INTEGRATED CROP MANAGEMENT OF SRC PLANTATIONS TO MAXIMISE CROP VALUE, WILDLIFE BENEFITS AND OTHER ADDED VALUE OPPORTUNITIES

ETSU B/W2/00400/REP

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Objectives

The primary objective of the work described in this report is to develop an Integrated Crop Management (ICM) approach for SRC willow and poplar crops. The work was funded by the DTI through ETSU over a four year period. The key component of this approach is a low input Integrated Pest Management (IPM) strategy for weeds and insect pests. This aims to minimise the cost and effort involved in high yielding crop production and hence maximises profitability, while also maximising the value of these crops to wildlife.

The work undertaken in this report does not in itself provide a complete ICM system for SRC. There are large areas of crop agronomics and disease control, for example the use of fertilizers and the management of rust, that have been considered by others. Furthermore, ICM systems are also continually developed and refined with changing circumstance and new knowledge.

Background

SRC was conceived as a low input crop system and as research has developed it is clear that the profitability of this crop depends on it. The main disease threat to SRC is rust. Work already indicates that fungicide applications to control rust would usually be uneconomic and developments have concentrated on natural control agents, rust avoidance and impact minimisation through plantation design, in particular the strategic use of mixtures.

With respect to weeds, previous research indicates that in newly planted SRC crops, control is essential and that herbicide applications are the best method of managing these weeds. For established SRC crops however, the development and effect of weed competition, and the need for weed control, is less clear and it is these issues that are investigated here. Regarding insects, previous surveys and anecdotal information suggest both willow and poplar SRC are prone to defoliation, although less obvious insect problems can occur. In this study we reassess the pest situation in current plantations, investigate the ecology of these pest species and develop a range of methods to manage them below economic thresholds.

We have also developed our understanding of the use of this crop by wildlife, following on from our previous work (ETSU B/W5/00277/REP). This work is important because an ICM approach contributes very little beyond a conventional crop management system if it does not take account of the impact to other plants and animals using the crop.

Summary of work carried out

The work described in this report is based primarily on field-based surveys, monitoring programmes and experimental trials, which have been undertaken in existing SRC plantations throughout Britain and Ireland. Occasionally, in collaboration with site owners or managers, we have adapted the original purpose of some sites to the needs of this study through, for example, altered cutting regimes.

Since 1994, when the current research programme began, we have visited and investigated most SRC sites in Britain and Ireland, to assess their suitability as study sites, an estimated 234 ha of SRC at 60 sites. SRC plantations planted since then have not usually been relevant to our research, which concentrates on the ecology of established plantations.

Of these 60 sites, by the end of 1997, we had undertaken occasional sampling and surveying work in around 60 – 80 ha of SRC at 30 sites, intensive sampling and surveying work in over 20 ha at 8 sites and experimental trials in another 20 ha at 6 sites, a total of 36 separate SRC sites, and including over 120 ha of SRC. These figures are not total site areas, but plot areas covered directly by surveys, monitoring, or experiments. During the course of the study we have also made substantial direct contributions to the design and layout of 16 ha of new SRC plantings at 4 sites. We have also used SRC plantations in Sweden and Denmark.

The field-based research programme undertaken at these sites and described in this report has involved the following studies:

- Silvicultural - SRC crop leaf area and defoliation surveys, methodology development of non-destructive yield assessment of SRC biomass, a trial to assess the effect of wind exposure on crop growth, and surveys to quantifying the structure and shadiness of SRC crops.

- Entomology - Intensive and extensive crop canopy invertebrate surveys – biodiversity and pest potential, chrysomelid spring dispersal trapping and edge colonisation monitoring, overwintering mortality assessments, investigations of chrysomelid predation and parasitism, ground beetle surveys and pest predation observations, an investigation of the effect of defoliation on yield, monitoring to assess clonal selection and colonisation sources by chrysomelids, and studies of stem aphids.

- Other wildlife - Songbird repeat-visit bird censuses, radio-tracking studies of snipe in SRC, pheasant and partridge use survey, winter songbird-use surveys, studies of songbird predation of insect pests and the accumalation of anecdotal information on use by other wildlife.

- Botany - Within-crop ground flora introduction trials, headland ground flora introduction trials, weed effect on crop growth trials, within crop extensive ground flora surveys.

This report, documenting these studies, is split into 22 sections falling under the four main themes, or groups of sections, as indicated above and in the Contents. Each section contains an introduction, a description of the methods used and the results, followed by a discussion of the work in the context of work by others. A summary of the main findings is provided at the beginning of each section. At the end of the group of sections under 'Invertebrates' there is a review section (13.0) which discusses an IPM approach to insect pests in SRC. Similarly, at the end of the 'Ground Flora' group of sections there is another review section (22.0) on an IPM strategy for weeds. In the context of the Introduction (Section 1.0) and the Executive Summary, these two sections represent a useful starting point for the reader.

Results

For weeds, we found through extensive surveys that plant communities in SRC tend to become less competitive with time as stable perennial species replace the invasive ruderal species that characterise disturbed ground are replaced by more. The use of contact herbicides after cut-backs, slows this process. In an intensive flora introduction trial, weeds similarly decreased in percentage cover while the introduced perennials increased over the three year study period.

In established willow coppices planted under typical conditions, the tolerance of the crop to weediness, and hence the economic threshold for taking action to control weeds, is high. Unless a complete ground cover of weeds above around knee height (or patchy weeds at increasing heights in proportion to the reduction in ground cover) is achieved, it is possible that a herbicide applications after cut-back will not lead to a cost-effective increase in yield.

Weed competition in recently cut but established coppice, may be affected primarily by competition for light and space in spring. In this case, where weeds are abundant, a knock-back by cutting weeds in spring may be sufficient, although this has not been tested.

These results indicate that the occurrence of other plants within these crops can be tolerated without compromising cost effective crop production, and that in time, a reduction in the proportion of invasive ruderal weed species and an increase in the less-competitive shade tolerating perennial flora will develop. This will have considerable benefits to wildlife use and potentially crop profitability as part of an ICM approach.

For insect pests, leaf eating beetles (chrysomelids), were identified as the main group of pest species of SRC in Britain. Sawflies, certain midge species and stem aphids were also identified as potential pests. We found that the abundance and diversity of insects in SRC crops (especially willow) was high compared to other crop types. This combined with the existence of potentially beneficial insect species, means that the environmental cost of overall insecticide applications in these crops would be very high.

Defoliation in UK SRC sites is caused primarily by chrysomelids although some individual sites are affected more by other species. During the course of the study, several sites were continually defoliated by more than 20% and some of these showed signs of stem die-back. The literature suggests that yield losses are proportional to defoliation and our studies of growth rates identified reduced stem extension with defoliation. Economic thresholds for chrysomelids have not been defined but an ongoing experiment should provide further information on this.

SRC sites that are planted near to certain free-living willow or poplar trees, have a high risk of repeated colonisation by chrysomelids. These sites can either be avoided, or plantations designed to minimise the impact of chrysomelid attack. High risk sites can be planted with species or varieties that are not susceptible to a locally abundant beetle species or the strategic use of highly suscetible willows could be used in sacrificial plantings (see below).

We found several insect species in existing SRC plantations that eat or parasitise chrysomelids and other potential pest species. The activities of these naturally occurring predators and parasites can be increased through silvicultural practices, particularly by managing the ground flora within and adjacent to plantations sypathitically. Where other methods fail, and large chrysomelid populations develop over several years, targeted insecticide sprays can be employed in the crop edges during the spring, when chrysomelids are re-colonising plantations from their over-wintering habitats. The strategic use of susceptible varieties, and by leaving islands of uncut coppice in cut plantations to trap and concentrate colonising chrysomelids, populations can be manipulated into certain parts of fields if necessary.

Intensive studies on the use of SRC crops by birds provided further data on the contribution these crops can make as wildlife habitat in farmland ecosystems. We document the use of certain SRC sites in the winter by partridges, pheasant, snipe and by winter passerine flocks. Intensive repeated spring surveys over three years at one site, provided details of territorial use and age class selection of SRC by breeding songibrds, some of which are of high conservation concern. At another site, we document the predation by breeding songbirds of insects feeding on the coppice canopy. These studies highlight some of the reasons these game and wildlife groups use SRC, facilitating sympathetic management as part of an ICM strategy. This includes the use of age class mixes within fields or between adjacent ones, and the importance of low ground cover and insect diversity.

Linking SRC with existing scrub and woodland habitats and hedgerows can effectively extend these habitats for some wildlife groups. A trial designed to quantify the effect of exposure on crop growth, and hence to encourage these planting practices, indicated that SRC yields would probably increase with increased shelter but the findings were not conclusive.

During the course of other studies, we collected data certain seasonal growth characteristics of SRC. We identify typical leafing times of willow and poplar, changes in the canopy density in terms of leaf area and shadiness throughout the season, and stem extension characterisitcs. We also present some biomass data over one and two years, for 10 different willow clones grown in large established non-experimental plots.

A non-destructive method of assessment of SRC biomass, involving simply the measurement of stem diameters of a predetermined number of coppice stems, was found to be sufficiently accurate for most assessment purposes requiring relative biomass. In this study the method was used to compare the growth of different varieties and different weed management regimes within a plantation.

Conclusions and Recommendations

We conclude from this work that there is considerable scope to manage SRC using an ICM approach. The key component is an Integrated Pest Management (IPM) strategy for weeds and insect pests in established SRC plantations. In particular, the economic threshold work on weed competition in established coppice, and the range of practical management tools for chrysomelid populations, should lead to reductions in the risks to production associated with these pests, and consequently a realistic expectation of significant reductions in the need for and hence use of pesticides. Through cost benefit analyses, we expect this low input IPM approach to weed and insect pest management in SRC to minimise the cost and effort involved in crop production without compromising yields. We also expect the approach to maximise the value of these crops to wildlife.

We also conclude that SRC, in particular willow, has a greater potential to increase the diversity of wildlife using farmland habitats than other row crops. Diverse plant communities can be allowed to develop within and around plantations without compromising production considerations. Insect diversity in the coppice canopy alone is high, and the whole insect community in plantations is substantially increased where other plants occur. Other wildlife groups, particularly birds but also some mammal species are also well represented in these crops, again, especially if other plants occur. These benefits may extend beyond the SRC, increasing the wildlife use of adjacent crops and hence further increase the biodiveristy of the whole farmland ecosystem.

As part of an ICM approach, we would recommend, for proposed SRC plantations:

- an assessment of the potential for insect pest problems, particularly chrysomelids;

- an assessment of the potential for weed problems, and opportunities for colonisation sources by other plants;
- an assessment of existing wildlife value at the site, and the associations between the proposed site and other nearby scrub and woodland habitats including hedgerows.

When designing and planting a new plantation:

- avoid sites with high existing wildlife value;
- include rides and headlands and link plots with existing scrub and woodand habitats;
- incorporate several different age class blocks within large fields;
- avoid sites with a high risk of chrysomelid infestation if possible;
- otherwise facilitate easy monitoring and management of chrysomelids through the strategic use of varieties, cutting regimes and layout;
- use contact and residual herbicides at establishment if necessary;
- incorporate varietal mixtures that minimise the impact of rust.

In terms of ongoing management of established plantations:

- monitor and keep records of insect and weed pest populations;
- calculate economic thresholds before considering any pesticide applications;
- simple relative biomass assessments can be made non-destructively;
- where weed problems occur, use local herbicide applications rather than overall sprays;
- undertake silvicultural practices in and adjacent to plantations that maximise the wildlife and game potential;
- encourage beneficial pest controlling plant and insect species;
- harvest blocks within fields on rotation to create an age-class mix;
- if necessary, use edge-sprays to control severe chrysomelid invasions;
- overall insecticide applications are not recommended in any circumstances.

1.0 INTEGRATED CROP MANAGEMENT IN SRC – INTRODUCTION

Over the last thirty years or so, Britain's agricultural landscape has dramatically changed through intensification. The continued increase in the use of pesticides, particularly insecticides, and the removal of boundary habitats to make bigger fields, have caused substantial reductions in the abundance and diversity of all wildlife groups in farmland ecosystems. Even in the 1990's, further increases in the use of insecticides on arable crops have been implicated in the most recent declines of several familiar songbird species.

Agriculture is constantly changing and reforms to the CAP are on the horizon. As cereal prices fall, farmers review their production methods to try to reduce production costs. It is apparent that the intensive crop management practices, which not only have negative effects on the wildlife use of the wider countryside, sometimes fail in their objective of providing cost effective crop production under these circumstances. It is this observation that provides the opportunity to develop alternative, practical crop management systems that have their feet firmly in economic crop production, but which also take account of the wider environmental concerns.

Integrated Crop Management (ICM) is the term used to describe a crop production system that is based on good husbandry and takes account of the impact of farming practices on the ecology of farmland. The intention is to integrate a range of farming practices in order to balance the economic production of crops with measures that preserve or enhance the environment. It is a pragmatic approach that recognises the over-riding importance of crop production and the profitability of the farm, and consequently it does not exclude the use of, for example, pesticides. Most importantly it depends for its success on a good understanding of the needs of the crop and its environment.

In the four-year study described in this report, we have investigated and developed an integrated approach to the management of SRC crops. We have also developed our understanding of the use of this crop by wildlife, following on from our previous work on this (ETSU B/W5/00277/REP; Sage *et al*, 1994). This work is important because an ICM approach contributes very little beyond a conventional crop management system if it does not take account of the impact to other plants and animals using the particular crop. An important conclusion of the work on the wildlife use is that willow and to a lesser extent poplar had the potential to provide habitat for an unusually wide range of plants and animals (compared to other farmland crops), without compromising the production potential. This report has extended this work and has shown that proper consideration of the ecology of SRC crops can lead to improved crop management and a greater efficiency of production.

ICM is also by one definition a whole farm approach. While the relationship between SRC crops, crop headlands and immediate boundary habitats have in many instances been taken into account in this study, the interactions between SRC and other crop types, and the effect of large scale plantations on a regional scale have not been studied. Large scale production plantations, where SRC forms a significant component of the cropping in a region have not yet been developed in this country. Even in Sweden, where SRC production is at its most advanced, fields of willow are local and sporadically planted. We can however make an informed assessment of the likely impacts of large-scale production of SRC for energy and this is discussed in the relevant sections.

The ICM strategy for SRC developed in this study, as with any ICM system, depends primarily on the approach taken to pest management. The principle of integrated pest management (IPM) in its widest sense, is simply to have a range of pest control and management methods available. Usually however, IPM implies a strategy based on stability, that does not aim to periodically eradicate pest species but to manage populations at acceptably low levels. In intensive farming systems, it is difficult to look beyond the use of pesticides. A range of chemical fungicides, herbicides and insecticides have been developed which can be used to kill most unwanted organisms that appear in crops. As already indicated, this does not mean they are cost effective and little account is taken of effect on the farmland environment, particularly in relation to wildlife habitats, and the recurrence of pest problems in the future.

In SRC crops, which attract a considerable diversity of wildlife, and for which profitability depends on low management costs, an intensive approach to crop, and in particular, pest management falls at the first hurdle. This was recognised by ETSU and others when basic agronomic research programmes into these crops first began. SRC not only requires a low input IPM approach, it is also suited to one, for a number of reasons.

The first is that unlike food crops, where cosmetic damage by an insect, fungus or weed is important, and where only a small part of the crop is actually useful, in SRC, substantial damage needs to occur before biomass yields are affected. A small hole in an apple or a tiny reduction in the growth of a cereal grain can dramatically affect the value of that crop. This means the economic threshold to pest damage, which balances the value of the loss in crop value with the cost of preventative action, is low in these crops. In SRC, the economic threshold to pest damage is relatively high. The whole crop is useful and severe pest damage needs to occur before yields are sufficiently reduced to warrant the expense of say, an insecticide.

The second is that SRC crops provide a relatively stable habitat for other plants and animals, compared to other crops such as cereals, which are typically destroyed and replanted on an annual basis. This means that the naturally occurring control agents of the pest species are provided with an environment in which they can colonise and develop, alongside the pest species. The importance of these beneficial species, particularly in relation to insect pests and diseases, is becoming increasingly evident in other crop ecosystems, and enhancing the abundance and activities of these species forms a key part of any low input, integrated approach to pest management. This has been important component of research by the Farmland Ecology Unit at The Game Conservancy Trust for many years.

An integrated approach to pest management (IPM) is then, an important goal for SRC crops, and should form the central plank of an ICM strategy. An IPM approach in SRC needs to use pesticide minimisation as guiding principle, although as already indicated it does not exclude their use. In terms of diseases of SRC crops, which have not been studied here, work already indicates that fungicide applications to control rust would usually be uneconomic and developments have concentrated on natural control agents, rust avoidance and impact minimisation through plantation design, in particular the strategic use of mixtures.

Consequently, the principle aim of this study has been to develop an IPM approach to weed and insect pests in SRC. To do this we needed to first identify the main pest groups, understand when they actually become damaging and to consider their management in the context of the other plants and animals using the crop. We have also considered some wider aspects of ICM in SRC, for example factors affecting wildlife habitat potential, other agronomic considerations affecting growth and non-destructive yield assessment methods.

2.0 SRC STUDY SITES

Between 1993 and 1996, The GCT visited almost every SRC site that was at least one year old in Britain and Ireland. At the beginning of 1995, our site records indicate that there was an estimated 234 ha of SRC in the UK at 60 sites (this compares to an estimated 90 ha in September 1992 (ETSU/B/W5/00277/REP, Sage *et al* 1994)). We consider this to be a reasonable estimate and included the great majority of plantations of any significant size. Abandoned plantations, or sites that were no longer characteristic of SRC crops for other reasons (e.g. single stem poplars) were excluded.

