor. There is a strong indication that future work with plants in grass should concentrate on plants known to grow in Eurasian meadow habitats.

The results of these trials points strongly towards the further investigation of the following factors:

- Effective basal cover, combined strongly with:
- Early emergence
- At least some ability to effective spread by ramets.
- Root competition may also play a part – further research is indicated.

4.6 APPENDIX - A QUALITATIVE ASSESSMENT OF THE GROWTH OF ORNAMENTAL HERBACEOUS SPECIES IN AN INFORMAL TRIAL IN GRASS WITH A MEADOW MANAGEMENT SCHEME

Species	**1997**	**1998**	**2000**	**2001**	**2002**	**2003**	**2004**
Cowley Manor							
Aster cordifolius	expanding	stable	expanding	disappeared			
Aster laevis	stable	declining	stable	disappeared			
Aster novae-angliae	stable	stable	expanding	disappeared			
Cephalaria gigantea	greatly reduced	disappeared					
Cirsium canum	stable	expanding	expanding	expanding	expanding	expanding	expanding
Echinops ritro	expanding	expanding	expanding	stable	stable	stable	stable
Eupatorium maculatum	stable	declining	reduced	reduced	disappeared		
Euphorbia cyparissias	stable	expanding *	expanding *	expanding *	expanding *	expanding *	expanding *
Geranium endressii	expanding	expanding	expanding	expanding	expanding	expanding	expanding
Geranium phaeum	stable	expanding	stable	stable	expanding	stable	stable
Geranium pratense	stable	seeding	seeding	seeding	stable	stable	stable
Geranium psilostemon	stable	stable	stable	stable	stable	stable	stable
Geranium x oxonianum 'Claridge Druce'	expanding	expanding	expanding	expanding	expanding	expanding	expanding
Helianthus 'Lemon Queen'	expanding	expanding	expanding	expanding	expanding	expanding	expanding
Hemerocallis 'Golden Chimes'	reduced	reduced	disappeared				
Inula cf. magnifica	expanding	expanding	expanding	expanding	expanding	expanding	expanding
Iris sibirica	stable	expanding	expanding	stable **	stable	stable	stable
Knautia macedonica	expanding	expanding	declining	disappeared			
Macleaya cordata	greatly reduced	greatly reduced	declining	disappeared			
Persicaria amplexicaule	reduced	reduced	declining	disappeared			
Rheum palmatum	greatly reduced	greatly reduced	declining	disappeared			
Rudbeckia fulgida	expanding	expanding	stable	stable	disappeared		
Rudbeckia 'Juligold'	stable	expanding	expanding	expanding	expanding	expanding	expanding
Symphytum asperrimum	stable	expanding	expanding	expanding	stable	stable	stable

* = not as a clump but through guerrilla penetration of grass resulting in sparse spread over a wide area
reduced = in comparison to growth in a conventional border situation

** = the number of shoots/area covered stayed more or less the same, but given the strongly tendency of the clump to radiate out, and break up, clump fragmentation was observed.

Elmtree Cottage	**1997**	**1998**	**2000**	**2001**	**2002**	**2003**	**2004**
Calamagrostis x acutiflora 'Karl Foerster'		stable	expanding $	expanding $	expanding $	expanding $	expanding $
Miscanthus sinensis 'Silberfeder'		stable	stable	expanding $	expanding $	expanding $	expanding $
Molinia caerulea subsp. arundinacea		stable	declining	declining	disappeared		
Stipa arundinacea		declining	disappeared				

$ = expansion of clump notably less per year than in conventional border conditions

5.

ASSESSING COMPETITION WITH TWO GRASSES OF CONTRASTING PRODUCTIVITY IN STANDARDISED CONTAINER CULTURE

ASSESSING COMPETITION WITH TWO GRASSES OF CONTRASTING PRODUCTIVITY IN STANDARDISED CONTAINER CULTURE

5.1 INTRODUCTION

In EBPS, issues of competition are key to the long-term success of these plantings, both with regard to unwanted species and between the members of the assemblage of species used. The comparison of the performance of several ornamental perennials with different morphological and phenological characteristics in a containerised competition trial is aimed at evaluating the effectiveness of competition and at assessing the contribution of different morphological and phenological traits to competitive effectiveness.

Grasses were chosen as competitors as they are most important and effective competitors of ornamental perennials in real-life situations. Two species were used: a high and a low competitor.

The use of container-grown plants has a long history in ecological research including in many of the studies considered here (Goldberg & Landa 1991, Keddy et al. 2002, Rösch et al. 1997). The use of plants in containers has many obvious advantages: the ability to completely control the planting medium, in particular nutrient and moisture content being the most important – in distinction to open ground trials where even on apparently homogenous sites, soil characteristics may influence nutrient and available moisture to different degrees.

The experience of horticulturalists with ornamental herbaceous plants is that soil nutrient levels have a major impact on growth – as might be expected, plants with a competitive (i.e.C-strategy) character show a clear response to different nutrient levels, in that low nutrient conditions tend to produce small, pale leaves and slow growth, high levels, lush green foliage and rapid growth. The ability of competitive plants to compete – with each other, with stress-tolerant (i.e. S-strategy) species, and in particular, with ruderals, is thus heavily dependent upon nutrient levels. This trial aims at investigating competitive effect and response between 8 ornamental perennials subjects and 2 grasses (the competitors) at three varying nutrient levels.

5.1.1 Aims

- To assess the effect the selected subject species have on the standing biomass of two competitor grasses at the end of one growing season, and the effect of the grasses on the biomass of the subject perennials; this being useful in furthering an understanding of competition mechanisms amongst ornamental forbs, particularly with regard to weed competition in horticultural practice.
- To assess how useful trials of containerised plant material might be to practitioners in the horticultural industry, in the assessment of competition and other aspects of plant growth.

5.1.2 Taxa selected

Aster cordifolius 'Little Carlow'	CR
Astrantia major	CR
Geranium x oxonianum 'Claridge Druce'	CR
Helianthus 'Lemon Queen'	C/CR
Iris sibirica	C
Knautia macedonica	CR
Ophiopogon bodinieri	C/SC
Solidago rugosa 'Feuerwerke'	C/CR

Using the terminology of Grime's CSR model of plant functional types (Grime 2001), species chosen have a C, a CR or a C/CR strategy – the dominant strategies for herbaceous ornamentals. One species with some S character was also chosen. CSR ordinations were those calculated in the section of this study *2. The CSR model of plant functional types...*

Species were chosen for the following reasons:

- All are valued as horticultural ornamentals
- Availability of plant material
- To look at different growth strategies within the broad C to CR area

Subject species exhibited a range of leaf-stem relationships, and regions of origin:
Clump-forming habit:

Leaf-stem relationships:

Clump-forming habit, with predominance of basal or apparently basal leaves:
Geranium x oxonianum 'Claridge Druce', *Knautia macedonica*

Basal leaves held strongly upright:
Iris sibirica

Basal leaves held near horizontally:
Ophiopogon bodinieri

More of less equal division between apparently basal and clear stem leaves:
Astrantia major

Similarly sized leaves distributed relatively evenly up robust stem:
Aster cordifolius 'Little Carlow', *Helianthus* 'Lemon Queen', *Solidago rugosa*

Region of origin

Europe:

Astrantia major, Geranium x oxonianum 'Claridge Druce', *Iris sibirica, Knautia macedonica*

East Asia

Ophiopogon bodinieri North America

Aster cordifolius 'Little Carlow', *Helianthus* 'Lemon Queen', *Solidago rugosa*

5.2 Methodology

The trial was based on a protocol developed for an evaluation of a wide range of garden and landscape flora drawn up for a proposed Marie Curie project (Hitchmough et al. n.d.).

5.2.1 Sources and nature of material

Bare-root divisions, made as equal-sized as possible, with soil washed off the roots, were used for all species tested, except for the knautia, where plug-grown seedlings were used. Owing to availability problems, the knautia seedlings came from two different sources, but where practically identical in age and size.

Vegetative divisions were used, rather than seedlings, as is more usual in trials of this kind. In many cases it is not possible to obtain seed of the taxa that were to be trialled, generally because they are available only as clones; it is clonal propagation which is the source of a great deal of herbaceous plant material used in planting schemes. The germination of many taxa can also be slow and problematic. It is also known for example that seedling growth of some herbaceous perennials is initially very slow, certainly slower than that of the competing grass species used, this reflecting the fact that subject plants and grass species originate in plant communities from very different climate regimes. Such a trial would be evaluating seedlings against seedlings, whereas the main focus here is on the relative competitiveness of more mature plants against seedling grass, which is a reflection of the real-life situation of planting schemes

5.2.2 Procedure

Three plants of each were planted in 15 litre pots of 75% coarse sand (by volume) and 25% peat, on 7.March.2004.

The pots were divided into three nutrient regimes as follows:

- No added nutrient
- Half recommended nutrient
- Full recommended nutrient, Osmocote 8-9 months NPK 16:8:12

They were also divided into three competition regimes:

- No competition
- Low competition, with *Festuca rubra* var. *commutata*
- High competition, with *Festuca arundinacea*

There were three replicates of each of the nine treatments:

nutrient **competition**	no nutrient	half -strength nutrient	full – strength nutrient
no competition	3	3	3
low competition	3	3	3
high competition	3	3	3

The grasses were introduced once the subject species were well established, by sowing seed at the rate of 1000 seeds per square metre, on 5.June.2004.

5.2.3 Progress of trial

Establishment was generally good, although there were some losses with the iris; which were replaced in the first week of April. The iris in particular was very slow to establish, which delayed the introduction of the grass seed. At the end of the trial, there was only one plant missing - an aster.

Growth was initially clearly affected by nutrient availability, with the plants in the no-nutrient containers appearing much smaller in all cases except the *Oophiopogon bodineiri*, during the first few months. In addition, growth on the *Geranium x oxonianum* appeared distinctly yellow. From July onwards however size differences between plants became less apparent, with only the *Geranium* foliage continuing to be distinctly paler in tone, which was still apparent at harvest time. *Ophiopogon bodineiri* was particularly slow to establish, with little sign that plants in the no-nutrient mix were disadvantaged; from July onwards, growth of all ophiopogon appeared to be stronger.

5.2.4 Management

Plants were regularly watered, by a combination of fixed oscillating sprinkler and hand-held lance. The *Aster*, the *Helianthus* and the *Solidago* were particularly badly affected by water stress, with frequent wilting during periods of dry weather in July and August. Where this occurred, plants were given additional water. Wind damage was also a problem with these three species. Any stems which were broken off were inserted in the pot adjacent to the plant from whence they came, and were included with them in the harvesting.

The pots were standing on a woven plastic geotextile membrane on earth. Rooting-through of plants was avoided as much as possible, by moving pots to sever any root growth every three to four weeks from July onwards. Nevertheless some rooting through did occur, so some nutrient absorption during rooting through must have been inevitable. The problem was worst with the *Helianthus*, but also occurred with the *Geranium*, the *Aster*, and the *Solidago*.

Flowering was fully assessed twice, on 27.June.2004 and on 27.August.2004, with a partial assessment on 25.September.2004.

5.2.5 Harvesting

Material was cut during the last week of October and the first week of November, being air-dried and then dried at around 80-100C in an oven for four hours, being weighed immediately it was removed from the oven, to minimise re-absorbtion of atmospheric moisture.

At the time of harvesting, growth of the current year's material had almost ceased. Some leaf drop had already started on the species of *Aster, Helianthus, Knautia and Solidago* studied, particularly so on the *Helianthus* and some individuals of *Knautia macedonica*. New basal growth had commenced vigorously on the *Aster* and the *Solidago*.

At harvesting, all above ground growth was cut and included, with the exception of the more-or-less horizontal stems of geranium, and the fleshy fruit of ophiopogon. Thus, the material consisted of:

- Living leaves
- Dead leaves still attached to the plant
- Living and dead flower/fruit stems
- Living and dead fruiting bodies, except for *Ophiopogon bodineiri*.

5.3 RESULTS

See 5. *Results of Container Trial* on *CD*)

5.3.1 Summary

1. There are 19 (out of 48) cases where the growth of the subject in the presence of a competitor is greater than in the corresponding control, i.e. subject dry matter as a percentage of corresponding control is > 100%. This indicates that growth of the individual subject plants is highly variable, and that there is little approximation to any kind of normal distribution. This is confirmed by the fact that out of 72 individual totals for subject dry weights (8 species x 9 different treatments) 12 do not indicate a normal distribution when a Kolmogorov-Smirnov test of normality is applied. Possibly this indicates that there are not nearly enough replicates in the trial for plant material which is as variable as this is.

2. There are relatively few cases where subject species growth is less than the control:
   - 16 where biomass is <76% of control
   - 5 where biomass is <51% of control

   This indicates that the competitor grasses had relatively little effect on the subjects, so it would be more appropriate to concentrate on subject effect on competitor rather than subject response to competitor.

5.3.1. Competitor effect and response

	LOW COMPETITION…………………………………>			HIGH COMPETITION…………………………>		
	no NPK	half NPK	full NPK	no NPK	half NPK	full NPK
Aster	42	99	92	65	110	113
grass	11.25	0.07	0.65	2.21	0.26	0.46
Astrantia	140	59	69	94	114	59
grass	29.07	9.91	5.48	5.72	1.84	7.66
Geranium	95	116	74	35	129	75
grass	18.51	0.11	0.14	3.89	1.22	0
Helianthus	88	136	159	80	135	38
grass	3.11	1.43	0.26	3.51	0.28	0.27
Iris	71	58	98	88	386	104
grass	14.01	17.92	13	9.68	2.9	10.61
Knautia	83	113	106	79	150	127
grass	14.88	1.58	0.86	5.18	1.06	0.28
Ophiopgon	50	172	81	42	128	80
grass	32.01	22.34	55.35	13.34	16.65	51.04
Solidago	209	135	75	163	115	75
grass	9.69	1.22	1.77	3.28	0.41	0.59

Table 5.2.

Competitor effect and response

Mean dry weight of target species and competitor grasses expressed as a percentage of mean of equivalent control.

Subject species percentages are rounded to the nearest unit

In table 5.2 there are only 7 cases where subject biomass is less than 76% of control (highlighted) and that of the competitor is 5% or greater, i.e. there is little indication that symmetrical competition is occurring.

	Mean of means
Aster	87.00
grass	2.48
Astrantia	89.00
grass	9.95
Geranium	87.00
grass	3.98
Helianthus	106.00
grass	1.48
Iris	134.00
grass	11.35
Knautia	110.00
grass	1.50
Ophiopogon	92.00
Grass	31.71
Solidago	129.00
Grass	2.83

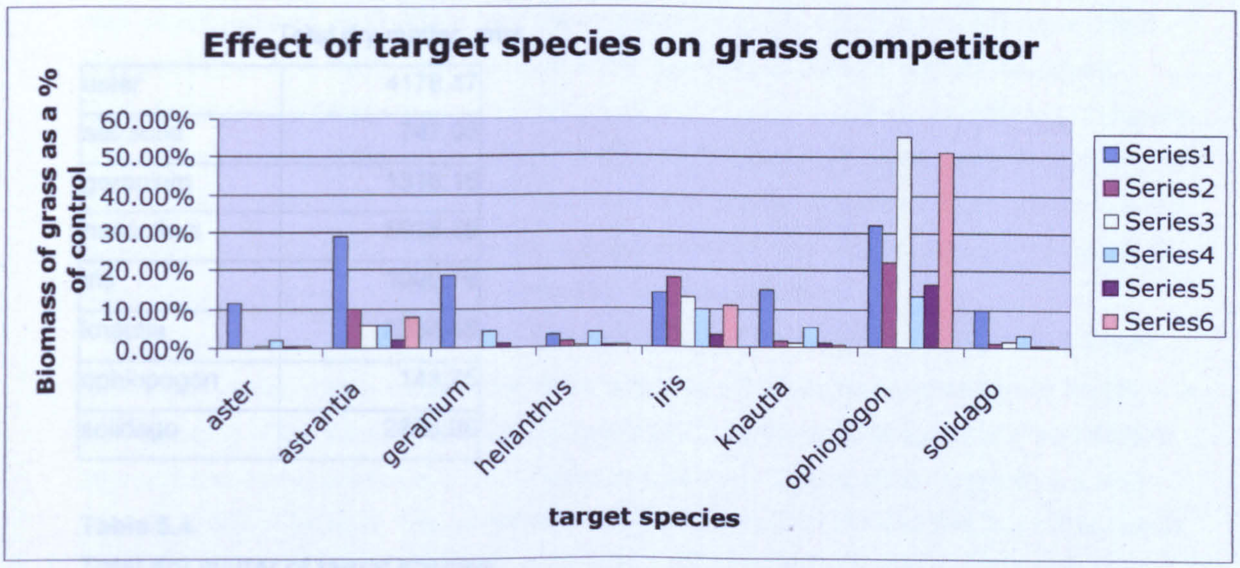
Table 5.3

Mean of the means shown in the *'Competitor effect and response'* table

'Mean' refers to mean of dry weight of target species and competitor grasses expressed as a percentage of mean of equivalent control. This provides a crude overall picture of the effect-response relationship between subjects and competitors.

In 4 out of 8 species table 5.3, the biomass percentage is over 100, i.e. more growth was made in the presence of competitors than without (see 1 above). *This indicates serious weaknesses with this trial.*

5.3.2 The effect of the target species on the grass competitor



X axis –= subject species,

Series 1 = no feed, low competition
Series 2 = half feed, low competition
Series 3 = full feed, low competition
Series 4 = no feed, high competition
Series 5 = half feed, high competition
Series 6 = full feed, high competition

Y axis – Mean dry weight of competitor grass expressed as a percentage of mean of grass control of equivalent NPK / competition category.

Graph 5.1

Effect of target species on grass competitors

In graph 5.1 the following is noted:

- The relatively high figures for competitor grass growth in 'no feed, low competition' i.e. the ability of *Festuca rubra* to grow in conditions of moisture/nutrient stress.
- The apparently significantly higher growth of the competitor grass in 'no feed, high competition' i.e. the limited ability of *F.arundinacea* to grow in conditions of moisture/stress where subject species growth is also limited by stress factors.
- At half and full nutrient levels, the ability of the competitor grasses to achieve what looks like some significant growth with *Astrantia major, Iris sibirica* and *Ophiopogon bodinieri*.

- The particularly strong growth of the competitor grasses with the *Ophiopogon*, which made the smallest increase in growth of any of the subject species. The only other two subject species where grass growth appears to be significant in the containers other than 'low nutrient, low competition' are the *Astrantia* and the *Iris*. It is noted that these two species achieved the next two lowest total dry matter totals:

	Total dry matter, gms.
aster	4178.47
astrantia	747.03
geranium	1318.15
helianthus	5938.59
iris	1020.79
knautia	2034.46
ophiopogon	143.25
solidago	2896.96

Table 5.4
Total dry matter of target species

5.4 DISCUSSION

Visual inspection alone reveals that the growth of the competitor grass was greatest in the containers with the subject species which made less growth, with the strongest competitor growth with the species which made the least growth (*Ophiopogon bodineiri*). Competitor growth was greatly reduced, in all others, with the exception of the less competitive (but more stress tolerant (Grime et al. 1990) *Festuca rubra* in the 'low feed' containers; nutrient resources appeared to be insufficient to support enough subject species growth to compete with the grass. This supports the idea that less productive environments are more conducive to floristic diversity (Grime 2001). The failure of the more vigorous *F.arundinacea* to achieve much growth in similar conditions suggests that more competitive species may be less able to establish effectively as seedlings when there is severe competition for water and nutrients.