Since mid 1994, when the current research programme began we have revisited many of these 60 sites, although there has been a process of removal of some experimental plots established under early ETSU research programmes. We have not however, incorporated more recent plantings into either our records, or in most cases, into our research programme. Recently planted SRC was not usually relevant to our research which concentrates on the ecology of established plantations. Our knowledge and records of SRC sites in Britain and Ireland can therefore be considered as a complete record of willow and poplar SRC established before January 1995. We estimate however, that through the activities of a small number of relatively large growers since 1994, in particular Project Arbre, Border Biofuels and Murray Carter & Associates, the area of SRC in Spring 1997 had doubled to approximately 500 ha at approximately 70 sites. This small increase in the number of sites reflects the loss of perhaps 10 experimental plantations over the period. In conjunction with the FC, MAFF have kept records of new plantings via the Woodland Grant Scheme (Pers. comm).

A consequence of this is that this study does not concentrate on recent willow variety releases. The continued use of *Salix viminalis* as the principal parent species in these new varieties means however that the ecology of the SRC plantations, in particular the interactions between the crop and the herbivores has not changed.

During the eighteen months from the start of the project in May/June 1994 and ending December 1995, we undertook occasional sampling and surveying work in 51 ha of SRC at 20 sites, intensive sampling and surveying work in a further 18 ha at 6 sites. Experimental trials occupied 12 ha at 3 sites. During the second half of the research programme, i.e. in the two years ending December 1997, we undertook occasional sampling and surveying work in around 60 ha of SRC at 22 sites, intensive sampling and surveying work in 22 ha at 8 sites and undertook experimental trials in 20 ha at 5 sites. In total, the GCT has conducted its studies at 36 separate SRC sites, and has included directly over 120 ha of SRC. During the course of the study we have made substantial direct contributions to the design and layout of 16 ha of new SRC plantings at 4 sites. All these figures are not total site areas, but plot areas covered directly by surveys, monitoring, or experiments.

Table 2.1 presents a summary of general site information for all the sites used during this study and Table 2.2 provides a list of the work programmes undertaken.

TABLE 2.1 NOT AVAILABLE ELECTRONICALLY

Table 2.2 Survey and trials programme

This table lists the various experimental trials and monitoring programmes associated with this project. The number of sites, annual involvement and collaboration with other organisations, especially Universities through student projects are also indicated.

	Sites	1994	1995	1996	1997	1998
Entomology						
Intensive crop canopy invertebrate surveys[1]	4	X	X	X[1]		
Extensive crop canopy invertebrate surveys	20	X	X	X	X	
Chrysomelid spring dispersal trapping	3		X	X	X	X
Chrysomelid overwintering mortality assessments	2			X	X	
Chrysomelid parasitism[11]	6			X[11]	X[11]	X[11]
Edge insecticide spraying	1					X[4,10]
Ground beetle surveys	2	X	X[7]			
Pest predation observations[2]	2			X[2]		
Effect of defoliation on yield experiment[1]	2				X[1]	X[1]
Clonal selection in field	20			X	X	
Stem aphid studies[8]	2				X[8]	X[8]
Flora						
Within-crop ground flora introduction trials[3]	2	X[3]	X[3]	X[3]	X	X
Headland ground flora introduction trials	3		X		X	
Weed effect on crop growth trials[5,12,13]	1			X[5]	X[12]	X[13]
Within crop general ground flora surveys	21			X		
Birds						
Songbird CBC surveys [6]	2	X[6]	X[6]	X[6]		
Radio-tracking snipe using SRC	1			X		
Pheasant and partridge use survey[7]	1	X[7]				
Songbird predation of insect pests[9]	1				X[9]	
Silvicultural						
Crop leaf area and defoliation surveys[1]	10	X		X[1]		X[1]
Non-destructive yield assessment surveys	1		X		X	
The effect of wind exposure on crop growth trial	1		X	X		
Quantifying crop shadiness	13		X		X	

Work undertaken in conjunction with:

1 Imperial College PhD student, Jeremy Griffiths – separate report available early 1999
2 Imperial College MSc student, Michail Vourdas – report available
3 Wye College plant ecology specialist, Peter Buckley & BSc student, Harriet High – report available
4 Hardi International Ltd
5 Avon Vegetation Research, David Clay
6 Contract surveyors
7 Wye college MSc student, David Baxter – report available
8 Imperial college PhD student, Tilley Collins - report available early 2001
9 Imperial college MSc student, Amanda Sharples – report available
10 Imperial college MSc student, Louise Cranmer – report available January 1999
11 Dundee University PhD student, Peter Marshall - report available early 2000
12 MSc student, Tim Austin, Wye college

13 MSc student, Rebecca Read, Reading University – report available.

3.0 ASPECTS OF CROP GROWTH

3.1 Summary

During the course of other research work within this contract, we collected data on aspects of crop phenology including stem size, biomass accumulation, leaf area and crop height, in response to age-class, coppice species, variety and time of year.

We recorded bud-burst and leafing times in SRC over several years. In southern England willow SRC produced leaves in early April and poplar SRC in late April in each year. In Northern England leafing would be later. For both species, leafing varied by up to two weeks between years. The trigger for leafing is thought to be a combination of day length and temperature.

Following full leaf emergence, actual leaf area, measured on a per m^2 plan of coppice basis, is at a maximum for the season. Both willow and poplar contained around 4 - 7 m^2 of leaf per m^2 of coppice in May, reducing steadily to 2 - 3 m^2 by September. This reduction in leaf area was reflected in a reduction in the mean canopy height or depth and shadiness.

Surveys of crop growth indicate that in the absence of stress or pest attack, increases in stem diameter and length will occur throughout the growing season (April – October). Stem extension however reduces with age class so that year 2 coppice may show no apparent increase in height at all. Data on biomass in one and two-year old coppice is presented for 10 willow varieties.

3.2 Introduction

During the course of other monitoring and sampling work, in particular the invertebrate monitoring programme (Section 7.0) and the weed effect trial (Section 21.0), we collected data on aspects of crop phenology including growth, leaf area and crop height, in response to age-class, coppice species or variety and time of year. These data are presented here.

3.3 Leafing times

Bud burst and leafing in SRC crops in the spring varies between species and varieties and with latitude. We did not specifically monitor spring leaf development at a sample of sites but we have noted leaf emergence on occasions, in particular, during the monitoring of colonisation process of SRC by chrysomelid beetles (Section 12.0). Recording leaf emergence to the day at remote sites can involve significant effort.

At a willow site in Oxfordshire, initial leaf emergence in *Salix viminalis* varieties occurred on or near April 3rd 1995, April 11th 1996 and March 27th 1997. At a poplar site in Avon, leaf emergence in 'Boelare' and 'Beaupre' varieties occurred on April 26th 1995, May 2nd 1996 and 21st April 1997. These data confirm that poplar leaf emergence is later than willow, consistently around three weeks later. It also indicates that leaf emergence varies substantially between years. Variation over the study period was up to two weeks for both species. It was apparent that some variation on leafing times between varieties did occur within sites, particularly for different poplar varieties. Other studies indicate that the trigger for leafing is a combination of day length and temperature, and consequently, leafing times are likely to be later in northern England and Scotland

3.4 Leaf area

Measurements of leaf area were taken in accordance with the methodology described in Section 8.0. The data were collected using a random repeated sampling methodology, based on the random selection and area measurement of 27 leaves per plot and an assessment of the number of leaves per lateral, laterals per stem and stems per stool. These data require considerable effort to collect but provide accurate assessments of leaf area and were collected primarily to quantify defoliation throughout the coppice canopy. This enabled us to calibrate estimation techniques and to identify systematic errors in estimation.

Except on one occasion at one site, leaf area always exceeded 1m^2 per m^2 plan of coppice (Figure 3.1). For both willow and poplar, the figure indicates that SRC plots contained between 4m^2 and 7m^2 of leaf per m^2 plan of coppice following full leaf emergence in mid to late May. The area of leaves declined steadily during the summer to typically 2m^2 or 3m^2 in early September, before autumn leaf fall. This steady decrease in leaf area is reflected in a reduction in the depth of canopy (Section 3.5 below) and a decrease in the canopy shading effect as measured by an increase in the percentage of active radiation penetrating the crop canopy (PAR, Section 5.0). A decrease in leaf area during the summer is typical of deciduous trees in temperate zones and is a response to both increased photo-energy, and to drought stress.

3.5 Stem size

At the intensive invertebrate monitoring sites described in Section 8.0, estimates of mean stem length, stem diameter and canopy height were taken in each plot on several occasions during the year. The data were collected to investigate the impact of defoliation by insects on crop growth but also provide more general information on patterns of crop growth during the summer in various conditions (see Figures 8.1 – 8.8).

The poplar and willow plots at Wishanger (Figure 8.6 & 8.7) both grew steadily throughout the summer with increases in stem length and mid-stem diameter on each visit. The other intensive monitoring sites contained high invertebrate pest burdens and the figures indicates poor or erratic growth over the same period (e.g. Figures 8.2 – 8.4). These data are investigated more thoroughly in Section 8.0. In all cases (eight plots at six site), the mean canopy depth decreased towards the end of the year. This reflects the reduction in leaf area described in Section 3.4 above, and the increase in PAR for SRC during the season, caused by dropping lower leaves (Section 5.0).

At other invertebrate monitoring sites described in Section 7.0, the height of willow and poplar coppices was also recorded during the growing season and are shown in Figure 3.2 & 3.3. These data are standing height (as opposed to stem length). The Figures indicate that in years 0 and 1, an increase in height is observable throughout the growing season. The rate of height increase during the year, and hence annual height increment, decreases with age class for both willow and poplar. For willow, Figure 3.2 suggests no increase in crop height in the study plots in year 2 (for poplar insufficient data were collected to provide a plot) and possibly a slight decrease. This could occur despite increases in stem length, as the coppice becomes less rigid and upright and more prostrate, possibly due to water stress. Biomass accumulation in these older stands is made through increases in stem diameter.

Further data on crop height and stem extension in the first year of coppice growth were collected from the weed effect trial described in Section 21.0. Coppice height was measured in 60 plots covering 10 varieties at the end of June 1996. These data are shown in Figure 3.4. Typically the coppice grew to around 1 m high by that time. The three *S. viminalis* varieties Orm, Bowles Hybrid and Ulv were the tallest. Figure 21.9 indicates that stem extension was actually greater where weeds were present than without The reasons for this are discussed in Section 21.5.

3.6 Biomass data

A large amount of crop growth data were collected during the weed effect trial (Section 21.0). While these data were investigated primarily in relation to weediness biomass increments were related to trial row and hence variety in the various analyses of variance. Biomass and crop height data were collected for ten willow varieties. For each variety, measurements were taken from 40 stools to provide an accurate estimate of biomass. At the end of 1995, the 10 varieties had one-years' growth on two year stools. Mean biomass for all varieties was less than 1 kg (wet biomass) per stool (20,000 stools per ha). There was significant variation between varieties as shown in Figure 3.4. The highest yielding variety, Orm weighed 0.826 kg per stool, equivelent to 16.5 wet tonnes per ha. The lowest, ST2481/55 weighed less than half this at 0.381 kg per stool (7.6 wet tonnes per ha).

The coppice in the weed effect trial was then cut and grown for two years. Absolute measures of biomass were taken at the end of this period and are also shown in Figure 3.4. Orm again was the highest yielding variety (2.78 kg/stool, or 55.6 wet tonnes per ha) followed closely by Bowles Hybrid and Ulv. These three varieties were significantly heavier than the other varieties in the trial. These data are consistent with other work on biomass production comparison between varieties. The comparison between one-year growth in 1995 and two-year growth in 1996/97 suggests that year two biomass accumalation was considerably greater than year one. However, the data are separated by a year and a harvest. In 1995, it is likely the coppice was not well established and root biomass production would have been more significant than in 1996/97.

While comparisons are normally made between varieties on a dry biomass basis, 55 tonnes per ha for two-year old coppice is a high yield. Typically, water content in growing willow coppice will account for 50% ± 5% of the weight. This indicates that the dry weight for this variety was around 27.5 oven dried tonnes per hectare (odt/ha) after two years or nearly 14 odt/ha/year. The equivelent figure for the Bowles Hybrid was around 12 odt/ha/year and 13 odt/ha/year for Ulv. The lowest yielding variety. Cambells produced 34 wet tonnes per hectare, equivelent to around 8.5 odt/ha/year. These good yields result from a relatively pest-free, properly established and well managed plantation growing in good soil conditions.

Figure 3.1 Leaf area per m^2 plan of coppice following full leaf emergence in mid to late May, for both willow and poplar.

Figure 3.2 The height of willow coppice, by age class, as recorded during the growing season. These data are standing height (as opposed to stem length).

Figure 3.3 The height of poplar coppice, by age class, as recorded during the growing season. These data are standing height (as opposed to stem length).

Figure 3.4 Mean biomass for ten varieties after year one and year two, and heights after year one. Data collected from the weed effect trial (Section 21.0), at Roves Farm where planting density was 20,000 stools per ha.

FIGURE 3.1, 3.2, 3.3, and 3.4 NOT AVAILABLE ELECTRONICALLY

4.0 NON-DESTRUCTIVE ASSESSMENTS OF SRC BIOMASS

4.1 Summary

We develop a non-destructive relative measure of SRC growth. The method has applications wherever comparisons are to be made in the response of SRC to treatments (e.g. fertilisers, weed control, etc.).

We measured the dimensions of all stems on a sample of stools from two physically dissimilar willow varieties, Dasyclados and Bowles Hybrid. We compared these data with dry biomass measurements for each stool using regression analysis.

The coppice stem volume, calculated from the stem length, basal and mid-length diameters and multiplied by the number of stems, provided an accurate estimate of relative biomass using least squares regression.

Each of the three stem dimensions correlated closely with each other. In a step-wise regression analysis including all three, the model included the mid-length diameter (plus stem number) and excluded the other two dimensions. This model still explained around 90 % in the variance in the dry biomass data for each variety.

We conclude that measuring mid-stem diameters (and counting stems) provides a fast and accurate estimate of relative biomass for both types of willow variety.

We then used the variance in the stool biomass data, as measured by mid-length stem diameter and stem number alone, to calculate the number of stools to be measured to achieve a desired level of accuracy and at a certain probability.

Results from a case study are then presented, where correlation’s between biomass and stem diameter for 10 different willow varieties, measured for assessing the impact of weediness on crop growth (Section 21.0), are presented.

4.2 Introduction

For most studies concerning SRC crop growth, some comparative measure of biomass accumulation is required. In most cases, this has involved cutting, drying (to remove variation in water content) and weighing a statistically representative sample of stems. This provides a very useful measure of yield with which to compare sites, varieties and treatments, to quantify for example the benefit of fertilisers or weed control on crop growth. It is however a time consuming process. It also precludes intermittent sampling which would allow the effect of treatments at stages during the growth cycle to be investigated - it is a destructive assessment method.

A non-destructive relative measure of SRC yields would be useful in many experimental situations, for example when investigating the effect of weed growth or insect-pest damage. A method of crop biomass measurement that does not involve cutting the coppice may also save time and effort. Diameter at breast height (dbh) is a standard measure used in forestry on large trees with tables used to provide conversions. For coppice Nilsson (1982) related biomass to stem diameter measurements for *Salix viminalis*. Verwijst (1991) extended the method, comparing several regression methods and concluding that least square regressions of the dimensions such as diameter squared x height (D^2H) were more accurate i.e. (had less non-linearity bias) than logarithmic transformations of some shoot diameter (D). Verwijst and Nordh (1992) thought that the methods developed for *S. viminalis* performed poorly when applied *to S. dasyclados* which has a less erect physiognomy than *S. viminalis* and tends to be more branched. In this study we re-investigate these methods by comparing several shoot dimension measures with actual biomass using least squares regression analysis, from two dissimilar SRC varieties *S. viminalis* variety and a *S. dasyclados* variety. We then take the one measure that provides the best estimate of biomass and test the method on 10 varieties

4.3 Method

4.3.1 Theory

An important distinction in developing a non-destructive measure of crop biomass is the need for an absolute measure of biomass, in Kg, or a relative measure - where differences in biomass only are of interest. The Mensuration Department at the Forestry Commissions' Research Division at Alice Holt are developing an absolute non-destructive measure of yield which will include an assessment of wood density (Armstrong *et al.*, 1997). For most experimental situations however a relative measure only is required and this is what will be developed here.

For relative biomass then, constant elements of the equation for mass (=Volume x Density) can be ignored.

Within a variety the density of wood can be assumed to be constant. A relative measure of stool biomass for coppice would therefore would be the stool volume or the sum of the stem volumes. This is convenient as it is clear that measuring the density is difficult without at least sampling and weighing stems or parts of stems. The volume in contrast depends only on external measurements.

The volume of a coppice stem approximates to the volume of a cone (or a cylinder plus a cone), where the diameter at the stem end is 0.

Volume of a cone = $(p /3)*R^2*L$

Where L is the stem length in m, R is the stem radius at L = 0 m, and p = 3.1416.

p /3 is a constant, so

Volume ~ R^2*L

We need therefore to measure stem radius and length, and to count the number of stems per stool. If however, these dimensions are closely correlated to each other, measurements of just one dimension could provide a suitable measure of relative biomass.

4.3.2 Trial site

At the Long Ashton Research Station (LARS) near Bristol, willow (and poplar) coppice trials were established in winter 1993 to investigate the *Melampsora* spp. rust virus and its impact on crop biomass. Within the trials, blocks of certain SRC hybrids are cut, dried and weighed to calculate absolute biomass responses to rust infection within and between varieties. Weights are recorded for each stool within plots. We negotiated with the trials managers to take non-destructive measurements of certain varieties within the trials, and to compare these data with the dry-matter biomass data subsequently collected by the LARS staff.