Where competitor growth was affected by that of the subject species, there is a clear distinction between those cases where there was very effective ground coverage by leaves at or near the base of the stem of the subject (*Geranium x oxonianum* 'Claridge Druce' and *Knautia macedonica*) and where there were none (*Aster cordifolius* 'Little Carlow', *Helianthus* 'Lemon Queen', *Solidago rugosa*). The geranium made the least growth of these five, but still achieved almost total suppression of the grass apart from the *F.rubra* in the lowest nutrient container; foliage was observed to almost completely cover the surface of the compost. The absence of foliage cover of the compost in the case of the *Aster*, the *Helianthus* and the *Solidago* points to effective root rather than shoot competition in these cases; indeed the logical corollary is that root competition must be assumed to be the primary source of competition in this trial.

Comparison of the results of this trial with what can be readily observed in many horticultural situations suggests that the inability of the grass competitors to establish in containers bears little relationship to reality; unwanted weed seedlings can often be seen growing immediately around, and indeed in, clumps of a great many perennial species; observation suggests that leaf shading is the more effective means of competition. This trial demonstrates however, that root competition is perhaps more fundamental, and that in different circumstances, ornamental forbs may be able to compete with unwanted weedy vegetation through root competition alone – in different climate zones for example.

5.5 CONCLUSIONS

- Effective competition occurs with species that are able to make relatively large amounts of aboveground growth (measured as dry matter at the end of the growing season).
- Root competition alone can greatly limit the growth of competitors.

5.6 METHODOLOGICAL ISSUES - THE TRIAL AS AN APPROPRIATE MEANS OF EVALUATING COMPETITIVENESS

The protocol for this trial was originally designed to be used for seedlings by those familiar with standard research measures in ecology. How suitable is this methodology for those relatively unfamiliar with such procedures and for vegetatively produced material?

The following observations were made:

5.6.1 Differential rates of growth between species

Differential rates of growth from division vary considerably between species. Since the grass seed needs to be introduced to every container on the same date, to ensure standard conditions of competition, and since subject plants have to be established well enough to be able to have a chance to compete effectively, the date of grass sowing is thus dictated by the slowest-establishing species. This means that by the time the grass is introduced, the majority of subject plants may be so well advanced that the grass has little opportunity of competing. This of course reflects one aspect of a competitive advantage over the grass (i.e. a phenological one) but makes it difficult to evaluate other aspects of competition.

5.6.2 Lack of equivalence between taxa, and amongst individuals

Vegetatively propagated material may lack the equivalence between plants of different taxa compared with seedlings. However, seedlings themselves are not necessarily equivalent – how valid is it to compare seedling of taxon A which develops very slowly taxon B which establishes rapidly in terms of competition.

Within species there are considerable differences in the rate of growth of new plants from division-derived material. A visual assessment of the trial after only a few months indicated that there was sometimes considerable variation between individual plants, much greater than would be expected from seedlings. Even when superficially similar, divisions may vary in the following ways:

- Age of material, leading to differences in vigour
- The number of dormant (and often almost invisible) buds
- The reserves of nutrients in the material.

5.6.3 Plant maintenance

With vigorously growing plants in containers, the risk of rooting through holes in the bottom of the pot, and then through the geotextile ground cover into the soil below is ever-present. Even with regular moving of containers, some rooting-through does occur. It is possible that short bursts of extra nutrients obtained during a brief rooting-through episode may result in the control of nutrient levels in the container being seriously compromised.

5.6.4 The trial as a comparison with the reality of horticultural practice

Competition is magnified by the high water stress, which prevails during dry summer weather. Compared to plants growing in the open ground, competition for water resources is much more intense, therefore reducing the relevance of the trial to the reality of horticultural practice. In particular the ability of those subject plants which compete through rapidly developing an efficient root network to extract moisture from the substrate could be at an advantage over those which instead compete largely through shading of the substrate surface. In real-life situations, soil moisture levels in the British climate are only very rarely reduced to the levels in the containers, and so this competition strategy may well be of much less importance to a plant's overall ability to compete.

5.6.5 The trial as a practical methodology for practitioners

The trial took up a considerable amount of space and was time-consuming to maintain, although this latter factor could have been ameliorated if an automatic drip irrigation system were used. The costs of containers, compost, and the labour involved in filling and planting them are also factors which make this trial procedure an unattractive one for practitioners with a limited budget, especially since the number of replicates used could be regarded as minimal.

5.6.6 Recommendations for further use of this trial by practitioners:

- That instead of using divisions, young plants grown from cuttings could be used; this would almost certainly reduce the differences between individuals noted above.
- That containers are placed on a clean hard surface or other nutrient-free surface.

6

EVALUATING THE COMPETITIVENESS OF HERBACEOUS PERENNIALS USING A PHYTOMETER IN OPEN GROUND CONDITIONS

EVALUATING THE COMPETITIVENESS OF HERBACEOUS PERENNIALS USING A PHYTOMETER IN OPEN GROUND CONDITIONS

6.1 INTRODUCTION

Open ground trialling of plants is well established in order to assess their viability and value in cultivation for particular locations, and in particular to assess the value and performance of one taxon against another, e.g. by Britain's Royal Horticultural Society (Royal Horticultural Society 2007, 2008). Agricultural research, e.g. in crop breeding, also uses this technique (Chahal & Gosal 2002).

The technique is not normally used in the investigation of plant competitiveness by ecological scientists. Given the problems in managing container trials however, it is suggested that the technique may have value in assessing competition. Conditions in containers can be managed much more closely than in the open ground – in particular differences in soil composition which may affect outcomes in open ground trials are eliminated. For practitioners however, the greater inaccuracy of open ground trials may be outweighed by the relative ease, and cost-effectiveness, of conducting open ground trials.

Phytometers have been used in researching plant interactions in a number of fields. In its original meaning the word 'phytometer', as defined by Clements and Goldsmith 1924, was the use of plants as 'biological instruments' – vigorous and predictable species that could be used to measure the impact of abiotic factors on growth, as a means of assessing environmental variables. In agriculture the technique has been used to explore a range of biotic and abiotic variables, e.g. the potential of growing understorey crops (Newman 1984). Others have used the word to describe the use of plants to measure the impact of the growth of other plants – i.e. competition. Rösch and others have used a phytometer-based technique in an attempt at predicting competitive outcomes with South African semi-desert species (Rösch et al 1997); Gaudet and others at the relationship between competition and nutrient levels amongst shoreline plants in Canada (Gaudet & Keddy 1988, Gaudet et al 2000).

Here, the decision was taken to use test the competitiveness of a number of herbaceous species against one species of competitor; the subject species are well-established young plants, the competitor is introduced either as seed or as seedling plugs. The balance of competition is therefore heavily weighted against the competitor; whilst it is in no way expected that there will be no competitive effect exerted on the subject by the competitor, it is reasonable to assume that the competitor's growth (measured as dry matter weight) at the end of a growing season will to a large extent reflect the competitive effect exerted on it by the subject – the competitor's dry weight will therefore measure the level of competitive effect, and be acting as a phytometer. What the phytometer will be measuring is the total competitive effect, primarily a sum of the allocation of light, nutrient and moisture resources.

6.1.1 Selecting a phytometer species

In the first trial, the phytometer species was intended to be competitive with the subject species (24 ornamental forbs), so that competitive effect and response on both subject and phytometer/competitor might be expected to be of significance. Plants used were mostly divisions, of a size which would typically be used by practitioners in horticulture and landscape in establishing permanent plantings.

In the first trial, *Festuca arundinacea* was selected as a phytometer, to be sown from seed, because:

- It is known to be a rapidly-growing and easy to establish species from seed,
- Its performance, including that in the container trial in this study, indicates that it can be expected to exert competitive pressure on neighbours,
- Its morphology, with a clump which by the end of the first year can be readily pulled up from the ground with an absence of long tillers to get tangled up in the subject species, makes it suitable for efficient harvesting.

The species is known to be an aggressive competitor with other herbaceous species (Walck et al. 1999).

In the second trial, *Achillea millefolium* 'Summer Pastels', an F_2 mixture of different coloured flowers, was selected as phytometer because:

- Several years experience of growing the plant from seed has established its reliability in maintaining good growth in mesic or dry garden conditions,
- Seedlings show great consistency in all morphological characteristics
- Growth is rapid, with flowering occurring within five months from seed
- Relatively little foliage is lost during the first year – so that biomass at the end of a growing season can assume to represent a cumulative total of growth through that season,
- It has no commonly observed physiological or pathological problems,
- Its combination of upright flower heads, carrying some foliage, and strongly clump-forming habit, indicates that it might be expected to exert considerable pressure on neighbouring plants. Generally a substantial clump is formed (around 250mm across) by the end of the first growing season. Clump-formation is by formation of underground shoots, which emerge a short distance from the parent, with a phalanx spread. Ground coverage within the clump is total, weed penetration almost unknown.
- Practical experience suggests that it does both survive competition from neighbours and exerts it,
- There are no morphological factors which might make it difficult to harvest or separate from target species

The only other species considered was *Lythrum salicaria*, as used as a phytometer by Gaudet and Keddy 1988. This has the advantage that it is easily harvested, as it has only one central root-stem union – however author experience suggests that its seedlings show enough variation in vigour as to make it unsuitable as a phytometer. It is also more likely to be wholly suppressed by shading.

In addition, seedling plugs were used, which has considerable advantages over sowing seed:

- There is no risk of germination failure,
- The number of plants used is known,
- Individual plants can be precisely positioned relative to subject plants,
- Weeding is made easier by precise positioning of desired plants.