4.3.3 Data collection

We undertook measurements of 18 Bowles Hybrid *S. viminalis* stools and 18 Dasyclaydos *S. caprea x S. cinerea x S. viminalis* stools in December 1995. At the time, the plots contained one year-old stems on two year-old stools. First, we counted all stems on each stool over 1m in length or 5 mm in diameter (smaller stems were not considered to contribute significantly to the overall biomass of a stool). Then we measured, for each stem, the stem diameter at 10 cm from the base, the stem length and the stem diameter at half stem length. Branches over 1 m/5 mm were treated as separate stems. The two hybrids chosen represent the extremes of growth forms for the commonly available SRC hybrids - the Bowles Hybrid being tall, straight and near vertical, the Dasyclados being more prostrate, curved and branched.

In January 1996, the stems were cut, dried and weighed by staff of LARS, who kindly allowed us to use the data for the numbered stools.

4.3.4 Analyses

We investigated correlations between the actual stool dry weight (as measured by Long Ashton) against the stem dimensions. First, stool volume was calculated, taking into account the number of stems per stool and this was compared with the dry weight data using least squares regression. Each measurement (stem diameters and length) as recorded were then compared with stool dry weight in a least-squares linear regression analysis including stem number separately. Of these, the model that explained the most variance in the dry weight data identified the best single measurement of biomass to use. A forward step-wise multiple regression analysis of dry stool weight including the same explanatory variables was also used to confirm whether this analysis technique selected the same variable as the best single measure of biomass. In all cases relationships for un-transformed data were compared with those for log transformed data. An index, based on this best single measure ($I=N.X^3$ see below), was also tested. All analyses were carried out using Systat (Wilkinson, 1991).

We then calculated the number of stools from which measurements would be required to achieve a certain level of accuracy (i.e. to detect a difference between means) at a given probability P. An index based on the number of stems (N) and one stem dimension (X) cubed ($I = N.X^3$) was calculated (cubing was to required to give the index the same dimensions as volume i.e. L^3). The variance of 'I' for the two plots (Bowles hybrid and Dasyclados) was then used to calculate the quantity of stools required to get an estimate of the relative plot yield to within a certain accuracy limit. This was done in accordance with Sokal and Rohlf (1981).

$$N = 2(SD/diff)^2 \times t^2$$

from Sokal and Rohlf (1981)
N = number of stems required
SD = standard deviation of the sample
Diff = The smallest difference it is desired to detect
t = value from two-sided t-table with df degrees of freedom

4.3.5 Case study

The non-destructive method of assessing SRC biomass developed here, was used to quantify crop growth in the weed effect trial described in Section 21.0. The objective of this trial was to quantify the impact of weed competition on the growth of established willow coppice over two years. Ten different varieties were assessed. Crop growth was measured at the end of year one, by measuring stem diameters at half stem length. At the end of year two, stem diameters were again measured, but the crop was also cut and weighed. This enabled a comprehensive assessment of the relationship between the single stem measurement, and stool biomass as before, but using wet weights (this should make no difference as water content would be expected to be reasonably constant between stools within varieties).

Forty stools were measured in each of 15 blocks. Each block contained one of four weed treatments. Each of the 10 varieties occupied either one or two blocks so the number of stools and hence the sample size for the purposes of this analysis for each variety was either 40 or 80 stools. The mid-stem diameter for each stem was cubed, to get an index of volume (as before in Section 4.4.1) and then summed for all stems to give a single independent variable representing stool volume. The relationship between stool volume and this volume index was then tested using least-squares regression analysis for each variety.

4.4 Results

4.4.1 The relationships between actual biomass and stem dimensions

The results of the regression for stool dry weight against each of the three dimension and the estimate of stool volume are given in Table 4.1 (logged data) and Table 4.2 (un-logged data). Relationships between the unlogged data are illustrated in Figure 4.1 for Dasyclados and Figure 4.2 for Bowles hybrid and for the logged data in Figures 4.3 and 4.4 respectively.

In the first regression, the calculated value of stool volume explained almost all variance in the dry stool weight data for both Dasyclados (logged and un-logged data, 98.2 %) and Bowles Hybrid (logged 97.4 %, un-logged 96.3 %). In the second set of regression analyses, Nstems + Dhalf explained more of the variance in the data than Nstems + (Dten or Length) for logged (Table 4.1) and un-logged (Table 4.2) data.

Incorporating all three dimensions and the number of stems into the forward step-wise multiple regression analysis of dry stool weight, only Nostems and log(Dhalf) were selected for both Dasyclados ($n=18$, $T=8.253$, $P<0.001$, $T=2.892$, $P<0.01$ respectively) and Bowles Hybrid ($n=18$, $T=14.896$, $P<0.001$, $T=2.930$, $P<0.01$ respectively). This confirms that the variance in the stool weight data explained by the stem diameter at 10 cm and the stem length measurements, is better explained by the diameter at half stem length.

Combining Nstems and Dhalf for both varieties gives the index of biomass used in subsequent analysis ($\text{Index}=\text{Nstems}*\text{Dhalf}^3$). The relationship between dry biomass and this index is given in Table 4.3 and illustrated in Figure 4.5 (together with stool volume).

Note that the regression line intercept has been extrapolated beyond the collection of data points in Figure 4.5. These models are reliable for dry matter biomass of between about 0.5 kg and 1.5 kg.

Table 4.1 a) & b). Least squares regression for (log) dry stool weight against different measurements (also logged). Stool n = 18 for both a) Dasyclados and b) Bowles Hybrid.

a) Dasyclados	T	P	R^2
1 independent variable,			
log(Vstool)	29.444	<0.0001	98.2%
2 independents,			
Nstems + log(Dhalf)	9.599 + 7.551	<0.0001	88.3%
Nstems + log(Dten)	7.248 + 5.772	<0.0001	82.6%
Nstems + log(L)	5.763 + 3.676	<0.0001	70.5%

b) Bowles Hybrid	T	P	R^2
1 independent variable			
log(Vstool)	24.379	<0.0001	97.4%
2 independents,			
Nstems + log(Dhalf)	13.212 + 9.498	<0.0001	93.2%
Nstems + log(Dten)	10.881 + 9.142	<0.0001	92.8%
Nstems + log(L)	9.593 + 7.328	<0.0001	89.3%

Length = Stem length.
Nstems = Number of stems per stool.
Dhalf = Stem diameter at half L.
Dten = Stem diameter at 10cm from stem base.
Vstool = Stool volume calculated from Dhalf, Dten and L.

FIGURE 4.1, 4.2, 4.3, 4.4, AND 4.5 NOT AVAILABLE ELECTRONICALLY

Table 4.2 a) & b). Least squares regression for dry stool weight against different measurements (un-logged). Stool n = 18 for both a) Dasyclados and b) Bowles Hybrid.

a) Dasyclados	T	P	R^2
1 independent variable, (Vstool)	29.444	<0.0001	98.2%
2 independents,			
Nstems + (Dhalf)	9.669 + 0.705	<0.0001	88.3%
Nstems + (Dten)	7.507 + 5.937	<0.0001	83.4%
Nstems + (L)	5.871 + 3.750	<0.0001	71.3%

b) Bowles Hybrid	T	P	R^2
1 independent variable, (Vstool)	20.348	<0.0001	96.3%
2 independents,			
Nstems + (Dhalf)	11.870 + 8.388	<0.0001	92.6%
Nstems + (Dten)	10.828 + 9.026	<0.0001	91.6%
Nstems + (L)	10.510 + 7.915	<0.0001	90.8%

Length = Stem length.
Nstems = Number of stems per stool.
Dhalf = Stem diameter at half L.
Dten = Stem diameter at 10cm from stem base.
Vstool = Stool volume calculated from Dhalf, Dten and L.

Table 4.3. Least squares regression for dry stool weight against the index of biomass ($I=Nstems*Dhalf^3$). Stool n = 18 for each.

	Slope	Intercept	T	R^2
Index for Dasyclados	0.962	0.074	10.288	86.9%
Index for Bowles Hybrid	1.225	-0.225	13.740	92.2%

4.4.2 How many stools need to be measured?

The analysis above indicates that as a single measure $Nstem*Dhalf^3$ is the most representative of stem biomass.

Using this index of biomass, the mean and standard deviation of this Index:

For Dasyclados: I_{mean}=9735.3, SD=1827.2

For Bowles Hybrid: I_{mean}=10543.0, SD=2338.5

The number of stools for which measurements are required to detect a pre-determined difference at a given probability can be calculated using the equation (from Sokal and Rohlf 1981):

$N= 2(SD/diff)^2 \times t^2$

Where
N = number of stems
SD = standard deviation
Diff = difference to detect, as a percentage of the mean
t = statistic for given probability

Example calculation:

To detect a difference of 10% of the Dasyclados stool mean biomass, diff=973.5
For P=0.05, t=2.1

$N=2(1827.5/973.5)^2 \times 2.1^2 = 31.1$

Results for this and other difference detection levels and probabilities are given in Table 4.4.

Table 4.4. The number of stools from which measure of Dhalf are required to detect a difference in the means of two samples at the desired probability level P.

	Difference	P<0.05	P<0.10
Bowles Hybrid	5 %	173.6	120.0
	10 %	43.4	30.0
	15 %	19.3	13.3
	20 %	10.8	7.5
Dasyclados	5 %	124.3	85.9
	10 %	31.1	21.5
	15 %	13.8	9.5
	20 %	7.8	5.4

4.4.3 Case study results

For each variety the stool biomass was significantly and positively related to the volume index (Table 4.5). The data for each variety are shown in Figure 4.6 and for all varieties in Figure 4.7.

Table 4.5. Least squares regression analyses on stool biomass and volume index for each of 10 varieties and for all ten varieties combined (n=600). P<0.001 in all cases

Variety	n	Slope	Intercept	T	r^2
Orm	40	1.279	0.092	13.928	0.836
Cambell	80	1.544	0.084	18.305	0.811
Mullatin	80	1.465	0.080	18.345	0.812
Bowles	40	1.498	0.070	21.377	0.923
SQ683	80	1.248	0.049	25.609	0.894
ST2481	40	1.290	0.045	28.687	0.956
SV699	40	1.564	0.077	20.377	0.916
Gigantea	80	1.676	0.084	19.915	0.836
Q83	40	1.320	0.055	23.969	0.938
Ulv	80	1.382	0.067	20.622	0.845
All	600	1.351	0.023	58.005	0.849

4.5 Discussion

4.5.1 The best measure of biomass

As Tables 4.1 and 4.2 indicate, by measuring the stem diameters and length, and calculating the total stool volume using Nstem, it is possible to make a very accurate relative estimate of the dry matter crop yield, with R^2 values of around 98% for both varieties. This result then provides an accurate non-destructive measure of crop growth that can be used to compare experimental treatments. Measuring length and diameters and calculating a volume however, is a lengthy process. What is potentially more useful is that the individual stem dimensions each correlate with actual biomass with R^2 in excess of 70 %. The log transformations do not improve any of these relationships substantially for any of the models.

Table 4.1 and 4.2 indicate that the measure of half-way diameter combined with the number of stems (expressed as Nstem + Dhalf) is the best single measure of biomass for both Dasyclados and Bowles Hybrid explaining 88.3% and 92.6% of the variance in dry weight respectively. In the step-wise multiple regression analysis which considers all measured variables simultaneously, dry weight was significantly related to Nstem and Dhalf but not Length or Dten.

FIGURE 4.6 AND 4.7 NOT AVAILABLE ELECTRONICALLY

This confirms the extent to which Length, Dten and Dhalf are correlated, and again that Dhalf is the best single measure of dry biomass. These results suggest that in most instances, there is little point in measuring more than the diameter at half stem length and the number of stems per stool to give a relative estimate of biomass. We found that measuring stem length takes 20 - 30 seconds, around 10 times as long as measuring the mid-stem diameter using callipers.

The models in Table 4.3 describe the relationship for the stools measured in this study. In other situations these models will probably be different. It is however not necessary to define this relationship when applying this non-destructive method when relative measures of biomass are required. Figure 4.5 and Table 4.3 also indicate that the intercept for the regression lines are non-zero. The intercept however occurs beyond the set of data points and the extrapolated straight line does not in any case necessarily reflect the actual relationship for very small stool biomass. The method is applicable for the normal range of stool biomass - for this trial 0.5 kg to 2.0 kg.

The method is similar to that developed in Sweden by Neilson (1982) for *S. viminalis* but uses a different diameter measure. For *S. dasyclados*, Verwijst and Nordh (1992) thought that measuring diameters at a fixed height was a poor measure of biomass because of the difference in growth form. They found by measuring all diameter of all stems and branches at a height intercept of 55 cm gave the best correlation with biomass. We addressed the branching of Dasyclados by treating stems over 5 mm in diameter as separate stems.

4.5.2 How many stools

Table 4.2 provides a useful indication of the number of stools a researcher would include in an experiment to achieve a given result. Given the high correlation between Dhalf and actual biomass, these figures, i.e. the number of stools to be measured, would be similar even if stools were being cut and weighed. Although Dhalf was a better measure of dry weight for Bowles Hybrid than Dasyclados (Table 4.1), the calculations presented in Table 4.2 indicate that more Bowles Hybrid stools need to be measured to detect a difference between samples at probability P. This is because this calculation depend on the variance (or standard deviation) in the stool biomass data, however measured, which was higher for Bowles Hybrid.

The results in Table 4.2, derived from data from one plot only, can still provide guidance for other experiments where comparisons in biomass are required. In this study the sample standard variation for both varieties was around 20 % of the sample mean. The equation for stool number includes the term (SD/diff) squared. This means that if the standard deviation of a sample doubles to 40 % of the mean, four times as many stools will be required (for the same difference). In practice, in most well established SRC plantations, variance in growth and stool size within varieties is reasonably small (a consequence of using clonally identical material) and 20 % is likely to be a representative figure.

In conclusion, for a one off comparison of the mean stool biomass between two plots with different treatment regimes, the diameter at half stem length of around 40 stools will provide sufficient data to detect a difference of 10% at $P<0.05$ (this is a standard probability level). Larger differences will be detected with fewer stools and for replicated experiments fewer stools still would require measurement. In most experimental situations, time and effort expended in comparing yields would be considerably reduced and the crop would remain for further assessment if required.

The non-destructive measurement of biomass developed in this section was used in a trial to investigate the impact of weed growth on biomass in established willow SRC (Section 21.0).

4.5.3 Case study discussion

Work undertaken by the Forestry Commission by Matthews (1995) and Armstrong *et al.* (1997), indicates that measuring basal diameters is preferred to measuring higher up the stem because more reliable 'zero intercept' models of biomass versus diameter can be calibrated using the former. Measuring higher up the stem however is more convenient and these authors recommend estimating basal diameters from measurements at some other convenient point at a fixed height. It is possible that by measuring stem diameter at a variable height, as we did, increases the reliability of the model.

The slope for each relationship in Table 4.5 varies indicating the difference in growth forms for each variety. A smaller slope indicates a greater mean stem diameter for a given biomass. This means that varieties with a high slope in Table 4.5 tend to have a thinner, taller growth form, and/or that the wood density or water content is higher. It is also interesting that the 'strength' of the relationships between volume and weight in Table 4.5, as measured by the T statistic and the R^2 value (which is a measure of the variance explained by the model) is not consistently greater where n=80. In fact in all four cases in Table 4.5 where the r^2 is greater than 0.9, stool n=40.

The intercept for all varieties is close to zero (within 10 % of the slope). However it does not vary equally around zero indicating a consistent bias in the regression technique used. The bias is due to some small non-linearity in the data which becomes pronounced when volume and weight values are close to zero. As indicated above, the intercepts occur beyond the data points and the extrapolated straight line does not in any case necessarily reflect the actual relationship for very small stool biomass. For the two-year old coppice measured in this case-study, the straight line relationships can be relied upon for stool biomass of between around 0.5 kg to 4 - 5 kg although this varies considerably between varieties.

The case study indicates that the mid-stem diameter method developed here was readily applied to a range of other varieties of different age. The method was used to assess the impact of weed competition on crop growth in Section 21.0. Considering all 600 stools in a single model (Table 4.5) provides a straight line relationship with a high r^2 (0.859) and a low intercept (0.023, less than 2% of the slope). This relationship could be used to provide a rough estimate of relative biomass in two-year-old *S. viminalis* SRC across varieties.

4.6 References

Armstrong A. Johns, C., Matthews, R., & Straw, N., (1997) *Second Interim Report on contract B/W2/00525/00/00* Yield models for energy coppice of Poplar and willow. Phase II May 1996-May 1997. Forestry Commission Research Agency.

Matthews (1995) Non-destructive assessment of biomass growth and yield in short rotation coppiced tree crops. *A report to ETSU for the DTI on contract B/W2/00502/00/00.*

Nilsson, L.-O. (1982) Determination of current energy forest growth and biomass production. Swedish Energy Forest Project, Swedish University fo Agricultural Sciences, Uppsala, Sweden. *Technical report no. 27.*

Sokal R. R. & Rohlf F. J. (1980) *Biometry.* Second Edition. Freeman and Co., New York.

Wilkinson, L. (1990) *Systat, The System for Statistic.* Systat Inc. Evanstan, Illinois, USA.

Verwijst, T. & Nordh, N. (1992) Non-destructive estimation of biomass of *Salix dasyclados*. *Bioresource Technology*, **41**: 59-63.

5.0 SHADINESS IN SRC

5.1 Summary

Crop shadiness, measured as the Percentage of Active Radiation penetrating the crop canopy (PAR), was measured at a range of willow and poplar plantations. The information was collected as part of the work on ground flora within SRC and weed competition (Sections 20.0 - 21.0)

Following full leaf emergence and until mid summer, PAR was found to vary between approximately 2 % to 12 % in the willow plots and 2 % to 20 % in the poplar plots. The mean difference between the two tree species was not significant.