6.1.2 Selection of species for trial

The species selected for trial are listed in the *Open Ground Trial Pershore, Plant Characteristics* table (Table 6.1). Commonly grown species in EBPS, or species with aesthetic and cultural characteristics, which indicate possible suitability for EBPS were chosen, with regard to a range of the following:

CSR values
Growth Cycle Group (see 7. *An analysis of plant traits and characteristics*)
Leaf-stem relationship (ditto)
Ground Coverage + Shading Effectiveness (GC+SE) (ditto)
Estimated Competitive Ability (ditto)

	CSR ordination *	Growth Cycle Group *	Leaf-stem relationship *	GC+SE *	ECA *	Notes
Alchemilla mollis		4b	4	19	4	
Aster cordifolius 'Little Carlow'	CR	4c	10	18	4	
Astrantia major	CR	5	6	16	3	
Baptisia australis	C/CR	5	10	8	3	
Bergenia cordifolia	C	1	3	24	3	Growth cycle etc. codes are for the very similar B. 'Abendglut'
Carex buchanii	SC	1	1	16	2	Growth cycle etc. codes are for the very similar C.dipsacacea
Cirsium canum	CR	4b	4	13	3	
Echinacea purpurea		5	9	20	3	
Echinops ritro	C	5	6	26	4	
Filipendula ulmaria		4b	6	19	4	
Geranium x oxonianum	CR	2	4	30	4	
Helianthus 'Lemon Queen'	C/CR	5	10	17	4	
Helleborus x hybridus	C	1	2	20	3	
Iris sibirica	C	4b	1	10	4	
Knautia macedonica	CR	5	9	18	3	
Lysimachia punctatum		4b	9	12	5	
Lythrum salicaria	C-S-R/C-R	4b	9	13	3	
Macleaya microcarpa	C	4b	7	10	3	
Nepeta x faassenii	C/SC	2	9	25	3	
Ophiopogon bodinieri	C/SC	1	1	16	3	
Persicaria bistorta 'Superba'		2	4	20	5	
Phlomis russelliana	C	1	4	23	4	
Salvia nemorosa	CR	2	9	16	2	
Solidago rugosa	C/CR	5	10	19	3	

Table 6.1. Open Ground Trial Pershore, Plant Characteristics.

* = for explantion refer to 7. *An analysis of plant traits and characteristics*

For the second trial using achillea (2007), a reduced version of this list of species was used:

Alchemilla mollis
Aster cordifolius 'Little Carlow'
Baptisia australis
Bergenia cordifolia
Carex comans
Geranium x oxonianum
Helianthus 'Lemon Queen'
Iris sibirica
Lysimachia punctatum
Lythrum salicaria
Nepeta x faassenii
Phlomis russelliana
Solidago rugosa

6.1.3 Aims

- To assess the competitiveness of a range of ornamental herbaceous species through the impact on the standing biomass of a competitor species during one growing season.
- To assess the value of open-ground trials of competitive character, as a tool for industry practitioners.
- To assess the value of using a phytometer species as a means of evaluating competition.

6.2 METHODOLOGY

6.2.1 2005 and 2006 trials

A site at Pershore College, Worcestershire, with a level alluvial soil, was used for the trial. Previous vegetation was sprayed with glyphosate, and the soil rotovated prior to planting. The site was open, with little shelter from wind.

Two groups of plots were prepared, and planted on 24.March. 2004.

Nine well-established plants of the subject taxon were planted at 33cm intervals forming a square of 1x1m, with a distance of 1.2m between the outermost plants of the square and the plants of adjacent squares. Details of plant size are given in the table *Open Ground Trial (Pershore), 2. Planting Details* (6.7 .Appendix.1).

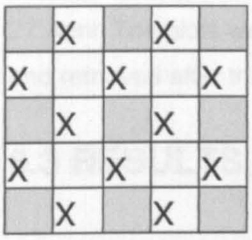
6.2.2 2005 Trial

One group of plots were kept free of competition, the other was sown with *Festuca arundinacea*, at a rate of 1,000 seeds per square metre (2.5gm/m^2) over the planted areas of the competition plot, i.e. within the 1x1m square, on 28.April.2005. The intention was to harvest the phytometer/competitor and subject species in the autumn and compare their dry matter content.

6.2.3 2006 Trial

The plants used during the 2005 trial were kept *in situ*. There were only a few losses over the winter; one each of the following were replaced: knautia, cirsium, filipendula, ophiopogon. In each case a plant of open ground origin was chosen, of a size suitable for potting into a 2 L container.

On 28 April, 25mm cell size plugs of *Achillea millefolium* 'Summer Pastels' were introduced as a competitor/phytometer. 12 plants were planted into each 1x1m square of one each of the subject species, evenly distributed amongst the subject plants, see fig. 6.1.



▨	X	▨	X	▨
X		X		X
▨	X	▨	X	▨
X		X		X
▨	X	▨	X	▨

Fig.6.1 Distribution of target plants (shaded) and achillea competitor/phytometer (X), within each 1x1m square.

6.2.4 2007 Trial

Plants were arranged in an identical arrangement as described as above at Montpelier cottage, Brilley, Herefordshire. The site had an apparently uniform sandy clay loam soil, a gentle slope, with higher moisture availability at the bottom. The site was divided into four strips following the contour line, and plots of subject species with achillea and plots without were placed on the same strip, to ensure equal moisture availability between the two. One control plot of achillea was planted on each strip, making a total of four, see fig 6.1.

alchemilla	solidago		alchemilla + achillea	nepeta + achillea	achillea control	solidago	nepeta	
baptisia + achillea	aster	lysimachia + achillea	bergenia + achillea	baptisia	aster + achillea	lysimachia	achillea control	bergenia
phlomis + achillea	helianthus + achillea				achillea control		phlomis	helianthus + achillea
carex + achillea	achillea control	geranium + achillea	iris + achillea	lythrum + achillea	carex	lythrum	geranium	iris

Table. 6.2. Arrangement of plants on trial plot at Montpelier Cottage, 2007. Each plot was separated from its neighbours by a gap of 800mm. The arrangement of plants within each plot was exactly as in fig. 6.1.

Subject plants were planted on 2.February.2007, the achillea competitor plugs were planted on 27.March.2007. Plant sizes are detailed in the table *Open ground trial, Montpelier Cottage 2007, Planting Details* (6.7 Appendix 2). Plots were watered weekly until 18.April, with no irrigation after this. Slug pellets were applied after noticing some minimal slug damage 27.April. The plots were thoroughly weeded on 20.May; only occasional weeds were noticed and removed after this.

6.3 RESULTS

6.3.1 2005 Trial

An almost total failure of germination of the *Festuca arundinacea* seed meant that no effective competition was present. The trial was therefore aborted.

A control sample of festuca seed achieved acceptable germination in a container. Weed seed germination at the site at Pershore was also vigorous.

Establishment and condition of subject species

Some of the *Helleborus x hybridus* and *Persicaria bistorta* looked stressed, caused possibly by drought during spring 2005. The persicaria recovered, but the helleborus had foliage damage throughout the summer.

The *Macleaya cordata* experienced frost damage in May. A number of spare plants left over from the Pershore planting, at Elmtree, still in containers, allowed a comparison to be made, of shoot height and leaf stretch on the same date (13.May), although it should be pointed out that the sample size (3 at Elmtree) was small. The *Macleaya* appeared to have made twice as much growth at Elmtree, the absence of frost, and possibly reduction in wind chill could have accounted for this. Frost damage, apparently killing all foliage on tthis species was observed during April at Pershore; no other plants in the trial were affected. Comparisons between other spare plants, from the same batch as planted at Pershore (*Baptisia australis,* *Echinacea purpurea, Lythrum salicaria*), at Elmtree showed no difference in height on this date.

6.3.2 2006 Trial

Despite 3 weeks rain immediately after planting, the *Achillea* plants failed almost totally in the exceptionally hot summer, which followed. Irrigation was not possible for a variety of reasons. The trial was therefore aborted.

Following the cessation of the trial, a survey of subject plant survival was carried out on 21, January. 2007. All plants were healthy and had increased in clump size apart from the following:

Astrantia major	2 showed poor growth
Baptisia australis	5 had disappeared - possible rabbit predation
Cirsium canum	2 disappeared, 4 showing poor growth – no apparent reason
Echinacea purpurea	1 disappeared, 1 poor growth – possible rabbit predation
Echinops ritro	5 disappeared –
Knautia macedonica	5 disappeared –
Macleaya cordata	3 disappeared – no apparent reason
Nepeta x faassenii	1 disappeared – rabbit predation
Salvia nemorosa	1 disappeared – rabbit predation

It was noted that weed competition during this final year was minimal.

The eventual disappearance of several of the *Echinops ritro* and *Knautia macedonica* highlights a major problem in the specification and use of herbaceous perennials – lifespan is often unknown, no reference sources detail lifespan and very little research has been done – only Hansen & Stahl 1993 make reference to any studies. Anecdotal evidence from experienced gardeners suggests that cultivated echinops taxa and *Knautia macedonica* are short-lived (Pasley-Tyler 2007, Dent 2007); the absence of distinctly autonomous shoots, i.e. true and clear ramets, indicates the vulnerability of individual plants, and many species with this non-clonal habit are observed to be short-lived (see 'selection and measurement of plant characters' in 7.*An analysis of plant traits and characteristics.*

6.3.3 2007 Trial

6.3.3.1 Assessment during trial

An assessment of mollusc damage was made 29.April: only achilleas appear to have been affected, with one damaged on *Alchemilla mollis* and Nepeta x faassenii plots, and three on *Phlomis russeliana* and *Carex comans* plots. All plants recovered however.

On 22. July, a visual assessment of ground coverage and shading by subject plants was made, and of growth of achillea phytometers.

1) The control plots were inspected by looking down on the clump from head height, and an assessment made of ground coverage and shading at ground level by an estimation of the amount of bare ground visible *within* the area defined by the centres of the outer nine plants:
   1 – at least 95% of ground invisible
   2 – between 75%-95% ground invisible
   3 – between 25%-74% ground invisible
   4 – less than 24% ground invisible.
   This is termed a 'bare ground visibility'.

2) The phytometer species were assessed:
   a) For the number in flower
   b) For average height of the plants to the top of the inflorescence

Results are given in the table *Open Ground Trial, Montpelier Cottage, 22. July Assessment* (6.7 Appendix 3)

The 22.July.2007 visual assessment attempted to evaluate the amount that ground was either covered or shaded by the subject – it is not the same as Ground Cover and Shading Effectiveness (GC, SE) discussed in 7. *An Analysis of Plant Traits and Characteristics* (which aimed at evaluating coverage close to the ground), and the impact of the subject plant on the *Achillea* phytometer. All individuals in the control plots were in flower, whereas many growing with the subject species were not – in many cases this represented a delay in flowering rather than its suppression.