Towards the end of the summer (but before autumn leaf full) there was a tendency for PAR to increase. This trend was significant for the sample of willow plots. PAR did not differ significantly between age classes of coppice. It is likely that many factors influence leaf cover and shadiness.

A large number of PAR samples were collected at a well-established and vigorous two-year-old willow coppice site that did not suffer from drought stress, pest or disease. The mean PAR for this site across 10 varieties was 6.8 %. This value provides a useful baseline PAR value for general interpretation.

Many woodland and hedgerow herbs will survive and propagate at PAR levels between around 5 and 10 % and some as low as 2 %. Most arable weeds are not suited to these shady conditions.

5.2 Introduction

Survey work undertaken during summer 1995 provided information on the shadiness of SRC crops. This was done primarily to assess the conditions SRC crops provide for other plants. These data contribute to the work on weeds and flora introductions described in Sections 19.0 - 21.0 and provide useful data for other researchers on the micro-habitat conditions provided by these crop types.

5.3 Methods - equipment and sampling strategy

Measures of shadiness within SRC crops were recorded from 20 willow and 12 poplar plots at 13 sites in 1995, during the course of other monitoring and sampling work. Data were collected from April 1st to August 31st in year 0, year 1 and year 2 coppice growth.

We also undertook intensive PAR measurements in the weed effect trial and the flora introduction trial in 1997 (Sections 21.0 and 20.0 respectively). One hundred and twenty measurements were taken with two readings from each of 60 plots. The mean of these data is also given here. The site contained well-established and vigorous two-year-old willow coppice that did not suffer from drought stress, pest or disease and was considered as representative of well managed production willow plantations.

Measurements were taken using a custom made light metering system designed and manufactured by Stan Burridge at London University, Wye College, Kent. The equipment compared the incident light within and outside an SRC plot. The difference between the two levels enabled a proportion to be calculated, the percentage of active radiation (PAR), representing the reduction in light levels within the coppice.

Within the coppice, the user held, in the appropriate position and height, a 1 m-long integrated light meter, which averaged the light levels along its length (this accounted for local variations in light levels). This meter was linked via a cable to a second light meter mounted on a tripod and stationed outside of the coppice. This meter measured ambient light. The difference between this measurement and that within the coppice was calculated and displayed as a percentage on a meter held by the operator.

For the extensive monitoring work in 1995, within each plot, a sample of 20 measurements were taken to get a mean for each plot. Locations were randomly selected and the meter was held just above any weeds present. Two measurements were recorded in each location, the second with the meter held perpendicular to the first. Two measurements were taken in each of sixty marked plots (i.e. not random) in the weed effect and flora introductions trials in 1997 (Sections 21.0 and 20.0).

Analysis of variance (ANOVA) was used to identify differences in PAR between willow and poplar plots and between age classes, and regression analysis used to investigate any trends in PAR through the summer. Statistical analyses were carried out using Systat (1990).

Further measurements of PAR were recorded on other occasions related to specific trials. These data are described in detail in the appropriate sections (5.0, 20.0, 21.0).

5.4 Results

The mean PAR of different SRC plots (varieties and age classes) at the survey sites are shown in Figure 5.1 for willow and poplar separately. In an analysis of variance, the measured PAR was not significantly related to either the age since cut-back (age class, $F_{34,2}$=0.801, P>0.1), time of year ($F_{34,1}$=0.044, P>0.1) or tree species (willow or poplar, $F_{34,1}$=2.887, P>0.05).

Measurements in early April for willow and for early and mid April for poplar were taken before full leaf emergence (Section 3.0). By excluding these early season measures, i.e. those taken before full leaf emergence (for willow this was days 1 - 5 and for poplar days 0 - 20) PAR did increase through the season for the sample of willow plots ($F_{19,1}$=2.477, P<0.05).

The mean PAR recorded from 60 trials plots in established year-two willow coppice in 1997 was 6.8 %. The PAR varied significantly between varieties and between treatments (weeded or unweeded plots - this is considered in more detail in Section 21.0). Mean PAR for each variety is shown in Figure 5.2. The varieties with the highest PAR, i.e. with the least dense canopy, tend to be the tallest and highest yielding varieties (Section 3.0, Figures 3.5).

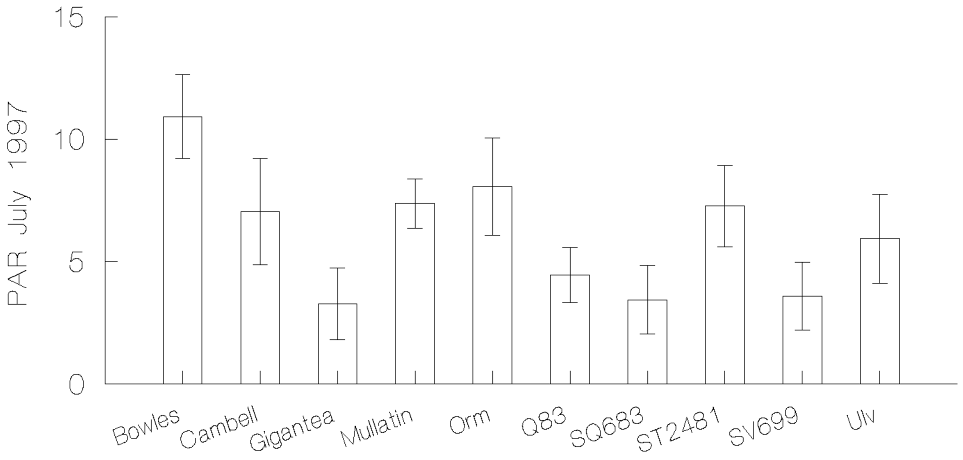

Figure 5.2 The percentage active radiation penetrating the canopy of 10 two-year-old willow varieties at the weed effect trial (Section 21.0).

Figure 5.1 The percentage active radiation penetrating the canopy at a sample of 20 willow sites (top graph) and 12 poplar sites. Each mean value is based on a sample of 20 measurements from within the plot and PAR is plotted against date from 1st April to 1st September

FIGURE 5.1 NOT AVAILABLE ELECTRONICALLY

5.5 Discussion

The PAR light meters calculate the difference in light levels between two locations. The meters were designed to be insensitive to the ambient levels (i.e. that the difference should remain the same regardless of the daylight strength). In practice we found that in the grossly different ambient light conditions that occurred as the sun went in and out, the measured PAR in the same spot varied significantly. We therefore confined data collection to periods of cloud cover.

The variance in recorded PAR for the 32 study plots was large and no measured explanatory variables were found to significantly influence the measure of PAR. This non-significant result probably reflects the high variance in the recorded PAR but also suggests other influencing factors that were not accounted for in the analysis. PAR is likely to depend not only on leaf area but also leaf thickness and on various site and crop factors such as spacing, defoliation, drought stress and so on. However, regarding the plot of PAR for willow, excluding the two data points at the beginning of April (i.e. before full leaf emergence), the PAR did increase through the summer. This reflects the decline in leaf area illustrated in Figure 3.4, Section 3.4. A similar but less clear trend exists for the poplar.

In the main body of the crop, PAR for willow SRC varied between around 2 % and 12 % for most of the summer, and between 2% and 20 % for poplar (Figure 5.1). The higher levels tended towards the end of the summer. The mean PAR for the willow site used in the weed effect and flora introduction trials (6.8 %, see Section 20.0) was an highly replicated mid-summer measurement from a well-established two-year-old plantation. At just under the mean for the extensive PAR surveys, this provides a useful single point measure of PAR for willow SRC.

These levels are similar to traditional woodland and coppice habitats and many woodland herbs and grasses are adapted to surviving similar shady conditions (Grime *et al.* 1988). Woodland plants that can survive at 5% PAR or less are less common and in many flowering and propagation becomes less frequent. At 2% PAR or less for extended periods, few plants can survive. Most arable weed species are not suited to these levels of shade and in SRC crops with PAR levels below around 10 % during early summer, some weed suppression can be expected. The effects of PAR and the plant communities are considered in more detail in Sections 19.0, 20.0 and 21.0.

5.6 References

Grime J.P., Hodgson J.G., & Hunt R. (1988) *Comparative plant ecology*. Unwin Hyman, London.

6.0 WIND EXPOSURE AND CROP GROWTH

6.1 Summary

We designed a 4ha SRC plantation that incorporated an experimental trial to assess the impact of exposure to wind on crop growth.

The site also incorporated some design and management features that were developed during the ETSU/GCT study B/W5/00277/00/REP, to maximise crop production and efficient management, while also maximising the potential of the plantation as a wildlife habitat.

For the exposure trial, the experimental design and implementation was successful but due to the repeated vandalism of the windscreens used, which were located in a necessarily exposed position, we were unable to accumulate sufficient data to provide a significant result.

However the trend was towards increased biomass accumulation in the first and second years' after planting in SRC plots screened from the prevailing wind, compared to unscreened plots.

6.2 Introduction

In Northumbria, SRC is being used by the County Council and other organisations as a way of increasing woodland cover in the county and at East Sleekburn, The Council are supporting an Earth Balance Farm project which includes several hectares of SRC plantings each year from 1995. In May 1995, a 3.8ha field was planted following GCT design recommendations and included the crop exposure trial described here.

The trial was designed to provide a statistically rigorous test of the hypothesis that wind exposure reduces growth of willow coppice, plus a quantification of the effect. The aim of the experiment was to encourage hedgerow planting for this and possibly other similar crops. The site as a whole was designed to incorporate some design and management features that were developed during the ETSU/GCT study B/W5/00277/00/REP, to maximise crop production and efficient management, while maximising the potential of the plantation as a wildlife habitat.

6.3 Study site and method

The planting design at the East Sleekburn site is shown in Figure (6.1) which indicates the wildlife and landscape features and the exposure experiment.

One block of each of six varieties, roughly equal in length, was planted along the west edge which is exposed to the prevailing wind in the area. The blocks were 10m - 15m deep, around one quarter to one third of the planted width at the narrowest point. Half of each block was screened and half unscreened (with a fine poly-mesh) as indicated in the figure. The screens, erected in late May following planting, were supported on five posts, and were around 2 – 2.5m high and approximately 15m long. They were sloped slightly towards the crop to reduce turbulence and to copy the effect of an 'A' shaped hedge.

We then establish a triangular quadrat that led into the crop perpendicular to the screened and non-screened areas. The quadrat was bounded by the screen at the edge of the field (or the equivalent position in the non-screened control plots) and by two lines running at 45^{O} from the ends of the screen into the crop and hence crossing. Crop yield was measured by cutting and weighing a sample of approximately 30 individual stools within the quadrat area. This was to be done at the end of the first year of growth and at the end of subsequent years in each of the six plot pairs.

6.4 Results

6.4.1 Wildlife and landscape

When planted, the 1995 East Sleekburn SRC plot incorporated several of the proposed wildlife conservation design and management features (Figure 6.1). The overall design maximised the physical diversity of the planting without compromising production, planted area or ease of management, in particular mechanical harvesting. Developing a coppice age class rotation and hybrid mix, and by incorporating headlands and sheltered rides were the key features (Sage et al. 1994).

The annually cut, close spaced edge strips of willow at the ends of the rows and in the middle, provide low down cover for two and three year old stands which are otherwise often exposed, and hence increase shelter for wildlife (the end strips will be cut each year before cutting the main crop). Combined with a four metre headland they should provide enough space for any harvester to turn. The other headlands are six metres in width to allow open ground floral communities to develop. Narrow rides can become completely shaded allowing few open ground plants to survive (Sage et al. 1994).

6.4.2 Exposure trial

The screens used in the exposure trial were regularly vandalised, with the screening material being stolen. This was done despite efforts to protect the screens with anti-theft paint. In year one, we were able to repair five of the screens sufficiently quickly to collect yield data at the end of the year. In year two, four of the screens were still intact for most of the year. Subsequently the trial was abandoned.

The mean mass of individual stools after year one and two from the five experimental sections are shown in Table 6.1.

Table 6.1. The mean biomass in grams, of a sample of approximately 30 individual stools in the exposure trial after one years growth in each of the paired screened and unscreened plots. 1995 was the establishment year and 1996 was the growth after cut-back. Note that data were collected from five of the six screens in 1995 and four in 1996, due to vandalism

1995

Variety	Screened plot	Unscreened plot
Bowles hybrid	37.3	15.5
Dasyclados	15.8	14.2
Q83	19.0	13.2
Germany	20.7	21.2
Ulv	19.1	10.4
Mean	22.5	14.9

1996

Variety	Screened plot	Unscreened plot
Bowles hybrid	104.7	35.6
Dasyclados	58.4	45.3
Q83	75.6	43.8
Ulv	55.4	66.5
Mean	73.5	47.8

While the mean biomass of stools in the screened plots was greater than that in the unscreened plots in both years, the difference was not significant at the P=0.05 level (year 1: T=1.907, df=4, P=0.129, year 2: T=1.521, df=3, P=0.226). It is likely that had the six plot pairs remained throughout the period, and the difference in mean biomass in the other plots was in the same direction, the result would have been significant.

With screens further vandalised in year 3, no further meaningful result were obtained from this trial.

6.5 Discussion

A considerable amount of effort went into the exposure trial at East Sleekburn in 1995 and the regular theft of screening material prevented any significant conclusions to be drawn from it.

However the results in year one and two, in five and four of the six treatment pairs respectively, do suggest that during the establishment year, the willow cuttings protected from the prevailing wind were probably more vigorous than those in the exposed control plots. This result would make biological sense as in other studies of certain tree species, exposure to wind has been shown to reduce growth by, for example, increasing transpiration and observations of tree growth and form in any exposed situation indicates that trees are affected by the wind.

These results indicate that planting SRC crops adjacent to other woodland and scrub type habitats such as hedgerows, or by planting hedgerows along exposed edges, may lead to increased biomass yields in these crops. While these increases may be small, these practices make a considerable contribution to the wildlife value of SRC crops, and in some circumstances, the prospect of increase in yield may provide the incentive to undertake hedgerow planting or sympathetic siting of plantations.

6.6 References

Davies, R.J. (1987) *Trees and Weeds: Weed Control for Successful Tree Establishment*. Forestry Commission Handbook 2, pp. 36. HMSO, London.

Sage R.B., Robertson P.A. and Poulson J.G. (1994) Enhancing the conservation value of short rotation biomass coppice - Phase 1 The identification of wildlife conservation potential. *ETSU B/W5/00277/REP*, Harwell Laboratories, Oxford, pp. 44.

Figure 6.1 The 3.8ha SRC plantation at East Sleekburn in Northumbria, incorporating ICM design features and the exposure trial.

FIGURE 6.1 NOT AVAILABLE ELECTRONICALLY

7.0 INVERTEBRATES COLONISING UK SRC PLANTATIONS - BIODIVERSITY POTENTIAL

7.1 Summary

In 1994 and 1995, we sampled invertebrates occupying the canopy of willow and poplar SRC plantations throughout Britain and Ireland. From a smaller number of sites we also collected invertebrates on the crop floor.

We found many insects using the SRC study plots, reflecting the abundance and diversity of insects known to be associated with free-living willow and poplar trees. Considering species actually on the coppice (i.e. not those on the ground or flying around the coppice), on average, the willow SRC plots contained significantly more species and in greater abundance than the poplar SRC.

It is estimated that between around 100 and 400 phytophagous (plant eating) invertebrate species will have the potential to colonise willow plantations and perhaps half this in poplar ones. Predatory and parasitic invertebrate species which feed on the polyphagous ones were also common in the sample plots accounting for around 40 % of the total species recorded.

Many more invertebrates species can therefore be expected in SRC than in other common farmland crops such as wheat and barley. Consequently, cultivating willows, and to a lesser extent poplars, on improved agricultural land will in most instances lead to an increase in the abundance and diversity of invertebrates using that land. This in itself will lead to a net increase in biodiversity. It will also encourage other wildlife to colonise plantations, further improving the biodiversity potential of the field itself and in adjacent land, and possibly providing habitat opportunity for some declining species.

7.2 Introduction

Broadly speaking, there are two types of invertebrates that can be found in habitats such as SRC - the herbivores (phytophagous invertebrates) feeding on the crop or on other plants in the field, and the predators and parasites that feed on them (invertebrates includes all insects plus spiders - slugs, snails and other small terrestrial arthropods that don't have six legs such as millipedes). The type and quantity of invertebrates using SRC has implications for crop productivity and management, as in theory any phytophagous or polyphagous (meaning eating many things) species could become sufficiently numerous to constitute a pest. In reality the majority never do - the pest potential is explored in subsequent sections of this report, in particular Section 8.0. On the other hand, the abundance and diversity of invertebrates in SRC also has implications for the crops value as a wildlife habitat. The invertebrates contribute to the biodiversity of the crop in themselves and by attracting other wildlife groups who, for example, feed on them (biodiversity refers simply to the quantity of different plants and animals).

The value of these crops to wildlife has been an important component throughout the GCT's research programme on SRC. We have already studied key invertebrate groups, such as butterflies (Sage *et al* 1994). This study provided an opportunity to collect and identify many other invertebrates that have colonised SRC plantations and which contribute to the biodiversity of the crop. Primarily however, our aim was to identify any invertebrates that were causing (or had the potential to cause) sufficient damage to the crop to be considered pests. Armed with this information we went on to look at aspects of the population dynamics and behaviour of the main pests that may help to develop methods to manage or control them as part of an integrated pest management strategy (IPM).

In this section however we consider the biodiversity aspects of invertebrates in SRC. An extensive invertebrate monitoring programme was set up at in spring 1994 which involved at least 21 sites throughout Britain and Ireland and which evolved during the course of the project to answer specific questions. During the 1994 and 1995 field season its aims were to:

1. to sample the invertebrate communities occupying existing SRC plantations in a wide range of crop types and geographic locations

2. to describe and compare the range of species using the willow and poplar coppices

3. to quantify any damage caused to the SRC that could be attributed to any of the invertebrates recorded in the coppice

4. to describe the abundance and distribution of the invertebrates found to be causing significant damage to the crop

In this section we address the first two aims. In the next section we consider the third and fourth. The extensive surveys described in these two sections underpin much of the more specific work on invertebrate pests described in subsequent sections in the report. While the methods used to collect data from the invertebrate survey sites are described in detail here, some of the techniques apply to subsequent sections.

7.3 Methods

Sampling the entire invertebrate fauna at a large number of sites, i.e. all species that may periodically use the coppice or its vicinity, was beyond the resources of the project. It is also a pointless exercise - repeat sampling of a habitat will eventually include most of the invertebrate fauna in the locality. It is more useful to consider those species groups for which the crop is in some sense a host plant. We also took into account an invertebrate survey being conducted at several SRC sites under another ETSU supported programme The Farm wood fuel and Energy Project - Environmental Monitoring and Assessment of short rotation coppice, by Environmental Resource Limited (ERL). This survey began in 1993 and targeted mainly ground dwelling invertebrates through the use of pitfall traps set up on the coppice floor. We therefore concentrated our invertebrate sampling effort on those occupying the coppice canopy, i.e. on those species that depend directly on the crop. This approach, while minimising any duplication of ERL's work, was also essential if the herbivorous pest species were to be recorded - a key aim of the programme. At three sites however, we did collect ground invertebrates as an assessment of the predator potential for the main pests (Section 13.0).

7.3.1 Site selection and sampling strategy

Using The GCT SRC site database, 21 farms or research stations throughout Britain and Ireland growing SRC were selected for extensive invertebrate sampling in 1994. Sampling sites were required to be at least 2 years old at that time, and to contain continuous areas of recommended willow and poplar hybrids (Tabbush & Parfitt 1996) over 0.3ha. The sites exhibited a range of environmental attributes with varying topography, soil type, surrounding land use and field boundary types.

Most sites contained several plots with a range of willow and/or poplar hybrids present and it was not possible to sample them all. However, relatively few varieties are resistant to the main pest groups (Kendall *et al*. 1996, Sage & Tucker, In press, Section 11.0) and all sites contained varieties palatable to the main insect pests. Insect sampling per site was therefore confined to those currently recommended for SRC (Tabbush & Parfitt 1996). Of these, hybrids that appeared to contain the highest pest burdens at the particular site were sampled (clonal selection by the main pest group is discussed in Section 11.0). At many sites pest distribution was roughly even across hybrids. Between one and three hybrids were sampled per site.

Most sampling sites were visited once or twice between April and October 1994 and once in 1995. Five of the 21 sites however were visited at approximately 50-day intervals during summer 1994 and 1995 for more intensive assessments of certain species (Section 8.0). Invertebrate and crop phenology data were collected in accordance with the methods outlined below.

At three of the 21 sites in southern England a total of 162 pitfall traps were set in the ground to collect ground and rove beetles (Coleoptera: Carabidae and

Coleoptera: Staphylinidae respectively) over a 1 to 2 week period during August 1995. This work was undertaken with GCT supervision by a postgraduate student at Wye College, Kent (Baxter, 1996) and is included in Section 13.0.

7.3.2 Sampling invertebrates from the coppice canopy

Beating

In early 1994 we considered a range of techniques to collect invertebrates from the coppice. An important consideration was the ease and speed at which samples could be collected. After a series of pilot surveys it became clear that beating methods collected most of the invertebrate groups occupying the coppice canopy. This method is widely used by entomologist who wish to collect invertebrates from shrubs and small trees (Southwood 1978). It involves shaking or beating the vegetation to dislodge the invertebrates. Those that fall to the ground (rather than fly away) can be caught in a sheet laid out under the vegetation. It is then possible to collect the sample, using for example a pooter, or to identify and count individuals without collection.

Invertebrates were collected in this way at three randomly selected points within a single plot of willow or poplar SRC to provide a sample. Two plots were surveyed at most of the 25 sites (a days work for one surveyor). At each collection point, a sheet was laid beneath the trees between the stools and adjusted to cover an area of $2m^2$. Care was taken to cause as little disturbance as possible to avoid dislodging invertebrates on the foliage. The stems of all the stools surrounding the sheet, up to a distance equal to the height of the tallest stems, were then shaken vigorously to dislodge as much of the invertebrate fauna as possible. Those individuals falling on the sheet were collected using a pooter and taken away for counting and identification.

The sheet-beats were found to be satisfactory for assessing the absolute abundance of most species of arboreal Coleoptera as adults. These species readily fell to the sheets and remained for sufficient time to be counted. Numbers were then converted per m^2. The majority of Hemiptera (plant bugs) and larvae of Hymenoptera: Symphyta (sawflies) were also effectively sampled by the sheets. The larvae of non-galling and non-stem-boring Lepidoptera were also recorded from the sheets but many remained in the crop canopy following beating, hence giving information on presence rather than abundance. Some aphids were also recorded from the sheets but again, many remained in the crop canopy or on the stems. Most active flying insects (e.g. Diptera) were not considered to have been well sampled using these methods but were still recorded regularly.

Stem counts

To support the sheet-beat method of sampling, a careful inspection of a random selection of crop stems immediately surrounding the sheet was made to identify any invertebrates which may have avoided being shaken free.

Three whole stems were inspected at each sheet location, i.e. nine stems per panel. This also enabled an assessment of which species were effectively sampled by this method and which were not. For chrysomelids, this was the only way of assessing the presence and abundance of egg colonies on the leaf (Section 9.0). Leaf and stem galling was also assessed in this manner. The presence and abundance of rust pustules on the sample leaves was also recorded although these data are not presented here..

Recently cut stools did not have sufficient growth to facilitate sheet-beating during the spring and early summer. These panels were sampled for invertebrates by a careful inspection of all the stems on a selection of stools, identifying and counting animals *in situ* and collecting those which could not be identified.

7.3.3 Sampling ground and rove beetles using pitfall traps

Between 50 and 60 pitfall traps were installed at each of the three pitfall trap sites in southern England in August 1995. A pitfall trap consisted of a plastic cup, set into the ground and filled with a water and preservative solution. Over a period of one or two weeks, ground and rove beetles that fell into the trap were collected and returned to the laboratory for sorting and identification.

7.3.4 Invertebrate identification

Sheet-beat and other insect samples were usually collected using a pooter and sorted and identified back at The GCT laboratory. Individual animals were identified to species level if possible but only to genus or order in the case of some difficult to identify groups (e.g. members of the Hymenoptera and certain Hemiptera or members of other groups which occurred only infrequently).

7.3.5 Analysis

Species lists were compiled for each collection method. For the canopy beating samples and stem searches, the number of individuals for each species or species group per m^2 of canopy was calculated. We used these data to compare the abundance and diversity of invertebrates between willow and poplar SRC using analysis of variance (ANOVA). Comparisons were also made between the SRC data and data collected by others for free-living willows and poplars, and for cereals.

7.4 Results

7.4.1 Invertebrates in the canopy of the coppice plantations

Over 120 invertebrate species or groups of species were collected and identified from the beat samples in the 12 willow plantations in 1994 (Table 7.1, Appendix 7A), of which 77 were herbivorous species. The equivalent figures for the nine poplar plantations were 70 species in total and 48 herbivores (Table 7.2, Appendix 7B). It is likely that the actual number of different species collected was considerably more than these figures indicate. Due to the differences in sample size, it is not possible to conclude that the willow sites contained a greater diversity of invertebrates than the poplar from these data although it does suggest this.

In Sage & Tucker (1997, *Invertebrates in the canopy of willow and poplar short rotation coppices*), we describe how we made a comparison between willow and poplar by considering SRC sites in England only (nine for each tree species), and by taking account of differences in the age of sites and mean date of sampling for each tree species group. The species lists in Tables 7.1 and 7.2 were also compressed to give a total of 48 species or species groups (Table 7.3). From this we found that the willow sample plots contained a significantly greater diversity of invertebrates than the poplar plots (38 compared to 28), and significantly more individuals of most groups.

Table 7.3. Mean invertebrate numbers with standard deviation (per m^2 plan) collected from each sample plot for the SRC sites in England. For willow n=9 and for poplar n=9. Differences between groups are by 't'test.

	Willow	SD	Poplar	SD	P
Hymenoptera: Parasitica	0.243	0.452	0.019	0.047	ns
Hymenoptera: Symphyta	0.251	0.234	19.48	69.26	ns
Other Hymenoptera	0.043	0.117	0.595	1.491	ns
Diptera	0.567	0.770	0.088	0.161	<0.05
Neuroptera	0.012	0.040	0.000	0.000	ns
Tricoptera	0.008	0.036	0.000	0.000	ns
Plecoptera	0.002	0.009	0.000	0.000	ns
Mecoptera	0.008	0.036	0.000	0.000	ns
Coleoptera: Chrysomelidae	7.546	13.29	11.64	18.47	ns
Coleoptera: Curculionidae	0.129	0.234	0.097	0.181	ns
Coleoptera: Coccinelidae	0.038	0.085	0.013	0.046	ns
Coleoptera: Staphylinidae	0.065	0.125	0.009	0.031	ns
Coleoptera: Carabidae	0.016	0.043	0.000	0.000	ns
Coleoptera: Cantharidae	0.020	0.074	0.000	0.000	ns
Lepidoptera	0.605	0.991	0.213	0.337	ns
Arachnidae	0.807	0.990	0.554	0.621	ns
Hemiptera: Aphidae	0.849	1.464	0.106	0.258	ns
Other Homoptera	0.413	0.544	0.237	0.338	ns
Heteroptera	0.743	1.041	0.129	0.270	<0.05
Gastropoda	0.124	0.252	0.038	0.100	ns
Total invertebrates	4.737	3.637	2.098	2.463	<0.05

For both tree species Table 7.3 indicates that herbivorous leaf beetles (Coleoptera: Chrysomelidae) were the most widespread and abundant invertebrates (Section 8.0). Flea beetles (Coleoptera: Chrysomelidae Halticinae) were also widespread but less common. A sawfly larvae, *Nematus melanaspis* (Hymenoptera: Symphyta), reached high densities at one poplar site and occurred at over half of the other poplar site surveyed. *Nematus flavescens* occurred at most willow sites. Various Lepidoptera larvae (butterflies and moths) were encountered at almost all sites, the most frequently recorded species being *Operophtera brumata* (winter moth). Spiders (Arachnidae), aphids and froghoppers (Homoptera), shield bugs, flower bugs and mirid bugs (all Heteroptera), weevils (Coleoptera: Curculionidae) and snails (Gastropoda) were all encountered at several sties each (Table 7.3).

The other groups listed in Table 7.3 tend to include species that would not be sampled effectively by the sheet beating method. As already indicated, flies, wasps and other genus whose primary mode of movement is flight are not well sampled by beating. Despite this, various fly (Diptera) and wasp species (Hymenoptera) and to a lesser extent midges (Culicidae) were collected from many sites. These groups were sampled more effectively using different collection methods undertaken in 1995 (see Section 7.4.3).

The stem searches indicated the presence of one or two species largely missed by the beating method. The aphids *Tuberolachnus salignus* and *Pterocomma salicis* giant willow aphid (Hemiptera: Aphidae) did occasionally appear in the sheet samples but were usually encountered during the stem searches (Section 8.0). They were noted as being patchily abundant in some plantations, especially in late summer. At one site in the UK, a midge *Dasinuera marginemtorquens* was found to be abundant during stem searches.

7.4.2 Ground and rove beetles

Thirty species of ground beetle and 15 rove beetle species were collected from the pitfall traps in 1995 by Baxter (1996) (Table 7.4). The ground beetles were far more common representing 97% of the total number of beetles collected (2893).

Table 7.4. Ground and rove beetles collected from pitfall traps at three sites

Carabidae	Staphilinidae
Carabus violaceus	Micropeplinus fulvus
Carabus nemoralis	Tachinus marginellus
Carabus glabratus	Tachinus sp.
Cychrus rostratus	Metopsia clypeata
Leistus ferrugineus	Stenus sp.
Notiophilus biguttatus	Stenus brunnipes
Loricera pilicornis	Oxypoda sp.
Clivina fossor	Staphylinus sp.
Bembidion sp.	Staphylinus olens
Ophonus sp.	Gabrius sp.
Harpalus sp.	Philonthus sp.
Pseudophonus pubescens	Quedius sp.
Patrobus sp.	Xantholinus sp.
Patrobus excavatus	Oxytelus sp.
Amara sp.	Neobisnius sp.
Calathus sp.	Seven unidentified species
C.fuscipes	
C.piceus	
C.melanocephalus	
Cyrtonotus fulvus	
C.aulicus	
Poecilus cupreus	
P.coerulescens	
Pterostichus madidus	
P.macer	
P.niger	
P.vulgaris	
Olisthopus rotundatus	
Tachys sp.	
One unidentified species	

7.5 Discussion

For both tree species many of the invertebrates collected from within the canopy at the SRC study sites by beating and stem searches were identified to genus only and species separation was made within the constraints of time and effort that apply to most studies of invertebrate communities. Many closely related species are almost identical and would have been overlooked. The numbers of invertebrates collected for both willow and poplar were therefore probably underestimates. Despite this the list of species, particularly from the willow samples was long. Many would be associated with the crop itself and would not be present without it. Of the 125 in Table 7.1 (Appendix 7A), 63 % are classified as phytophagous and the great majority of these would have been feeding on the crop. Some of these would be willow specialists, such as some Lepidoptera larvae and chrysomelid beetles amongst others, while some would be more generalist feeders. The poplar contained proportionally fewer predatory and parasitic species as sampled with 69 % of the 71 species listed in Table 7.2 (Appendix 7B) being herbivores.

The pitfall trapping provides an insight into some of the other invertebrates associated with these crops, although it is not reasonable to conclude most of the species collected from these groups would not have occurred a the site had the SRC not been there. Most of the ground and rove beetles are predatory species although some are polyphagous. The data on these beetles were collected primarily to provide an indication on the potential for natural pest control through predation of the main pest species and are discussed in more detailed in section 13.0. In 1994 we reported the results of butterfly surveys in and around SRC crops (*Sage et al*. 1994). We found 14 species, mostly occupying the coppice headlands.

7.5.1 Phytophagous insects on free-living willows and poplars

Kennedy and Southwood (1984) listed 450 phytophagous insects (or mites) on five willow species (*Salix* spp.) in Britain, more than any other tree or genus (Table 7.5). This rich insect fauna is often given as a reason for including native willows in new woodland planted as a wildlife habitat. Poplar also contained an abundant invertebrate fauna (189 phytophagous species) compared to most other British tree species.

Table 7.5. Invertebrates associated with trees in Britain, from Kennedy & Southwood (1984). These are phytophagous insects, all of which eat part of the tree at some stage of their life cycle and hence excludes predators and parasites that depend only on other insects. The entire list is included to provide a context for the numbers associated with willow and poplar.

Willow	**450**	Rowan	58
Oak	423	Lime	57
Birch	334	Field maple	51
Hawthorn	209	Hornbeam	51
Poplar	**189**	Sychamore	43
Scots pine	172	Larch	38
Blackthorn	153	Juniper	32
Alder	141	Sweet chestnut	11
Elm	124	Holly	10
Crab apple	118	Horse chestnut	9
Hawthorn	106	Walnut	7
Beech	98	Yew	6
Norway spruce	70	Holm oak	5
Ash	68	False Acacia	2

The number of insects is greatest on trees that were abundant in the countryside and which had been in Britain for a long time (Kennedy & Southwood 1984). Ten species of willow (*Salix. alba, S. fragilis, S. purpurea, S. viminalis, S. triandra, S. petandra, S. caprea, S. cinerae* agg., *S. aurita, S. repens,*) and three poplars (*Populus tremula, P. canescens, P. nigra*) are considered to be 'native' to Britain (e.g. Rose, 1981) and several of these are commonly used in breeding programmes to develop SRC varieties, for example *Populus nigra* (Black poplar) in ‘Ghoy’ ‘Gibecq’ and ‘Robusta’ and *Salix viminalis* (Osier) in the majority of commercial willow varieties. There are therefore genetic similarities between many of the willow and poplar varieties grown for SRC in Britain and free-living trees of the same species in the British countryside. It is then perhaps not surprising that many of the long list of insects associated with willows and poplar trees will colonise SRC plantations, especially where wild willow and poplar plantations occur in the locality (Section 10.0).

A key difference however is the age and maturity of uncultivated trees compared to SRC. Many phytophagous insects will only use mature trees, for example many of the wood-boring species, and would not be expected to be found on SRC crops. Similarly, SRC does not normally provide crevices in its stems, which many insects will use as refuge and shelter. It is likely therefore, that for these and other reasons, the number of phytophagous insects that could potentially colonise SRC plantations will be less than the figures produced by Kennedy & Southwood (1984), but more than the numbers recorded in the surveys described here, i.e. between 125 and 450 for willow and 71 and 189 for poplar.

7.5.2 Comparing invertebrate numbers between willow and poplar

In comparing tree species, the willow SRC did contain more invertebrate species groups than otherwise similar poplar stands, reflecting the findings of Kennedy & Southwood (1978) on free-living trees (Table 7.5). Discounting the main pest species groups (see section 8.0), the willow also contained more invertebrate individuals than the poplar. The greater abundance and diversity of non-pest invertebrate species in willow also has implications for biodiversity potential of new SRC plantations on farmland. Some invertebrates such as the plant bugs (Hemiptera, Homoptera and Heteroptera) were encountered frequently (more than one per m^2 of willow on average), but did not attain high densities at any site (illustrated by the lower standard deviation in Table 7.3). Caterpillars were also recorded frequently in low numbers and only occasionally reached high numbers on individual coppice stools. Many of the other insect species listed in Table 7.3 are not herbivores (see Table 7.6).