Growth of the *Achillea* fell into three distinct groups:

- Where there was no difference in the growth of the control,
- Where flowering was reduced/delayed, but height unaffected, or increased
- Where flowering was reduced/delayed, and height reduced.

It is noted that where flower stems were not present on 22.July, they were virtually always produced later on – as nearly all the *Achillea* material harvested at the end of the year had produced flowering stems, however weak; only some *Achillea* plants growing amongst carex, helianthus and phlomis produced no flowers (2 in each case).

6.3.3.2 Quantitative evaluation – The *Achillea millefolium* phytometer

Achillea plants were harvested on 7.October, and were air-dried in paper bags in a polytunnel with the aid of a de-humidifier. They were weighed on 29.October, when all the material appeared to be dry. The results are shown in 6.7 Appendix 4 - *Open Ground Trial, Montpelier Cottage, Dry Weights....* (on CD)

As noted, total suppression of flowering in individual phytometer plants was rare, and occurred with 2 out of 3 of the most competitive species, total elimination of the phytometer occurred in only 3 cases: 2 with the phlomis and 1 with the solidago.

During harvesting, it was noted that with the *Aster cordifolius* , *Geranium x oxonianum* and *Helianthus* 'Lemon Queen' there was a distinct suppression of ramet production. In the *Lysimachia punctata* plot, it was very difficult, indeed almost impossible, to separate out which ramets belonged to which parent plant. A Kolmogorov-Smirnov test (Dytham 2003) was carried out on each sample to assess normality of distribution; the *Baptisia australis*, and control 2 and control 3 showed a P value of <0.05, indicating a distribution significantly skewed from normal; the mean of the control however had a P value of > 0.05.

A *t* test was then performed on each set of data to establish whether there was a significant difference with the control. Given that the controls varied widely, see below under 'Discussion, Questions of methodology', *Achillea* dry weights were compared twice, once with the control plot in the same row of the trial plot for that species, i.e. the same position on the gradient, and with the mean of all the controls.

	mean weight as % of mean row control	mean weight as % of mean of controls
Alchemilla mollis	35	51
Aster cordifolius 'Little Carlow'	27	28
Baptisia australis	92	94
Bergenia cordifolia	108	111
Carex comans	46	25
Geranium x oxonianum	40	22
Helianthus 'Lemon Queen'	6	6
Iris sibirica	77	42
Lysimachia punctata	61	62
Lythrum salicaria	37	20
Nepeta x faassenii	32	47
Phlomis russeliana	10	10
Solidago rugosa	9	13

Table 6.3

Open Ground Trial, Montpelier Cottage.

Mean dry weights of one year's growth of *Achillea* phytometers as a percentage of the control.

- Heavy shading indicates where a *t* test gave a P value of >0.05 for both sets control data (mean of relevant row and mean of all controls), indicating no significant difference with the control.
- Light shading indicates where only one comparison with the control gave a P value of <0.05, indicating that a difference with the control may not be significant.
- No shading indicates where both comparisons with the control gave a P value of <0.05, indicating that there is a significant difference with the control.

Despite the variation between the two sets of control weights in table 6.3, three groups stand out:

- The helianthus, *Phlomis russeliana* and *Solidago rugosa* show values of at least 13% of both controls, indicating highly effective suppression of the growth of the phytometer.
- The *Baptisia australis* and *Bergenia cordifolia* showed no statistically significant effect on the growth of the phytometer, indicating no appreciable competitive effect
- The *Alchemilla mollis*, *Aster cordifolius*, *Carex comans*, *Geranium x oxonianum*, *Lythrum salicaria* and *Nepeta x faassenii* all showed a significant reduction in phytometer growth, indicating some competitive effect; the *Iris sibirica* and

Lysimachia punctata gave ambiguous results – it is possible that they did have at least some competitive effect.

6.3.3.3. Plants of subject species

The subject species were harvested during the second week of November and air-dried over the next few weeks. In the case of the *Bergenia cordifolia*, the air-drying of the fleshy leaves was so slow that they were oven dried. Air drying is of course, not as complete as the standard oven-drying of samples (see 2.*The CSR model of plant functional types – an evaluation of its value in ecologically-based ornamental horticulture*) but since samples of only one species were being weighed relative to each other, this lack complete desiccation can be regarded as unimportant. All samples of a species were weighed within 30 minutes of each other so that they were weighed at the same humidity level.

A Kolmogorov/Smirnov test of normality was applied to each of the 9 results for each planting block – all showed normal distribution. A Paired *t*-test was then used to evaluate significance of the difference between those grown with the *Achillea* and the controls.

Results are shown in table *'Dry weights of subject plants in open-ground trial'* in 6. Appendix 5 on CD).

The following is noted:

- That only 5, out of 13 species, showed a significant difference in the dry weights of plants grown with the *Achillea* compared with controls.

	A	B
Aster 'Little Carlow'	211%	28%
Baptisia australis	23%	111%
Bergenia cordifolia	53%	94%
Lysimachia punctata	38%	62%
Solidago rugosa	41%	13%

Table 6.4

Dry weights of plants which showed a significent difference between controls and plants grown in competition with *Achillea*.

The dry weight of plants grown with *Achillea* shown as a percentage of controls in the relevant row shown in column A, and the mean dry weight of the competing *Achillea* as a percentage of the mean of all four control plots of *Achillea* in column B.

Of the dry weights of plants shown in table 6.4, two would appear to be anomalous, the *Aster cordifolius* and the *Solidago rugosa*; *Achillea* growth with both was restricted; possible reasons are discussed below under *Questions of methodology*.

Since the growth of the remaining 3 species showed what would appear to be have limited or no effect on *Achillea* growth, it is assumed that the *Achillea* must be exerting a competitive effect on the subject plants.

6.4 DISCUSSION

6.4.1 Qualitative evaluation

Both reduced/delayed flowering and reduced height are dysfunctional for species survival, the former because it reduces possibilities for recruitment and the latter because height is regarded as an important factor is competitive ability (Grime 2001). However, reduced height cannot be regarded as an outcome of reduced performance alone; whilst competition with four subject species resulted in both reduced/delayed flowering and reduction of height, competition with four others resulted in height being unaffected (i.e. height was no lower than the shortest control) and in two cases height was increased – in both cases where the subject was considerably taller than the *Achillea* normal height; it must be assumed that shortage of light stimulated this increased height of the flowering stems. Growing amongst species of a typically greater height however does not automatically result in greater *Achillea* height – as can be seen from the result for the *Helianthus* 'Lemon Queen', whilst competition with the *Solidago rugosa* resulted in reduced height.

Where height and flowering were unaffected, it is noted that bare ground visibility was high, where height and/or flowering were affected, bare ground visibility varied, but tended to be low. It might be expected that species with a high level of ground coverage by low-level foliage (as measured by GC and SE, see 7.*An Analysis of Plant Traits and Characteristics*) are effective competitors by their ability to shade out competition around the core of the clump, i.e. the *Alchemilla mollis*, *Phlomis russeliana* and *Carex comans* species trialled; the effective suppression of both flowering and height by the *Solidago rugosa*, where there is very little shading of the ground surface by low-level foliage, suggests that root competition is playing an important role.

6.4.2 Quantitative evaluation

6.4.2.1 Comparison with qualitative evaluation

If the results of the July qualitative evaluation and the end-of-season dry weight figures are compared, it is noted that:

- The lack of clear impact on the growth of the Achillea by the *Baptisia australis* and the *Bergenia cordifolia* is reflected by the dry weight figures; *Lysimachia punctata* showed little obvious effect either.
- Of the species which appeared to most adversely affect Achillea growth in the visual assessment, by reducing/delaying flowering and in reducing height, 2 out of 4 (*Phlomis russelliana* and *Solidago rugosa*) show a major competitive impact on Achillea when dry weights are measured.
- Where Achillea growth was clearly affected by the subject species in that flowering was reduced/delayed but height not significantly affected, this is confirmed by dry-weight measurements.

- As noted above, competition with subject species did not always result in reduced height; however it is worth noting that the species which reduced/delayed *Achillea* flowering the most effectively, as measured in July, the *Helianthus* 'Lemon Queen', also achieved the most effective suppression of *Achillea* growth, as measured by dry weight.

It is suggested that there is a correlation between suppression of flowering in the *Achillea* and a general suppression of growth through competition.

6.4.3 The nature of competition

6.4.3.1 Species with effective suppression of phytometer growth

Of the 3 species which achieved the most effective suppression of phytometer growth, the *Solidago rugosa* and *Helianthus* 'Lemon Queen' species trialled are very similar in having a high proportion of biomass devoted to sturdy flowering stems and more or less equal-sized leaves (they are Leaf-stem relationship group IV plants, see 'Categories based on leaf-stem relationship (L/S)' in 7. *An Analysis of Plant Traits and Characteristics* – they are very typical North American prairie species. Neither has a high, nor a low, GC + SE rating (19 and 17 respectively, compared to the highest rating of 30). Shading of competition, whilst strong, is nothing like as effective as the almost complete exclusion of light from the soil surface by species with large or widespread basal leaves (see 6.2). Much of the impact on light available to the competing phytometer must be through the height of these species. The other two species here with a similar habit and leaf-stem relationship and roughly comparable height, the *Aster cordifolius* and the *Lythrum salicaria*, did not achieve similar levels of suppression; although the quantity and spatial distribution of the above ground biomass of the *Aster cordifolius* was very similar to the *Helianthus* 'Lemon Queen' and the *Solidago rugosa*. It must be assumed that root competition plays an important role in competition.

The third species shown to be a highly effective competitor was the *Phlomis russeliana*, almost certainly through its large, wide and numerous basal leaves, its GC + SE rating of 23 is moderate. The oldest and largest leaves are also held very close to the ground, forming a very effective blanket. The effectiveness of these leaves in shading the ground is enhanced through the spacing of the individual plants in the plot – almost total ground coverage is achieved (see fig. 6.2).

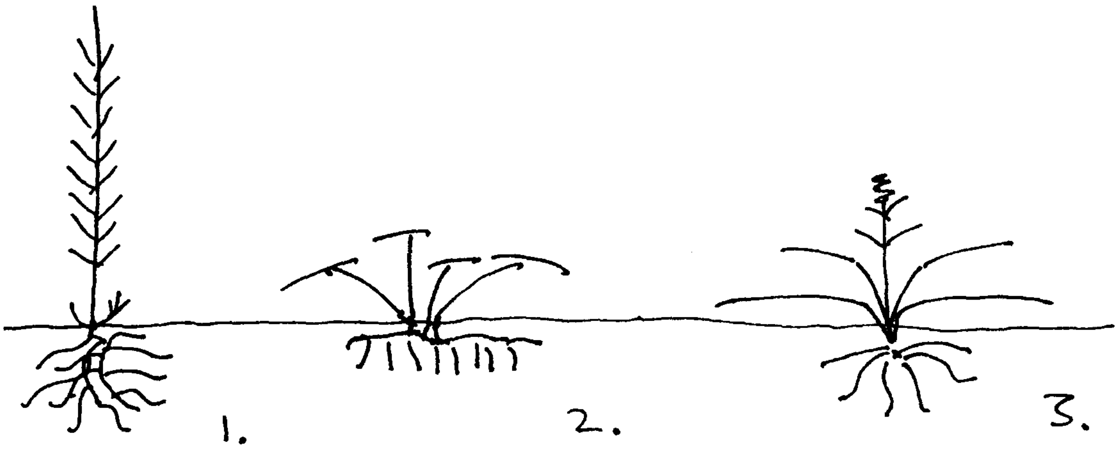


Fig.6.2

Aspects of morphology conducive to competition in species trialled.

Root competition (1), as in *Helianthus* 'Lemon Queen' can only be evaluated for certain through trials such as these as clear aboveground visual indications are lacking.

Shading of the ground (2), as in *Alchemilla mollis*, reduces light available to competition, e.g. weed seedlings.

Shading of the ground by large and low-lying foliage (3), as in *Phlomis russelliana*, may also involve additional costs to competing weed seedlings, such as providing shelter to molluscs and high levels of humidity conducive to fungal pathogens.

6.4.3.2 Species with moderate suppression of phytometer growth

The remaining species which achieved statistically significant suppression of phytometer growth were all, with the exception of the *Lythrum salicaria*, species with foliage near ground level: the *Carex comans*, with a dense mass of ground-shading linear leaves, the *Alchemilla mollis* and the *Geranium x oxonianum*, both with broad low-level leaves, and the *Nepeta x faassenii*, with dense production of trailing stems. The four species with ground-shading foliage do exhibit different morphologies which impact on shading.

The *Geranium x oxonianum* has the highest GC + SE rating, of 30 – a function of very early production of large leaves at ground level. Its performance here was not as vigorous as is often observed in garden conditions; results from the *5. Assessing competition with two grasses of contrasting productivity in standardised container culture* suggest that it is a highly effective suppressor of competition only when nutrient levels are high; it is possible that conditions at this site were not so favourable to vigorous growth – the performance of the *Achillea* control in the relevant row (row 4) suggested that nutrient levels were lower than further up the plot (*Achillea* control row 4 produced only one third the biomass of row 2). The Achillea has a GC + SE of 19 and an ability to continue to produce basal growth through the growing season. The *Nepeta x faassenii* has a higher GC + SE (24). Both the effectiveness of the *Alchemilla mollis*and the *Nepeta x faassenii*'s in shading the ground has to be seen in context with a canopy height which does not exceed 600mm; that of *Geranium x oxonianum* can be nearly 1m.

The performance of *Carex comans* is interesting. It was not measured for GC + SE[1]; this however could be estimated at 23. On its own, the foliage of this carex species, and that of many other low-growing evergreen carex species currently in cultivation, does not shade the ground particularly effectively owing to its being angled upwards, and because its light and linear nature means that it is easily blown aside – even in the case of this species where the ends of the leaves tend to flop down towards the ends. However, grown together, as in this research plot, at 330mm distances, leaves tend to interlock, forming a more effectively shaded area between the plants. This effectively enhances the pronounced tendency of this species to have a very wide foliage canopy for a relatively small basal area, a features of several other caespitose graminoids, e.g. *Stipa arundinacea*. This is noted in some species in the wild as resulting in an almost closed community, as in Sporobolus *heterolepis* (Weaver 1954). The importance of interlocking otherwise loose foliage also indicates that in measuring species with widely-spread but fine leaves, it is not only foliage spread which must be taken into account; the multiplier effect of interlocking needs to be recognised (see fig. 6.3).

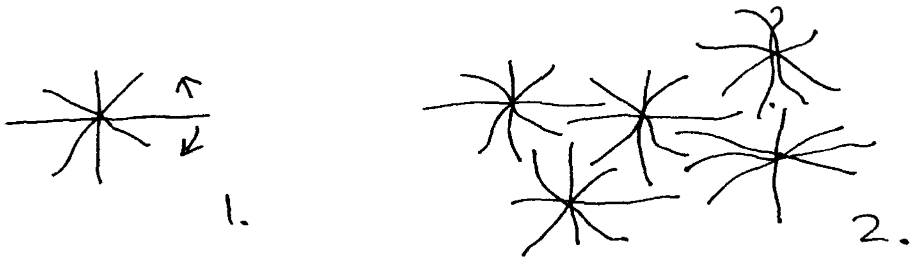


Fig. 6.3

Multiplier effect of interlocking foliage

Species with basal narrow linear foliage which is very light, e.g., many caespitose graminoids are liable to have their leaves blown around by wind (1). In addition the shading effect of the almost hair-like leaf tips can only be minimal. However when growing in a clump, the leaves have a tendency to interlock (2) ensuring a more stable shaded beneath them, as well as increasing the amount of shade where the foliage of more than one plant occurs over an area of ground at once.

Of the two species with only an ambiguous impact, the *Iris sibirica* does little to shade the ground (GC+SE of only 10), likewise the *Lysimachia punctata* (GC+SE of only 12). Both are interesting to consider in the context of this trial. *Iris sibirica* is noted elsewhere in this study as being extremely resilient in horticulture, despite not having traits which might make it a strong competitor (see *7. An Analysis of Plant Traits and Characteristics*). *Lysimachia punctata* is noted as being one of the most competitive garden ornamental perennials, and able to form virtual monocultures outside in competition with native species (see 5.3 of *3. Use*

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[1] Its use in this trial was as a substitute for the unavailable C. dipsacea.

of transects to investigate established ecologically based plantings). It is possible that the *Lysimachia punctata* is disadvantaged in this trial through having, in the first year, a much weaker central clump morphology than the other species used (see below *Implications of initial subject plant size on performance*). It is also possible that this species is slow to establish (although this unlikely, see discussion below), and is an effective competitor through an additional aspect to those so far discussed; this species is tall enough (1-1.5m), with enough foliage density to effectively shade the ground, although it has minimal shading of the ground early in the year (GC + SE = 12, i.e. low); it is suggested that the rapid production of rhizomatous roots followed by new ramets in a guerrilla fashion, enables this species to dominate space quickly by a multiplier effect, i.e. moderately effective shading and root competition is multiplied by not only the increase in numbers of root/shoot material but also in their dispersal. There is a clear distinction with the other species here with a similar above-ground architecture (the *Aster cordifolius*, *Helianthus* 'Lemon Queen', *Solidago rugosa*); whilst the latter three produce ramets to form a tight clump, this *Lysimachia punctata* species produces long rhizomes - in the first year after transplanting this is probably a disadvantage as there is little opportunity to monopolise resources below ground or to cast much effective shade above ground, but thereafter, it could be an advantage, as it would enable the plant to extract resources from a wider area than species with tight clumps and to cast shade over a wider area, i.e. to become a more effective competitor.

It is noted that when harvesting the *Achillea* from the plot where it was growing in competition with the *Lysimachia punctata*, it was very much more difficult to distinguish amongst the Achillea, which ramet belonged to which parent *Achillea* clump, than in the other plots – suggesting that competition with the *Lysimachia punctata* had disrupted and limited the phalanx clonal spread of the Achillea. It is also noted that although the biomass of the *Lysimachia punctata* was substantially less in the Achillea plot, that shoot numbers indicated the potential of the plant to spread and compete more effectively in the next growing season. In the case of this plot, the number of what appeared to be mature *Lysimachia punctata* shoots (well-developed, with senescent lower leaves) had increased from 45 to only 52, whereas in the control plot the increase was from 45 to 75; however the number of young shoots was more or less the same for both (27 and 29 respectively); in both cases also, some young shoots were observed at the very limits of the plot square.

Lysimachia punctata clearly has an effective guerrilla strategy, the distribution of ramets in the plot with the Achillea and the control was similar – nevertheless the fact that its growth was considerably limited by the Achillea in this first year suggests that the two species might possibly achieve some sort of balance. The Achillea has a strategy which combines guerrilla outlying ramets which is followed up by a solid mass of ramets – the fact that both produce guerrilla ramets allowing for a relatively fine-textured integration of the two further suggests that it might be possible for the two species to achieve some sort of equilibrium in some circumstances.

Schmid & Bazzaz 1987 report that severing root connections in species with widely spreading roots has little effect on growth, Schmid & Harper 1985, that such species are likely to dominate in early stages of succession. It seems likely then that *Lysimachia punctata* is a species with traits, which enable it to establish rapidly in vacant sites.