Table 7.6. The number of herbivorous and carnivorous invertebrate groups collected from the 12 willow and 9 poplar SRC beat samples and stem searches.

HERBIVORES	Poplar	Willow	CARNIVORES	Poplar	Willow
Beetles and weevils	13	18	Predatory beetles	4	9
Flies and midges	4	11	Flies, lacewings etc.	2	7
Hoppers and aphids	5	12	Parasitic wasps	8	17
Plant bugs	8	13	Spiders	8	12
Sawfly larvae	2	2	Others	0	2
Moth larvae	8	7			
Others	8	14			
Total	48	77		22	47

7.5.3 Comparing the number of invertebrates on SRC with cereal crops

A general comparison can be made between SRC and cereal crops. SRC may be planted on a wide variety of sites and displace as many land-uses, but if set-aside becomes a seasonal fixture, SRC may replace cereal fields. The invertebrate community of cereal fields has been extensively studied and the total number of phytophagous invertebrate species that may live at least part of their life cycle on wheat or barley in Britain is around 45 , 10 % of that found on willow (Table 7.7) and around a third of the number found by this study in the canopy of SRC in one season. Of the cereal insects, a handful can become pests.

Table 7.7. The number of phytophagous insect species, by insect order, on willow and poplar trees compared to oak (from Kennedy & Southwood, 1984), and on wheat (Gair *et al*. 1972). In each case, the table includes all insects where the tree or cereal is the normal or typical host plant.

		Willow	Poplar	Oak	Cereal
Coleoptera	Beetles & weevils	64	32	67	5
Diptera	Flies	34	14	7	19
Homoptera	Hoppers and aphids	56	34	43	8
Heteroptera	Other bugs	21	8	38	1
Hymenoptera	Wasps and sawflies	104	29	70	3?
Lepidoptera	Butterflies & moths	162	69	189	9

SRC will therefore lead to a net increase in the invertebrate biodiversity in most farmland situations. This will also encourage other wildlife to colonise plantations, further improving the biodiversity potential in the area, and possibly providing habitat opportunity for some declining species. In a previous study we found that many songbird species nest in and around SRC plantations in the spring (Sage & Robertson, 1996). The majority will be feeding their young invertebrates, even if as adults they are herbivorous, many of which it can be assumed are collected from the coppice. In section 13.0 we look in more detail at songbird predation of invertebrates in SRC.

The extensive invertebrate sampling programme dominated the project in terms of effort during the 1994 and was also prominent in 1995. By the end of the period we had addressed our aim to quantify the characteristic invertebrate species of the willow and poplar coppices, and to identify which species were defoliating the coppice leaf or apparently causing other damage (Section 8.0). The work also provided us with the necessary information to define a more specific programme of research on the key pest species of SRC, the chrysomelids.

7.6 References

Baxter D.A. (1996) Carabids. Unpublished report. Wye College.

Gair R., Jenkins J.E.E. & Lester E., (1972) *Cereal Pests and Diseases* - 4th ed. Farming Press Ltd.

Kennedy C E J. Southwood T R E. (1984) The number of species of insects associated with British trees: a re-analysis. *Journal of Animal Ecology,* **53**, pp. 455 - 478.

Kendall, D. A.; Hunter, T., Arnold, J., Morris, T., Wiltshire, C. W., (1996) Susceptibility of willow clones (*Salix* spp.) to Herbivory by *Phyllodecta vulgatissima* (l.) and *Galerucella lineola* (Fab.) (Coleoptera, Chrysomelidae). *Annals of Applied biology* **129**: 379-390.

Rose, F. (1981) *The Wild Flower Key.* Frederick Warne & Co., London.

Sage, R.B. & Robertson, P.A. (1996) Factors affecting songbird communities using new short rotation coppice habitats in spring. *Bird Study* **43**: 201-213.

Sage, R.B., Robertson, P.A., & Poulson, J.G. (1994). Enhancing the conservation value of short rotation coppice - Phase 1, the identification of wildlife conservation potential. *ETSU B/W5/00277/REP*. Harwell Laboratories, Oxford. 119pp.

Sage, R.B. & Tucker, K. (1997) Invertebrates in the canopy of willow and poplar short rotation coppices. *Aspects of Applied Biology* **49**: 105-111.

Sage, R.B. & Tucker, K. (In press) The distribution of *Phratora vulgatissima* (Coleoptera: Chrysomelidae) on cultivated willows in Britain and Ireland*. European Journal of Forest Pathology* ??: 00-00.

Southwood T R E. (1978) *Ecological Methods, 2nd edition.* Chapman and Hall, London.

Tabbush, P.; Parfitt, R., (1996) Poplar and willow clones for short rotation coppice. *Forestry Commission Research Information Note 278*. Alice Holt Research Station, Farnham, Surrey.

Appendix 7A

Table 7.1 Invertebrates recorded from the canopy of 12 willow plantations in summer 1994. H/P is (H)erbivorous or (P)redatory/parasitic. Polyphagous species are classified as herbivores in this table.

Order, family or species name	Common name	No. spp.	H/P
Hymenoptera: Parasitica	**Parasitoid wasps**		
Braconid sp.	Parasitoid wasp	8	P
Chalcid sp.	Parasitoid wasp	6	P
Ichneumonid sp.	Ichneumon fly	3	P
Hymenoptera: Symphyta	**Sawflies**		
Nematus sp. larva	Sawfly	1	H
Other Tenthredinidae	Sawfly	1	H
Hymenoptera: Formicidae	**Ants**		
Formicid sp.	Ant	2	H
Diptera	**True flies**		
Dolichopodid sp.	Predatory fly	1	P
Syrphus sp.	Hoverfly larva	1	P
Bibio sp.	Bibionid fly	2	H
Culicid sp.	Mosquito	3	H
Dasinuera sp	Midge	1	H
Other *culicid*	Midge	1	H
Sepsis sp.	Picture-winged fly	1	H
Tipulid sp.	Cranefly	1	H
Phora sp.	Scuttle-fly	1	P
Psychodid sp.	Owl midge	1	H
Scathophage sp.	Dung fly	1	H
Psocoptera	**Barklice**		
Psocid sp.	Bark louse	1	H
Orthoptera	**Crickets and grasshoppers**		
Meconema thalassinum	Oak bush cricket	1	H
Neuroptera	**Lacewings and alder-flies**		
Chrysopid sp.	Green lacewing	1	P
Hemerobid sp. larva	Brown lacewing larvae	1	P
Sialis sp.	Alder fly	1	P
Dermaptera	**Earwigs**		
Forficula auricularia	Common earwig	1	H
Tricoptera	**Caddis flies**		
Limnephilid sp.	Caddis fly	1	H
Other *Trichoptera sp.*	Caddis fly	1	H
Plecoptera	**Stoneflies**		
Plecoptera sp.	Stonefly	1	H
Mecoptera	**Scorpion flies**		
Panorpa sp.	Scorpion fly	1	P
Coleoptera: Chrysomelidae	**Leaf-eating beetles**		
Chaetocnema concinna	Knotgrass flea beetle	1	H
Chalcoides aurata	Willow flea beetle	1	H
Chalcoides aurea	Willow flea beetle	1	H

Chalcoides plutus	Willow flea beetle	1	H
Galerucella lineola	Brown willow beetle	1	H
Gastrophysa polygoni	Knotgrass leaf beetle	1	H
Lomaspilis marginata larva	Ragwort leaf beetle	1	H
Plagiodera versicolora	Broader willow leaf beetle	1	H
Phyllodecta vulgatisima	Blue willow beetle	1	H
Coleoptera: Curculionidae	**Weevils**		
Anthonomus pedicularius	Weevil	1	H
Apion sp.	Weevil	2	H
Phyllobius sp.	Weevil	1	H
Sitona sp.	Weevil	1	H
Balanobius sp.	Weevil	1	H
Coleoptera: Coccinelidae	**Ladybirds**		
Adalia bipunctata	2-spot ladybird	1	P
Coccinella quatuordecampunctata	Ladybird	1	P
Coccinelliid larva	Ladybird		P
Thea 22-punctata	22 spot ladybird	1	P
Coleoptera: Staphylinidae	**Rove beetles**		
Tachyporus sp.	Rove beetle	1	P
Tachyporus sp. larva	Rove beetle larva		P
Coleoptera: Carabidae	**Ground and tiger beetles**		
Pterostichus diligens	Ground beetle	1	P
Dromius sp.	Ground beetle	1	P
Leistus sp.	Ground beetle	1	P
Coleoptera: Cantharidae	**Soldier beetles**		
Cantharis livida	Soldier beetle	1	P
Cantharis rufa	Soldier beetle	1	P
Coleoptera: Cerambycidae	**Longhorn beetles**		
Stenocorus meridianus	Longhorn beetle	1	H
Coleoptera	**Detritivorous beetles**		
Monotoma sp.	Detritivorous beetle	1	H
Acritus sp.	Detritivorous beetle	1	H
Lepidoptera	**Butterfly and moth larvae**		
Archiearis notha larva	Light orange underwing larva	1	H
Colotois pennaria larva	Feathered thorn moth larva	1	H
Eligmodonta ziczac larva	Pebble prominent larva	1	H
Laothoe populi larva	Poplar hawkmoth larva	1	H
Orgyia antigua larva	Vapourer moth larva	1	H
Operophtera brumata larva	Winter moth larva	1	H
Tanthia icteritia larva	Sallow moth larva	1	H
Arachnidae	**Spiders and harvestmen**		
Aranid sp.	Spider	12	P
Opiliones sp.	Harvestman	1	H
Hemiptera: Aphididae	**Aphids**		
Aphid sp.	Green aphid	2	H
Tuberolachnus salignus	Stem willow aphid	1	H
Pterocomma salicis	Stem willow aphid	1	H
Other Homoptera	**Hoppers and other bugs**		
Aphrophorid sp.	Froghopper	3	H
Delphacid sp.	Froghopper	2	H
Cicadellid sp.	Leafhopper	2	H
Psyllid sp.	Plant louse	1	H
Heteroptera	**Bugs**		
Palomena sp.	Shield bug	1	H
Acanthosoma sp.	Shield bug	2	H

Pentatomid sp.	Shield bug	1	H
Anthocoris sp.	Flower bug	2	H
Other Cimicidae	Flower bug	2	H
Lygocoris pabulinus	Common green capsid	1	H
Heterotoma sp.	Mirid bug	1	H
Other Capsid sp.	Mirid bug	4	H
Other arthropods	**Arthropods**		
Chilopda sp.	Centipede	1	P
Armadilid sp.	Woodlouse	1	H
Diploda sp.	Millipede	1	H
Gastropoda	**Slugs and snails**		
	Snail	2	H
	Slug	1	H
Total	At least:	125	H=78

Appendix 7B

Table 7.2 Invertebrates recorded from the canopy of 9 poplar plantations in summer 1994. H/P is (H)erbivorous or (P)redatory/parasitic. Polyphagous species are classified as herbivores in this table.

Order, family or species name	Common name	No. spp.	H/P
Hymenoptera: Parasitica	**Parasitoid wasps**		
Braconid sp.	Parasitoid wasp	5	p
Chalcid sp.	Parasitoid wasp	2	P
Ichneumonid sp.	Ichneumon fly	1	P
Hymenoptera: Symphyta	**Sawflies**		
Nematus melanaspis. larva	Gregarious poplar sawfly larvae	1	H
Other Tenthredinidae	Sawfly	1	H
Hymenoptera: Formicidae	**Ants**		
Formicid sp.	Ant	2	H
Diptera	**True flies**		
Dolichopodid sp.	Predatory fly	1	P
Bibio sp.	Bibionid fly	1	H
Culicid sp.	Mosquito	1	H
Tipulid sp.	Cranefly	1	H
Phora sp.	Scuttle-fly	1	P
Scathophaga sp.	Dung fly	1	H
Psocoptera	**Barklice**		
Psocid sp.	Bark louse	1	H
Orthoptera	**Crickets and grasshoppers**		
Meconema thalassinum	Oak bush cricket	1	H
Dermaptera	**Earwigs**		
Forficula auricularia	Common earwig	1	H
Coleoptera: Chrysomelidae	**Leaf-eating beetles**		
Chalcoides aurata	Willow flea beetle	1	H
Chalcoides aurea	Willow flea beetle	1	H
Chalcoides plutus	Willow flea beetle	1	H
Chrysomela populi	Large red poplar leaf beetle	1	H
Phyllodecta vitellinae	Brassy willow beetle	1	H
Coleoptera: Curculionidae	**Weevils**		
Apion sp.	Weevil	1	H
Apion minimum	Weevil	1	H
Apion nigratarse	Weevil	1	H
Apion ruferostris	Weevil	1	H
Balanobius salicivorous	Weevil	1	H
Otiorhynchus sp.	Weevil	1	H
Sitona sp.	Weevil	1	H
Coleoptera: Coccinelidae	**Ladybirds**		
Adalia bipunctata	2-spot ladybird	1	P
Coccinelliid larva	Ladybird		P
Coleoptera: Staphylinidae	**Rove beetles**		
Tachyporus sp.	Rove beetle	1	P
Coleoptera: Cantharidae	**Soldier beetles**		
Cantharis rustica	Soldier beetle	1	P
Coleoptera: Elateridae	**Click beetles**		
Agriotes lineatus	Click beetle	1	P

Coleoptera:	**Detritivorous beetles**		
Monotoma sp.	Detritivorous beetle	1	H
Acritus sp.	Detritivorous beetle	1	H
Lepidoptera	**Butterfly and moth larvae**		
Alcis repandata larva	Mottled beauty larva	1	H
Archiearis notha larva	Light orange underwing larva	1	H
Orgyia antiqua larva	Vapourer moth larva	1	H
Furcula bifida larva	Poplar kitten moth larva	1	H
Laothoe populi larva	Poplar hawkmoth larva	1	H
Lomaspilis marginata larva	Clouded border larva	1	H
Operophtera brumata larva	Winter moth larva	1	H
Xanthia icteritia larva	Sallow moth larva	1	H
Arachnidae	**Spiders and harvestmen**		
Aranid sp.	Spider	8	P
Hemiptera: Aphididae	**Aphids**		
Aphid sp.	Green aphid	1	H
Other Homoptera	**Hoppers and other bugs**		
Aphrophorid sp.	Froghopper	1	H
Cicadellid sp.	Leafhopper	2	H
Psyllid sp.	Plant louse	1	H
Heteroptera	**Bugs**		
Acanthosoma sp.	Shield bug	1	H
Palomena sp.	Shield bug	1	H
Anthocoris sp.	Flower bug	2	H
Heterotoma sp.	Mirid bug	1	H
Other Capsid sp.	Mirid bug	3	H
Other arthropods	**Arthropods**		
Armadilid sp.	Woodlouse	1	H
Gastropoda	**Slugs and snails**		
	Snail	1	H
	Slug	1	H
Total	At least:	71	H=49

8.0 WHICH INVERTEBRATES ARE, OR COULD BECOME, PESTS?

8.1 Summary

From the SRC invertebrate data presented in Section 7.0 we identified several groups of species which occurred frequently at the 21 sample sites and which, according to the literature, have potential to cause damage to the crop. Further data on the occurrence of these insect groups were collected from these and a further 11 SRC sites in 1995.

We compared the abundance and distribution of these insect groups with a measure of defoliation recorded from each sample plot using multivariate statistical techniques. In both 1994 and 1995, defoliation was significantly and positively related to the abundance of a group of leaf-eating beetles (Coleoptera:chrysomelidae), and to the time of year.

Phratora vulgatissima was the commonest chrysomelid on willows and *P. vitellinae* on poplar. Defoliation increased during the summer, despite leaf turnover. Most damage by chrysomelids occurred in mid-summer, when the larvae of these beetles hatched and fed in groups on the willow and poplar leaves.

Several other insects were found to be responsible for isolated incidences of crop damage, in particular a sawfly larvae causing defoliation of poplar coppice and a midge species causing extensive leaf-galling on willow. Caterpillars caused very local stripping of stools at several sites. Aphid colonies on willow stems were also encountered. Little evidence of stem boring was found in the sample plots.

At several sites, data on the abundance of defoliating insects were collected on several occasions during the summer. Data on defoliation, leaf area and crop growth increments were also collected and compared with insect data. These comparisons indicate that while pest free SRC plots grew steadily throughout the summer plots containing numerous chrysomelids did not.

8.2 Introduction

The majority of insects collected from the beat samples in the willow and poplar coppices in 1994 were herbivores (Tables 7.1 and 7.2, Appendix 7 and 7B, Section 7.0). Pest species are simply herbivorous species (phytophagous or polyphagous) that become excessively numerous so by definition all of these are potentially pests (excessive implies exceeding some threshold beyond which economic losses to yields occur). In reality however, natural processes check the population size of most species for most of the time and the majority of invertebrates never reach this level.

In this section, we identify the most abundant and widespread herbivorous invertebrate groups in modern SRC plantations in Britain and Ireland and then try and link the abundance of certain species or groups of species with a measure of defoliation recorded during the extensive surveys. Certainly some of the species listed in Section 7.0 appeared to be sufficiently numerous to be causing significant damage to the crop. We also note all species recorded in the surveys which others have described as pests of willow or poplar anywhere in NW Europe (Sage, 1994).

We also attempt to demonstrate a link between invertebrate abundance with crop growth, by sampling invertebrates, defoliation and coppice stem size at regular intervals at several sites. Quantifying the abundance of a pest in relation to the damage it causes means that we can make judgements about the value, in terms of cost benefits, of any pest control or management steps that could be taken. In reality however, it is difficult to do this in such a way that the results can be applied from one situation to another. However, by considering the results presented here in the context of studies by others, particularly laboratory studies of defoliation and growth losses, we are able identify the main pest threats in UK and to make an assessment of when significant economic losses may occur.

8.3 Methods

8.3.1 Site selection and invertebrate sampling

Potential pest species were identified from the general invertebrate surveys at the 21 sites in 1994. Site selection and the invertebrate sampling strategy for these surveys are described in Section 7.0. In 1995 extensive invertebrate monitoring was continued at a larger sample of 32 sites (which included most of the 21 1994 sites). At each site in both years between 1 and 5 plots were sampled. Both willow and poplar plots were sampled at some sites in 1995 giving a sample size of 102 plots. In 1995, only insect species that have pest potential were monitored. In subsequent years, further data on invertebrates and pest status were collected and are reported in Sections 9.0 to 12.0.

In 1994, of the 21 extensive invertebrate monitoring sites, a sample was selected for more intensive study, with several surveys undertaken at intervals during the spring and summer at each. These sites were selected to include a range of defoliation potential i.e. herbivorous invertebrate abundance, and equal representation by willow and poplar varieties. Six sites in southern England fulfilled this criteria and all six were sampled at least twice. At two of these, one willow and one poplar, invertebrate samples were collected on four occasions during the year in one variety and at a further two, again one willow and one poplar, four invertebrate samples were collected from each of two varieties.

8.3.2 Measuring crop leaf area, defoliation and stem growth

At all 1994 invertebrate survey sites described in Sections 7.0 and 8.3.1, several measures of crop phenology were taken at the same time. At each invertebrate sampling point (three per plot), measurements were taken of the three randomly selected stools which were also searched for invertebrates (Section 7.3.2). For each stool, we counted the number of stems and randomly selected one of them. The stem length, diameter at 1 metre, depth of canopy and number of laterals were all recorded. Three lateral shoots were selected from which the number of leaves, the area of one of these leaves and the proportion leaf area lost to defoliation (holing and skeletonisation) was assessed. Selection of each stool, stem, lateral shoot and leaf was made using random number tables. Thus data on a sample of 27 leaves and laterals and nine stems and stools were collected from each invertebrate sampling plot. This process took approximately one man day for each plot.

This method enabled us to make an accurate assessment of defoliation but was time consuming. For the 1995 invertebrate survey, which involved more sites and plots, we estimated defoliation, taking account of our experience in measuring it the year before.

8.3.3 Investigating the relationships between crop growth, defoliation and invertebrate abundance

The 1994 and 1995 crop phenology data described above enabled comparisons to be made between the invertebrate data and defoliation. The herbivorous invertebrate groups were used as potential explanatory variables in a step-wise multiple regression analysis of defoliation. The categorical variable ‘site’ was used in the analysis to account for any between site effects that may affect the between plot effects. The continuous variable date was also included in the model. Regression analysis was used to confirm the statistical significance of selected variables. Analyses were carried out using SYSTAT (Wilkinson, 1990). Some of these results were published in Sage & Tucker (1997*, Invertebrates in the canopy of willow and poplar short rotation coppices*).

At the six 1994 intensive sampling sites, changes in invertebrate abundance and crop phenology over time could be investigated. We used the stem measurements to estimate mean stool biomass and hence to compare the relative growth of plots given different levels of herbivorous invertebrates and defoliation. These data are also presented graphically. Other crop phenology data described in 8.3.2 are presented in Section 3.0.

8.4 Results

8.4.1 The main abundant invertebrates

Pests or potential pests recorded from the canopy of the 9 poplar and 12 willow SRC sites surveyed in 1994 are listed in Tables 8.1 & 8.2. These lists, extracted from Tables 7.2 and 7.2 (Appendix 7A and 7B, Section 7.0), do not include all herbivorous species recorded in the surveys, only those considered to have a potential to achieve pest status (Sage, 1994).

Table 7.3 in Section 7.0 indicates that of these, the chrysomelid leaf beetles (Coleoptera: Chrysomelidae) were the most abundant and widespread group from both the willow and poplar (see also Sage & Tucker, 1997). Sawflies (Hymenoptera: Symphyta) were also common in poplar. However, the main species involved, *Nematus melanaspis* (gregarious poplar sawfly) reached high numbers at one site only (1100 larvae\m^2) and occurred at only low densities at the around half of the poplar plots (this is indicated by the large standard deviation for this group of species in Table 7.3, Section 7.0).

Three chrysomelids were common at many sites throughout the survey programme, *Phratora vitellinae* (brassy willow beetle), *P. vulgatissima* (blue willow beetle), and *Galerucella lineola* (brown willow beetle). *Phratora vulgatissima* was recorded from seven of the 12 willow sites in 1994 and 14 of the 24 willow sites in 1995, but not from the poplar sites. *P. vitellinae* were recorded from six of the nine poplar sites in 1994 and 10 of the 14 in 1995 and from no willow sites. *G. lineola* was collected from five willow sites in 1994 and four in 1995, all of which also contained *P. vulgatissima*.

Three willow plots and two poplar plots contained more than 20 adult chrysomelids per m^2 (plan) of crop when sampled in 1994 (Table 8.3) and in 1995 (Table 8.4). Both *Phratora* spp. and *G. lineola* occurred at levels up to 100 adults /m^2 in early and late summer and up to 175 larvae /m^2 in mid summer. The abundance and distribution of chrysomelids in Britain and Ireland in subsequent years, and changes within and between years, is considered in more detail in sections 10.0, 11.0 and 12.0.

Table 8.1. Insect species recorded in the UK poplar SRC plantations in 1994 that have the potential to become pests (extracted from Table 7.2, Section 7.0)

Order, family or species name	Common name	No. spp.
Hymenoptera: Symphyta	**Sawflies**	
Nematus melanaspis	Gregarious poplar sawfly larvae	1
Other Tenthredinidae	Sawfly	1
Diptera	**True flies**	
Tipulid sp.	Cranefly	1
Coleoptera: Chrysomelidae	**Leaf-eating beetles**	
Chalcoides aurata	Willow flea beetle	1
Chalcoides aurea	Willow flea beetle	1
Chalcoides plutus	Willow flea beetle	1
Chrysomela populi	Large red poplar leaf beetle	1
Phyllodecta vitellinae	Brassy willow beetle	1
Coleoptera: Curculionidae	**Weevils**	
Otiorhynchus sp.	Weevil	1
Sitona sp.	Weevil	1
Lepidoptera	**Butterfly and moth larvae**	
Alcis repandata larva	Mottled beauty larva	1
Archiearis notha larva	Light orange underwing larva	1
Orgyia antiqua larva	Vapourer moth larva	1
Furcula bifida larva	Poplar kitten moth larva	1
Laothoe populi larva	Poplar hawkmoth larva	1
Lomaspilis marginata larva	Clouded border larva	1
Operophtera brumata larva	Winter moth larva	1
Xanthia icteritia larva	Sallow moth larva	1
Hemiptera: Aphididae	**Aphids**	
Aphid sp.	Green aphid	1
Other Homoptera	**Hoppers and other bugs**	
Aphrophorid sp.	Froghopper	1
Gastropoda	**Slugs and snails**	
	Snail	1
	Slug	1

Table 8.2. Insect species recorded in UK willow SRC plantations in 1995 that have the potental to become pests (extracted from table 7.1, Section 7.0).

Order, family or species name	Common name	No. spp.
Hymenoptera: Symphyta	**Sawflies**	
Nematus flavesens larva	Sawfly	1
Other Tenthredinidae	Sawfly	1
Diptera	**True flies**	
Tipulid sp.	Cranefly	1
Dasinuera sp	Midge	1
Other *culicid*	Midge	1
Coleoptera: Chrysomelidae	**Leaf-eating beetles**	
Chalcoides aurata	Willow flea beetle	1
Chalcoides aurea	Willow flea beetle	1
Chalcoides plutus	Willow flea beetle	1
Galerucella lineola	Brown willow beetle	1
Plagiodera versicolora	Broader willow leaf beetle	1
Phyllodecta vulgatisima	Blue willow beetle	1
Coleoptera: Curculionidae	**Weevils**	
Phyllobius sp.	Weevil	1
Sitona sp.	Weevil	1
Lepidoptera	**Butterfly and moth larvae**	
Archiearis notha larva	Light orange underwing larva	1
Colotois pennaria larva	Feathered thorn moth larva	1
Eligmodonta ziczac larva	Pebble prominent larva	1
Laothoe populi larva	Poplar hawkmoth larva	1
Orgyia antigua larva	Vapourer moth larva	1
Operophtera brumata larva	Winter moth larva	1
Tanthia icteritia larva	Sallow moth larva	1
Hemiptera: Aphididae	**Aphids**	
Aphid sp.	Green aphid	2
Tuberolachnus salignus	Stem willow aphid	1
Pterocomma salicis	Stem willow aphid	1
Other Homoptera	**Hoppers and other bugs**	
Aphrophorid sp.	Froghopper	3
Gastropoda	**Slugs and snails**	
	Snail	2
	Slug	1

Table 8.3. The six SRC sites that contained more than 20 adult (ad) chrysomelids or 50 larvae (la) when sampled in 1994 (21 sites sampled).

Tree species	Date, 1994	Defol. %	*P. vit-ellinae*	*P. vulg-atissima*	*G. lineola*
Willow	30 Sept	68.3	0	52	65
Poplar	22 June	27.6	23 ad, 51 la	0	0
Willow	7 Sept	21.5	0	13	11
Poplar	30 June	16.2	59 la	0	0
Willow	8 June	11.4	0	22	0
Poplar	29 July	13.5	25	0	0

Table 8.4. The six SRC sites that contained more than 20 adult chrysomelids or 50 larvae (la), when sampled in 1995 (24 sites sampled).

Tree species	Date 1995	Defol %	*P. vit-ellinae*	*P. vulg-assima*	*G. lineola*
Willow	146	56.7	0	14	0
Willow	145	16.1	0	146	0
Poplar	95	3.6	175 la	0	0
Poplar	36	2.8	36	0	0
Poplar	74	14.5	15.6	0	0
Willow	91	56.6	0	47 la	100 la

8.4.2 Other species that have pest potential

One or more species of the genus *Chalcoides* (willow flea-beetles) were found at almost all the plots visited in both years but never in very high numbers. Cercopids (frog hoppers), cicadellids (leaf hoppers) and leaf aphids were frequently encountered but were never numerous. *Tuberolachnus salignus* and *Pterocomma salicis*, the stem willow aphids, have been encountered in large colonies on willow previously (e.g. anecdotal sightings in 1993, Royle *et al.* 1992) but were recorded relatively infrequently in surveys 1994 and 1995. In 1996 and 1997, more aphid colonies were again apparent. To address the pest potential of stem aphids in SRC plantations, The GCT initiated a three-year post graduate study of the two species in 1997 with Imperial College, London University. The results of this study will be reported in 1998 - 2000

Lepidoptera larvae were encountered at the majority of sites (Table 8.4). The most frequent species recorded was *Operophtera brumata* (winter moth) but many species were identified. At no site were Lepidoptera considered to be seriously defoliating the crop as a whole but at two plots significant defoliation could be attributed to Lepidoptera on a local scale. For example at a plot of poplar a number of branches were almost completely defoliated by *Semiothisa alternaria* (sharp-angled peacock) and in a willow plot the foliage had been stripped from one stool by *Phalera bucephala* (buff-tip moth).

Galling sawflies (Hymenoptera: Symphyta) were not encountered during the survey but galls were seen on willows not included in the survey. Galling midges (Diptera: Cecidomyidae) however, were recorded. Leaf furl caused by *Dasinuera* spp. was encountered in almost all plots of willow varieties to a small degree and particularly on narrow-leaved varieties. At one site in Yorkshire such leaf curl was extensive and may have been significantly effecting yield although there was no direct evidence of this. The species responsible was *Dasineura marginemtorquens* (although it doesn't have an official common name a good one might be leaf-curl midge). The majority of young leaves on all stools throughout certain varieties were curled while other neighbouring varieties were unaffected. Data on clonal selection by these midges at this site is reported in Section 11.0. Evidence of stem damage during the stool searches was encountered infrequently.

The abundance of the main invertebrate pest groups recorded for each sample in 1994 are listed in Appendix 8A with defoliation and crop growth data in Appendix 8B.

8.4.3 Defoliation

All sites surveyed contained some herbivorous insects in the canopy and evidence of leaf defoliation or galling. For the six survey sites where more than one sample was collected during the year, Figures 8.1 - 8.8 illustrate changes in the abundance of the commonest herbivores through time and allows a comparison between defoliation and crop phenology data. The Figures suggest that sites that contained most chrysomelids had higher total defoliation (compare for example Figures 8.1 and 8.2).

Considering all 1994 survey sites, in the step-wise regression analysis of defoliation as a dependant variable, and the various invertebrate groups (and date) as independent variables, only chrysomelids were significant, together with date (by plot, chrysomelids $T_{1,54}$=5.49, P<0.001, date $T_{1,54}$=3.13,P<0.005), see also Sage & Tucker (1997). For the 1995 dataset of 32 sites, a similar regression analysis again found that date and the abundance of chrysomelids were significantly related to the defoliation data (by plot, chrysomelids $T_{1,100}$=3.602, P=0.001, and day $T_{1,100}$=2.171,P=0.032).

These results indicate that across all survey sites, defoliation increased with the number of chrysomelids occupying each site, regardless of the number of other invertebrate groups recorded. Defoliation also increased during the summer. The relationship between defoliation and date for all plots in the 1994 sample is shown for willow and poplar separately (Figure 8.9), and for all the 1995 sample plots in relation to the abundance and chrysomelids (Figure 8.10). These relationships are described in Section 9.0. Figures 8.1 - 8.8 indicate that the adult beetles colonising the plantations cause early

Figure 8.1. Changes in the abundance of chrysomelids and other common herbivores, the defoliation they cause (holed and skeletonised) over time. Willow SRC, Henley, Buckinghamshire.

Figure 8.2. Changes in the abundance of chrysomelids and other common herbivores, the defoliation they cause (holed and skeletonised) and crop growth increments over time. Willow SRC, Bristol, Avon.

Figure 8.3. Changes in the abundance of chrysomelids and other common herbivores, the defoliation they cause (holed and skeletonised) and crop growth increments over time. Poplar SRC, Bristol, Avon.

Figure 8.4. Changes in the abundance of chrysomelids and other common herbivores, the defoliation they cause (holed and skeletonised) and crop growth increments over time. Willow SRC, Faringdon, Oxfordshire.

Figure 8.5. Changes in the abundance of chrysomelids and other common herbivores, the defoliation they cause (holed and skeletonised) and crop growth increments over time. Poplar SRC, Alice Holt, Hampshire.

Figure 8.6. Changes in the abundance of chrysomelids and other common herbivores, the defoliation they cause (holed and skeletonised) and crop growth increments over time. Willow SRC, Frensham, Hampshire.

Figure 8.7. Changes in the abundance of chrysomelids and other common herbivores, the defoliation they cause (holed and skeletonised) and crop growth increments over time. Poplar SRC, Frensham, Hampshire.

Figure 8.8. Changes in the abundance of chrysomelids and other common herbivores, and the defoliation they cause (holed and skeletonised) over time. Willow SRC, Buckfast, Devon.

Figure 8.9. The relationship between insect defoliation and date for all plots in the 1994 sample for both willow and poplar.

Figure 8.10. The relationship between chrysomelid abundance and date for all plots in the 1995 sample for both willow and poplar.
season holing of the leaves which is followed by skeletonisation from larval feeding.

FIGURE 8.1 – 8.10 NOT AVAILABLE ELECTRONICALLY

In terms of the magnitude of defoliation, Figures 8.1 to 8.8 indicate that of the intensive monitoring sites, four plots at three of them suffered in excess of 10 % defoliation for most of the season (note that the intensive monitoring sites were not a representative sample of the UK sites). Looking at the extensive survey data from 1994 and 1995, several sites in both years were substantially defoliated (>20% leaf loss when sampled) by at least one of the three chrysomelids *Phratora vitellinae* (brassy willow beetle), *P. vulgatissima* (blue willow beetle) or *Galerucella lineola* (brown willow beetle) (Table 8.3 & Table 8.4). However, to properly quantify the size and impact of a chrysomelid population it is necessary to sample abundance and damage regularly through the season.

8.4.4 The impact of defoliation on crop growth

Of the four intensive monitoring sites at which four visits were made to each plot in 1994, the maximum number of adult chrysomelids, sawfly and moth larvae recorded in each of the six survey plots on any one occasion are given in Table 8.5 (these data are from the same datasets for Figures 8.1 to 8.8). The Table indicates that the Bristol site and Friars Court both contained a high abundance of herbivorous insects, particularly chrysomelids, and Alice Holt slightly less so. The Wishanger site contained few herbivorous insects.

At the Wishanger site, both the willow and poplar hybrids showed a statistically significant increase in stem length and/or circumference during the 1994 growing season from a sample of nine stems (Table 8.6). This sort of growth increment would be expected from a biomass production crop. The four plots (three sites) that contained high numbers of herbivorous pests showed proportionately smaller (and for n=9, statistically insignificant) increases in stem length and circumference (Table 8.6).

Table 8.5. The maximum number of insect pests per m^2 of crop throughout the season. Mean of 3 sheet-beat samples. 'Total' gives a crude measure of the relative 'defoliating capacity' of the insect pests.