6.4.3.3 Species with no significant suppression of phytometer growth

Two species, *Baptisia australis* and *Bergenia cordifolia*, appeared to have no impact on Achillea growth, and to be substantially affected by the Achillea.
The *Baptisia australis* is noted as being slow to establish, but very long-lived and resistant to competition once mature (see 'Caespitose-type habit in forbs and the resource conservation strategy' in *7. An Analysis of Plant Traits and Characteristics*) (Cullina 2000, Gerritsen & Oudolf 2003). Despite the major impact of the Achillea on its growth, what stands out from the *Baptisia australis* performance is that the number of shoots is virtually the same for the plot with the Achillea and the control (32 and 34 respectively). Shoot numbers are determined early in the year, as no new basal growth is observed after initial growth (see *Perennial Data Table* 7.6.1 Appendix 1. in *7. An Analysis of Plant Traits and Characteristics*); competition with the Achillea resulted in poor shoot growth, but not elimination. The low GC+SE value of the *Baptisia australis* (8) suggests that its ability to suppress competition through shading is very limited; its ability to continue to produce tip growth through the summer (see *Perennial Data Table*) suggests that resource allocation to roots through expanding the photosynthetic area well above ground level can continue after the phase of initial shoot production in spring. If the 'caespitose-type' habit model is correct, and this species is able to store resources in some way (almost certainly in an extensive root system), then it may well be in a relatively strong position to compete in the next growing season. This is supported by Weaver 1968 who notes that development of many species is slow in early years – with an emphasis on belowground growth, but slow growth above ground.

It is suggested that the apparent ability of the Achillea to partly suppress growth with the *Baptisia australis* and the *Lysimachia punctata* illustrates that both these subject species are unable to show effective competitive effect or response during this first year – not only do they not compete effectively with the Achillea but they are out-competed by it. The known performance of *Lysimachia punctata* as an extensive clump-forming plants and *Baptisia australis* as a long-lived species indicate that in the case of both, competitive effect and response improve with time. In the case of the former the rapid production of ramets, possibly linked to a linked extensive root growth is the key, with the latter, effect may not be as important as response, i.e. the plant may not ever show effective competitive effect, but its ability to survive shows effective competitive response – possibly through investment in roots. Many prairie species do have very extensive root systems (Weaver 1919). A summary of the hypothesis that partition of resources varies between herbaceous plants is given in fig. 6.4.

The vigorous growth of the Achillea in the *Bergenia cordifolia* plot is perhaps also the result of the relatively slow growth of the *Bergenia cordifolia* – the almost woody stems suggest that resource allocation to stems might slow production of new foliage. GC + SE for *Bergenia cordifolia* is moderate to high (24), but leaves are held at an angle which does not maximise shading of the ground and hence are possibly less effective at limiting competition. MacKenzie 1997 and Thomas 1970 both recommend *Bergenia* species for ground cover, and in the UK they are amongst the few herbaceous species used for ground cover; it is possible that once established and planted at a high density, they perform well enough against competition to make them feasibly resistant to weed incursion. Indeed it is possible that *Bergenia cordifolia* species may illustrate another variant of the 'caespitose-type' habit – not through conservation of resources within the environs of a tight habit and possible extensive root system but through storage of resources in semi-woody stem tissue and over wintering leaves.

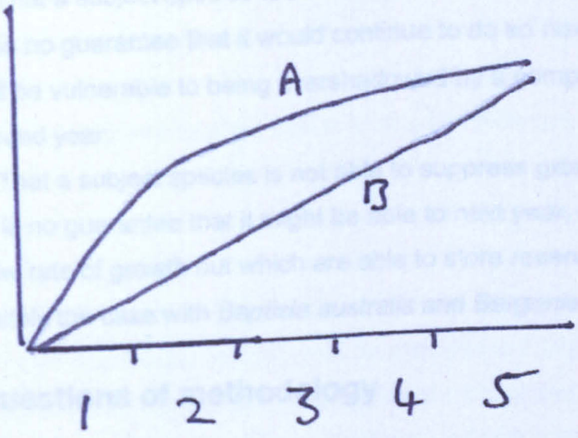

Fig. 6.4

Slow to establish species and the limitations of aboveground observation

x axis = number of years
y axis = above ground biomass

Most forbs in ornamental horticulture grow rapidly from seed in their first year, producing considerable aboveground biomass (trajectory A). Some species, such as *Baptisia australis*, do not, appearing to grow at a slower rate (B). This may be illusory, as partitioning may result in higher proportions of belowground biomass in B, invisible to the aboveground observer; i.e. if x = total biomass, A and B might be equal.

6.4.3.4 Mollusc predation and its implications

Although this trial experienced only very low predation from molluscs, with a very small sample size, it is worth noting that the most severe damage to the Achilleas occurred with the *Carex comans* and the *Phlomis russeliana*, which had the most effective ground cover during the spring; it is possible to surmise that this provided good mollusc habitat. This raises the possibility that a potentially important element of competition in herbaceous plantings is the ability of some species, with low mollusc palatability, to compete through providing shelter for molluscs, enabling them to predate more palatable competitors.

It is noted that during harvesting the plots, the only molluscs found were beneath one of the *Carex comans* plots (1 small slug) and the *Phlomis russeliana* + Achillea (6 small slugs).

6.4.4 Limitations of the one-year trial

A trial during the period of one growing season clearly only assesses what happens during that period. More specifically, it does address the following issues:

1. That many weedy species which cause problems in maintaining herbaceous plantings (in the British Isles) are wintergreen, and so able to photosynthesise and build up nutrient reserves whilst nearly all ornamental perennials are dormant.

2. That a subject species is able to dominate and suppress growth of the phytometer one year is no guarantee that it would continue to do so next year; short plants in particular might well be vulnerable to being overshadowed by a competitor with a higher canopy height in the second year.

3. That a subject species is not able to suppress growth of the phytometer species in one year is no guarantee that it might be able to next year, or indeed the year after – species with a slow rate of growth but which are able to store reserves effectively and cumulatively – as is possibly the case with *Baptisia australis* and *Bergenia cordifolia.*

6.4.5 Questions of methodology

6.4.5.1 Phytometer species selection

The use of *Achillea millefolium* 'Galaxy Hybrids' was vindicated by the Montpelier Cottage trial: plants performing well and consistently – it is noteworthy that only 3 out of 204 (1.47%) plants actually died during this trial, in each case almost certainly the victim of competition – this indicates that the taxon makes a good phytometer – a species which died under in conditions of less than extreme stress would be a poor recorder of the whole range of stress. Harvesting proved relatively quick and easy, the only problem being that sometimes it was difficult to distinguish which ramets originated with which plant as outermost ramets tend to emerge from underground roots; however these are nearly always clearly angled with respect to the ground surface, making it relatively easy to see the direction from which the ramet has come, and thus to locate the parent plant. The use of the taxon for trials of more than one year, may be difficult, as it would then be much more problematic working out ramet origin. The different flower colours present in the plant, and the degree to which they are partially preserved in dead flowers, also assists in separating out plants.

6.4.5.2 Differential ecological requirements in trialling plants

The Pershore trial raises questions about how to trial plants with different ecological requirements, specifically the reduced performance of the helleborus and macleaya species being trialled. The former's foliage damage through exposure/desiccation was the result in growing in conditions too far removed from its ecological optimum (Crawley 1997b) – therefore trialling it alongside a species nearer its ecological optimum is not a 'fair' trial. Given that a great many ornamental herbaceous species are ecological generalists (especially those in this whole study) this is possibly not a major problem for trial design. However it does suggest that care needs to be taken to grow subject species in situations where good horticultural practice would suggest they be planted to avoid facing inclement conditions. There is also an issue here for the selection of appropriate competitor/phytometer species, as these need to be as generalist as possible, in order to be able to make fair comparisons in different conditions. *Achillea millefolium* and its hybrids do flourish in light shade well enough to suggest this species and its derivatives are generalist enough to be able to use as competitors/phytometers in a reasonably wide range of light conditions, although the species rarely grows in shade in natural conditions (Klotz et al. 2002).

Frost damage to the macleaya in the trial raises a different question. Macleaya taxa in cultivation are observed to grow well in a range of different soil compositions and levels of moisture – they are undeniably generalists. They are however sensitive to frost, so arguably they are beyond their climatic ecological optimum in the British Isles; light frost causes almost total loss of young foliage – clearly a competitive disadvantage. It is noted that at Cowley (see 3. *The use of transects to investigate established ecologically based plantings*) *Macleaya cordata* completely disappeared from a border where it faced higher levels of competition than is normally found in garden borders. Unlike the growing of helleborus taxa in exposed conditions, which is not regarded as good horticultural practice, the growing of macleaya in situations where frost frequently defoliates it in spring is an accepted practice. The difference in terms of visual outcomes, is that macleaya damage is temporary (the plants grow new shoots within weeks of frost damage, helleborus foliage damage is visible until new leaves are grown next winter), and that plants are expected to recover from it, in the conditions of the conventional border. In EBPS however competition is higher, and the loss of foliage may be expected to reduce their survival rate (see *4. Investigating the growth of ornamental herbaceous perennials in grass swards*). The realised niche (Crawley 1997b Burrows 1990) for such species may be expected to be narrower for EBPS than for species with more frost-hardy foliage. In a trial, such factors will inevitably reduce species competitiveness. However, it needs to be pointed out, both with regard to both the macleaya's frost sensitivity, and the sensitivity of helleborus to desiccation damage, that both are dependent on weather conditions, which needs to be borne in mind when evaluating trial results, as a year when damaging weather conditions do not occur, may give a false impression of plant performance, for that particular location.

6.4.5.3 Planning open ground trials

Increasing the number of plots for each species being evaluated and scattering them randomly over the test site, as is normal in agricultural research, would give a sounder result, although the trade-off for busy practitioners is that there would be less space or time for the evaluation of a larger number of taxa.

Possible inconsistency in the soil across the area used for this trial is possibly illustrated by the anomalous growth of the *Aster cordifolius* and the *Solidago rugosa*, the former producing more than twice as much growth in the plot *with* the Achillea, whilst the *Solidago rugosa* grew only around half as well in the Achillea plot (Achillea growth was markedly reduced by both these subject species, that with the *Solidago rugosa* by nearly 90%. It is surmised that differences in soil fertility or nutrient availabity may have been the reason for these results. Along with the *Helianthus* 'Lemon Queen' and the *Lythrum salicaria* (where difference in growth was not significant) these two species produced the most biomass in the trial. Since vigorously growing species tend to be the most sensitive to different levels of nutrient (Grime 2001) it is suggested that the anomaly is explained by a nutrient difference between plots which was most likely to be reflected in growth by plants of vigorous species.

6.4.5.4 Implications of initial subject plant size (equivalence) on performance

As with the container trial (see 5.2 of *Assessing competition with two grasses of contrasting productivity in standardised container culture*) one of the problematic issues with this trial is the possible lack of equivalence of the material used as starter plants of the subject species. On this occasion, the use of rooted cuttings of equivalent age was considered. However it was rejected on the grounds that not all species used here can be grown from cuttings – and in the case of the *Alchemilla mollis* and the *Phlomis russeliana* species used, attempts at taking propagating material from ground-level stem material still faces the problem of their being a huge variation in the size, level of maturity, and possible nutrient reserves of cutting material used. In addition the size of possible cutting material between different species varies greatly – that of *Phlomis russeliana* being particularly large. However it could be argued that this is itself a factor in competition in garden conditions.

One additional issue needs to be raised, that of plant compactness at planting time – *Lysimachia punctata* has very wide-ranging ramets, which are more readily damaged when preparing for planting – the plant loses its cohesiveness, which may disadvantage it.

One possible answer to the problem of initial equivalence is to grow all plants in containers for a year before trialling, thus ensuring a more equal starting size. The break-up and damage of loose ramet-based systems would also be avoided.

6.5 CONCLUSIONS

This trial can be regarded as useful for two sets of reasons.

Firstly it indicates that a simple and easy to manage trial can produce clear results which may be of considerable value to practitioners, even though the methodology might be regarded as not rigorous enough by those in the scientific ecology community. The development of trial methodologies accessible to practitioners could potentially play an important role in encouraging those in the field to begin to evaluate and record plant performance – at the moment very little systematic work on performance is being carried out.

Secondly, the trial indicates a number of factors, largely related to morphology, which appear to relate to the ability of ornamental herbaceous plants to compete effectively in productive environments.

6.5.1 Methodology

- The usefulness of *Achillea millefolium* 'Galaxy Hybrids' as a phytometer is confirmed, in that it is reliable, with a very low death rate, thus enabling it to accurately measure competitive pressure.
- Suppression or delaying of flowering of *Achillea millefolium* 'Galaxy Hybrids' would appear to be a good indicator of competitive suppression of this taxon
- The correlation between a clearly visible reduction in growth, and/or reduction/delay in flowering in *Achillea millefolium* 'Galaxy Hybrids', with a reduction in growth as measured by end-of-season dry weight, suggests that practitioners wishing to undertake crude qualitative evaluation of the likely competitive effects of herbaceous perennials could use the methodology discussed here.

6.5.2 Factors favouring competition amongst species studied

- Species with high biomass are indicated as showing more competitive potential.
- Root competition is indicated as a very important component of competition.
- Large, wide spreading, low-level leaves enhance competitiveness.
- Species with wide-spreading foliage may achieve a 'multiplier effect' in enhancing competitiveness through ground shading when planted together.
- The role of unequal mollusc predation is recognised as an additional factor in competition.
- Slow-growing species, and those with widely distributed guerrilla ramets appear to be less competitive in the first year.

6.6 FUTURE RESEARCH

6.6.1 Trialling older, more established plants

One possibility would be to continue the trial next year using the existing plants to measure the extent to which the subject species continued to affect the growth of the Achillea phytometers. However this would not provide a fair trial of any wintergreen species. The Achillea taxon used makes some growth during the winter – it is effectively wintergreen itself, so the reduced ability of wintergreen species to compete because they have had their foliage harvested would make this an invalid comparison with deciduous species.

The effect on competition of subject species of various sizes and ages could be evaluated by repeating the trial with larger plants of the subjects – 2 or 3 year old container grown plants. Such a trial would evaluate the level of competitive pressure they could exert on potential weeds at different levels of establishment – such a trial would be a useful measure of the effects of weed incursion on herbaceous plantings at various times after initial planting.

6.6.2 Root competition

The level of root competition as against competition through foliage is essentially about competition for moisture/nutrients as against light. Whilst the species which in this trial achieved a high level of effective competition (e.g. *Helianthus* 'Lemon Queen') through what appeared to be root competition linked to high biomass, it cannot be assumed that this will translate into effective competition in horticultural situations; it is known from experience that very few ornamental perennials can compete effectively with rough grass (see *Investigating the growth of ornamental herbaceous perennials in grass swards*) – this suggests that competition from wintergreen weedy species is fundamental in reducing non-wintergreen perennial growth where the two are allowed to compete. Further investigation of the efficacy of root competition vis a vis competition for light through the shading effectiveness of foliage is needed. This could take the form of measurements of moisture and depletion of available nitrogen beneath subject plants.

6.6.3 Planting design and the multiplier effect

The fact that some species evaluated formed blocks of foliage which gave very effective ground cover indicated that further work could be carried out to assess whether:

- Block planting is inherently more effective at weed suppression than the intermingling of different species
- The combination of several different species with approximately similar foliage architecture might achieve a similar result
- The combination of species with radically different architecture might be possible, in order to achieve a balance of functional maintenance objectives (suppression of weeds) with aesthetic ones (an attractive mix of species providing a long season of interest).

6.7 APPENDICES

contents:

6.7.1 APPENDIX 1. Open Ground Trial (Pershore), Planting Details

OPEN GROUND TRIAL (Pershore)		
	origin	**plant size and notes**
Alchemilla mollis	pot	9cms pot
Aster cordifolius 'Little Carlow'	BR	6-10 shoots, root mass varied considerably
Astrantia major	BR	large clump fibrous roots,very variable 7-15cms across, 1-5 shoots, very variable in root mass, impossible to separate ramets or pare down
Astrantia major, seed grown	pot	1L pot, not well rooted in
Baptisia australis	pot	9cms pot
Bergenia mixed hybrid, seed origin	pot	9cms pot
Carex buchanii	pot	9cms pot
Cirsium canum	pot	9 cms pot
Echinacea purpurea	pot	9cms pot
Echinops ritro	pot	9cms pot
Filipendula ulmaria	BR	7.5-9cms across
Geranium x oxonianum 'Claridge Druce'	BR	6 shoots >7mm diameter
Helianthus 'Lemon Queen'	BR	+/- 6 shoots, very variable in root mass
Helleborus x hybridus	pot	3L pots
Iris sibirica	BR	7.5-9cms across
Knautia macedonica	pot	3 L pots
Lysimachia punctatum	BR	roots 7-10cms long, 3 large shoots to 7 shoots of mixed size - total 45 *visible* shoots
Lythrum salicaria	pot	9cms pot, barely rooted plugs
Macleaya microcarpa	pot	9cms pot
Nepeta x faassenii	pot	9cms pot
Ophiopogon bodinieri	BR	*robust clumps*, runners removed
Persicaria bistorta	pot	11 cms pot
Phlomis *russelliana*	*pot*	9cms pot
Salvia nemorosa	pot	9cms pot
Solidago rugosa	BR	9-12 cms wide clumps, > 10 shoots
	BR = Bare Root	

6.7.2 APPENDIX 2 Open Ground Trial (Montpelier Cottage), 2007. Planting details.

	origin	**plant size and notes**
Alchemilla mollis	BR	fist-sized divisions
Aster cordifolius 'Little Carlow'	BR	6-10 shoots, root mass varied considerably
Baptisia australis	pot	1 yr seedlings, 9cms pot
Bergenia cordifolia	pot	1 yr seedlings, 9cms pot
Carex comans	pot	1 yr seedlings, 1L pot
Geranium x oxonianum 'Claridge Druce'	BR	6 shoots >7mm diameter on half-fist sized clumps
Helianthus 'Lemon Queen'	BR	+/- 6 shoots, very variable in root mass
Iris sibirica	BR	*clumps 7.5-9cms across*
Lysimachia punctatum	BR	roots 7-10cms long, 3 large shoots to 7 shoots of various sizes. Total of 45 obvious shoots per plot.
Lythrum salicaria	pot	1 yrs old transplanted seedlings
Nepeta x *faassenii*	pot	9cms pot
Phlomis russelliana	pot	*fist-sized divisions*
Solidago rugosa	BR	9-12 cms wide clumps, > 10 shoots
	BR = Bare Root	

6.7.3 APPENDIX 3 Open Ground Trial (Montpelier Cottage), Visual assessment, 22.July.2007.

	Bare ground visibility	**No. in flower**	**Average max. height of achilleas - mm**	**Visual assessment**
Aster cordifolius 'Little Carlow'	1	10	790	reduced fl., increased ht.
Alchemilla mollis	2	10	560	reduced fl. reduced ht.
Baptisia australis	4	12	660	no difference to control
Bergenia cordifolia	3	11	700	no difference to control
Carex comans	1	4	530	reduced fl. reduced ht.
Geranium x oxonianum	1	9	640	reduced fl. unaffected ht.
Helianthus 'Lemon Queen'	1	3	760	reduced fl. unaffected ht.
Iris sibirica	4	9	660	reduced fl. unaffected ht.
Lysimachia punctatum	3	12	750	no difference to control
Lythrum salicaria	2	5	860	reduced fl. increased ht.
Nepeta x faassenii	1	7	670	reduced fl. unaffected ht.
Phlomis russelliana	1	4	520	reduced fl. reduced ht.
Solidago rugosa	4	7	530	reduced fl. reduced ht.
Control				
Achillea hybrids (1)	2	12	750	
Achillea hybrids (2)	3	12	710	
Achillea hybrids (3)	2	12	680	
Achillea hybrids (4)	3	12	640	

6.7.4 Appendix 4 - Open Ground Trial, Montpelier Cottage. End-of-season dry weights of achillea phytometer when grown with 13 herbaceous perennials. *(on CD)*

6.7.5 Appendix 5 - Open Ground Trial, Montpelier Cottage. Dry weights of subject plants in open-ground trial, grown in conjunction with *Achillea millefolium* phytometer and controls (ie. without *Achillea*). *(on CD)*