Site	Hybrid	Phratora sp.	Galerucella lineola	Sawfly larvae	Caterpillars	Flea-beetles	Total
Wishanger	Columbia R. yr 1	0.17	0.0	0.33	0.0	0.0	0.5
Wishanger	Dasyclados. yr 1	0.0	0.0	1.33	0.5	2.0	3.83
Alice Holt	Beaupre. yr 1	32.3	0.0	0.5	1	4.0	37.8
Bristol	Beaupre. yr 2	49.0	0.0	5.7	4.7	22.7	82.1
Bristol	Korso. yr 2	43.7	0.0	1.33	3.5	0.5	49.0
Friars Court	SQ683. yr 1	9.2	95.7	2.7	1.0	6.5	115.1

Table 8.6. Growth statistics recorded from the six intensively sampled SRC hybrids. For stem length and circumference, 1 is from the first sample at the beginning of the season, and 2 at the end. DF=16. * significant difference.

Site	Hybrid	Stem Length 1, cm	Stem length 2, cm	Difference between 1 and 2	Stem circumf 1, mm	stem circumf 2, mm	difference between 1 and 2
Wishanger	Columbia R.	197.0	259.1	T=2.93 P=0.01*	42.1	53.1	T=1.67 P=0.12
Wishanger	Dasyclados	273.0	373.3	T=2.84 P=0.012*	46.1	68.8	T=2.67 P=0.017*
Alice Holt	Beaupre	232.3	289.1	T=1.51 P=0.15	46.3	59.0	T=0.391 P=0.36
Bristol	Beaupre	283.1	340.4	T=1.53 P=0.15	51.9	57.2	T=0.513 P=0.62
Bristol	Korso	405.9	394.0	T=-0.23 P=0.82	68.1	74.6	T=0.54 P=0.60
Friars Court	SQ683	193.9	217.4	T=1.41 P=0.18	29.0	35.4	T=1.79 P=0.093

8.5 Discussion

8.5.1 The common herbivorous insects

The results of the two years' sampling and monitoring described in this section indicate that species from most potential pest groups were encountered during the surveys (Sage, 1994). A notable exception were wood-boring beetle species. Virtually no evidence of stem damage by these beetles was recorded during the surveys although stem damage was occasionally encountered during the course of other work undertaken during the study (this indicated to us that we were not over-looking evidence of wood-boring during the stem searches). In particular in both 1994 and 1995 we found evidence of extensive stem boring in withy bed willows in Somerset which we attributed to the osier weevil *Chryptorhyncus lapathi* (Sage, Pers. Obs.). This species has been recorded in SRC plantations in Ireland and elsewhere in Europe (Neenan, 1990). The weevil bores galleries in willow stool beds and is a long established pest of withy bed willows. In other forestry, beetles from this group are often the most widespread and abundant pests of mature trees and in Southern Europe this group of species is reported as the most damaging of cultivated poplars (Sage, 1994). While this preference for older woody growth may limit boring attacks in SRC the coppice stool does age and is exposed to attack.. Species from this group may yet become a pest of SRC.

Various Lepidoptera larvae were recorded from almost all survey sites and occasionally locally significant defoliation occurred. Despite this none were causing significant damage. According to the literature, many moth larvae, including over 150 of the larger species, feed on willow and/or poplar. Most cause damage as larvae by defoliating the leaf but some species not recorded in this study will bore into stems, roots and shoots. Many are generalist species and are associated with other trees, for example the winter moth *Operophtera brumata* recorded in these surveys and noted as being abundant and damaging in the centre of one SRC site in Ireland (Neenan, 1990). The white satin moth *Leucoma salicis* and the puss moth *Cerura* have both been recorded in SRC plantations and will defoliate. Larvae of the poplar shoot borer *Gypsonoma aceriana*, can cause growth deformations particularly in the Spring. Similar damage by tortricid moths to the leading shoots and buds of willow has occurred in SRC in Scandinavia. The willow web moth *Halias chlorana* has been the most serious pest of SRC in Denmark (Sage, 1994).

The likely dipteran pests of willow and poplar SRC are mostly midges that gall or mine leaves, young shoots or buds. The larvae of the Terminalis midge *Dasinuera terminalis* form galls in shoot buds and hence damaging subsequent growth of the shoot. In cuttings plantations where straight stems are required, this type of damage is particularly important. In a previous survey of UK sites, this midge was recorded from several sites (Royle, 1992) and damage attributable to this species was noted during the course of other survey work in this study (Pers. Obs.,). In the surveys described here, we found leaf edge rolling by *Dasinuera marginemtorquens* at several sites and at one site it had caused widespread damage. Although less damaging than the Terminalis midge, this reduces effective leaf area and therefore growth (Glynn, 1996). Midges can have many generations in one year, so population can build up rapidly. Some willows hybrids are particularly susceptible to attack by gall-midges while others are almost completely resistant (Section 9.0). In Sweden, which has the largest area of willow SRC plantations in Europe, galling midge species are currently the most serious pest of willow SRC (Glynn, 1996).

The abundance of the Gregarious poplar sawfly *Nematus melanaspis* (Hymenoptera: Tenthredinidae) at one site in the surveys and the occurrence of the species at low densities at many others, indicates a potential for this species to become a more widespread pest. The young larvae skeletonise the leaves, while later instars can completely defoliate. However it is not widely reported as pest of willow and poplar elsewhere in Europe (Sage, 1994). Other defoliating and galling sawflies can be found in UK willow and poplar SRC plantations and are noted as pests of willow and poplars in general forestry texts. They may become a more widespread pest as both larval defoliators and as gallers.

Hemipteran pests of willow and poplar in NW Europe are mostly aphids but include scales and some plant bugs. Most suck the sap from growing shoots, extracting nutrients and reducing vigour, interrupting the flow of sap and causing cracks and holes. The Large or Giant willow aphid *Tuberolachnus salignus* and the Black willow aphid *Pterocomma salicis* are widely reported in colonies on the stems and shoots of willow SRC plantations throughout the UK and were observed frequently during the course of this study, but were not widespread in the two survey years (it is possible that the invertebrate survey methods used did not suit the apparently patchy distribution of stem aphids and numbers may have been overlooked). Little is known about the aphid-plant relationship in stem aphids on willow SRC but a PhD study began in October 1997, by a student of Imperial College London and funded by The GCT. The results of this study will be reported in 1998 - 2000. Scales such as *Chionaspis salicis* can cause similar damage. Plant suckers *Aphrophora* sp. have been recorded causing young shoots to wilt and shrivel by ringing the stem with feeding punctures (Royle, 1992). Evidence of damage by an Eriophyid mite was occasionally recorded by Royle (1992) but may have been overlooked during the surveys.

The data collected during 1994 and 1995 (and in subsequent years, Sections 9.0 to12.0) indicate that young willow and poplar growth in modern SRC plantations is very palatable to several chrysomelid beetles, in particular the brassy beetle *Phratora vitellinae* and the blue beetle *P. vulgatissima*, and to a lesser extent the brown willow beetle *Galerucella lineola* and several other species including flea beetles. Another chrysomelid *Chrysomela populi*, noted as a pest in forestry, was recorded from only one poplar site. The presence of and damage caused by chrysomelid beetles to in particular young willows and poplars is reported by other authors throughout Europe (Sage, 1994). Historically, chrysomelids were the most widespread pests of willow beds grown for basket making (Hutchinson and Kearns, 1930). We conclude therefore that chrysomelid beetles are the most widespread and abundant invertebrate species that have potential as pest species on SRC crops in the UK. Subsequent chapters in this report consider the ecology of chrysomelids and their management in more detail. Figures 8.1 - 8.8 provide some basic information on population dynamics which is built on in sections 9.0. The two *Phratora* spp are morphologically very similar. Kendall *et al.* (1996) describes taxonomic separation of the two species. As a rule of thumb however, the blue beetle is usually bluer than the brassy coloured brassy.

8.5.2 Defoliation and pest numbers

Defoliation is the most obvious manifestation of pest attack. Other authors have commented that it is easy to overlook other effects such as boring damage and sap extraction and hence to over emphasise the importance of defoliation or other leaf damage. We attempted to account for this potential bias by including stem searches in our methodologies. This enabled us to incorporate stem damage into the survey and we systematically searched for evidence of boring insects. Similarly the method enabled us to include the presence of stem aphids in the surveys. These insects however occurred very patchily within plantations and in time making them difficult to quantify without using transect or other area surveys.

A combination of different herbivores may cause significant defoliation without any single species or group of species being excessively abundant in itself. However, in the regression analysis of defoliation, of the invertebrate groups investigated, the level of defoliation across all sites in this study increased with the abundance of chrysomelids (and with the time of year) and was not related to any other invertebrates in both 1994 and 1995. This indicates that these beetles were not only the most widespread and abundance herbivorous insects on SRC but also caused at least a significant proportion of the recorded defoliation. These results define chrysomelids as the principle defoliating pests of SRC crops in Britain and Ireland.

Despite the significant relationships between chrysomelid abundance and defoliation, measured defoliation rates in this study were thought to respond to many crop factors such as stress, leaf-fall and replacement and are not necessarily a good indicator of actual pest abundance (this emphasises the importance of a large sample size in identifying significant effects). For example a defoliated hybrid growing in otherwise ideal conditions may show little leaf area loss due to a high turnover of leaves. Considering the intensive study sites, in the absence of many herbivorous insects, the recorded defoliation of the willow and poplar hybrids at the Wishanger sites remained, as expected, relatively low throughout the season (Figures 8.6 to 8.7). Similarly, the increasing trend in defoliation at Friars Court reflects the abundance of larvae and second generation adult chrysomelids from mid-summer on. In contrast, at the Bristol site, a mid summer increase in chrysomelid numbers on the willow did not lead to an increase in defoliation (although skeletonisation did occur following the appearance of larvae). At Alice Holt almost all leaf area loss was due to skeletonisation following larvae emergence, despite the apparent high abundance of adult beetles before and after the larval phase. Note also that at most intensive sites defoliation decreased at the end of the summer, presumably following reduced herbivory and leaf fall.

The relationship then, between the pest species and their host plant is complicated and variable and is clearly influenced by a variety of factors. Palatability and resistance, drought and weed stress, nutrient status, leaf toughness, insect mobility and so on, will all affect the way insect interact with the crop. This variability not only affects the way chrysomelid populations impact the crop, but also the way they can be studied. This is considered further in subsequent Sections.

We found that chrysomelid adults tended to eat holes in willow and/or poplar leaves or eat young shoots as adults, while larvae skeletonise the leaves. This is reflected in the later increase in skeletonisation in Figures 8.1 - 8.8 (larvae are not well sampled by the sheet beating method and it is likely that the abundance is under-estimated in these Figures). Defoliation can be extensive as populations build up over several seasons causing obvious damage and even killing stems. Lower levels of defoliation, particularly early in the season cause less obvious damage but will still lead to direct growth reductions and subsequent losses in biomass yield or will encourage a weedy understorey in coppices causing less direct growth losses.

8.5.3 Defoliation and stem growth

The growth curves in Figures 8.1 to 8.8 indicate poor growth for the two willow hybrids at Friars Court and Bristol and for the two poplar hybrids at Bristol and Alice Holt compared to the (pest free) willow and poplar plots at Wishanger. Statistically, six out of six study plots in the right direction (i.e. showing a certain consistency of results as here) would be a significant result in a binomial test. However we do not have a random sample, and the relatively poor growth of the coppice in all four of the intensive study plots that contained many chrysomelids may have been caused by any number of site factors. It has been suggested that poor growth as a consequence of stress reduces the plants resistance to herbivory and hence encourages greater pest abundance. While it may be that the poor growth recorded was due at least in part to the presence of the leaf eating insects, other factors may be more important.

A replicated trial with controls is required to confirm the impact of herbivory on growth. Such trials, undertaken in the laboratory by others, have shown that defoliation of willows and poplars by chrysomelids and other insects will negatively effect growth in certain circumstances (Larsson 1983, Bach 1994). Essentially if leaf area is limiting growth, i.e. that the coppice is receiving sufficient water and nutrients, growth reductions are linearly related to defoliation and the curve will pass through the origin. This means some growth losses will occur as soon as defoliation occurs. Field scale trials to investigate such trends have practical difficulties in creating and maintaining representative controls (i.e. with no herbivory). It is also difficult to assess the extent to which other factors are limiting growth so trials would be required at a sample of sites. Despite these limitations, we are planning to conduct a trial at one site during 1998 as part of a PhD research programme on Chrysomleids the GCT is supervising in conjunction with Imperial College, London University and funded by ETSU (B/M4/00532/03/00). The work of this study is described in more detail in Section 9.0.

Based on the results presented here, and in the context of other studies of defoliation and growth losses of willows and poplars (Larsson 1983, Bach 1994), we estimate that around 10 or more adult chrysomelid beetles per m^2 of crop in May or June (i.e. following full dispersal into the field (see Section 12.0) but before the larval stage) probably represents, or is likely to become, a high pest burden for SRC crops. We would suggest that SRC plantations which contain this many beetles would probably benefit from some sort of pest control or management strategy. In assessing beetle numbers however, it is important to consider the uneven distribution of beetles that usually exist in plantations and apparent changes in the abundance of these beetles through time (both within and between seasons). These effects are considered in detail in Section 9.0 and 11.0 respectively. It is important to note also that overall insecticide sprays are unlikely to be economically justified in anything but the most extreme cases. They will also be extremely damaging ecologically and reduce natural pest control process. A principle aim of this study is to develop an integrated pest management strategy for the pests identified here, as an alternative to overall insecticide applications. An IPM strategy for chrysomelids will be developed in the next Sections of this report.

8.6 References

Bach C E. (1994) Effects of herbivory and genotype on growth and survivorship of sand-dune willow (*Salix cordata*). *Ecological Entomology*, **19**, 303-309.

Brendell T. (1985) *Willows of the British Isles.* Shire Natural History, Aylesbury, UK.

Glynn C. (1996) *Costs in the interactions between a gall midge and willow.* Swedish University of Agricultural Sciences, Uppsala.

Hutchinson H P, Kearns H G H. (1930) The control of *Phyllodecta vitellinae.* L. (chrysomelidae). *Annual Report Agricultural and Horticultural Research Station, Long Ashton* 112-126.

Kendall D A, Wiltshire C W, Butcher M. (1996) Phenology and population dynamics of willow beetles (Coleoptera: chrysomelidae) in SRC willows at Long Ashton. *ETSU B/M4/00487/14/REP*, Harwell Laboratories, Oxford.

Kennedy C E J. Southwood T R E. (1984) The number of species of insects associated with British trees: a re-analysis. *Journal of Animal Ecology,* **53**, pp. 455 - 478.

Larsson S. (1983) Effects of artificial defoliation on stem growth in *Salix smithiana* grown under intensive culture. *Acta Oecologica. Oecologia applicata.* **4**: 343-349.

Neenan, M. (1990) Pests and Diseases. In: *Short rotation forestry as a source of energy*, edited by Anonymous, pp. 44-48.

Royle, D.J., Hunter, T., and Pei, M.H. (1992) Evaluation of the biology and importance of diseases and pests in willow energy plantations. *ETSU B 1258*, University of Bristol Department of Agricultural Sciences:ETSU, pp. - 77.

Sage, R.B. & Tucker, K. (In press) The distribution of *Phratora vulgatissima* (Coleoptera: Chrysomelidae) on cultivated willows in Britain and Ireland*. European Journal of Forest Pathology* ??: 00-00.

Sage, R B. (1994) A review of the status and control strategies of known and perceived insect pests on *Salix* and *Populus* in North West Europe. *ETSU B/M3/00388/10/REP*. Harwell Laboratories, Oxford.

Sage R B, Tucker K. (1996) The distribution of leaf-eating beetles (Coleoptera: Chrysomelidae) on SRC willow and poplar in Britain and Ireland. In*: analysing pathogen and pest populations in poplar and willow.* IACR Long Ashton Research Station, Bristol.

Southwood T R E. (1978) *Ecological Methods, 2nd edition.* Chapman and Hall, London.

Tabbush P, Parfitt R. (1996) Poplar and willow varieties for short rotation coppice. *Forestry Commission Research Information Note 278.* Alice Holt Research Station, Farnham, Surrey, (1996).

Wilkinson, L. (1990) *SYSTAT, The System for Statistics*. Systat Inc. Evanstan, Illinois, USA.

Appendix 8A. The abundance of insects with potential pest status from SRC sample sites in 1994. Sample means.

Site code	Plot code	Days after April 1st	*Phratora* adult /m^2	*Chryso.* Larvae /m^2	*Galeruc.* Adult /m^2	Flea beetles /m^2	Sawfly larvae /m^2	Bfly/moth larvae /m^2	Stem aphids /m^2
9	1	158	0.0	0.0	0.2	0.2	0.3	0.2	0.0
9	2	158	0.0	0.0	0.0	0.0	0.3	0.2	0.0
11	1	159	3.8	0.2	0.3	0.1	0.3	0.2	0.0
11	2	159	15.3	0.5	5.0	0.2	0.2	0.8	0.5
11	3	159	14.5	0.8	7.5	0.0	0.5	2.0	0.0
17	1	160	0.5	0.0	0.0	1.3	0.3	0.0	0.0
19	1	76	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	2	76	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	3	76	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1	75	1.0	0.0	0.0	0.0	0.0	0.3	0.0
22	2	75	2.7	0.0	0.0	0.0	0.2	0.0	0.0
23	1	74	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	1	90	0.0	0.0	2.0	0.0	0.0	0.0	0.0
27	2	90	0.0	0.0	0.0	1.0	0.0	0.0	0.0
30	1	91	0.3	19.7	0.0	0.0	0.3	0.0	0.0
31	1	111	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	2	111	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	1	112	0.0	0.0	0.0	0.5	0.3	0.7	0.0
39	1	42	49.2	0.0	0.0	22.7	0.0	4.7	0.0
39	1	68	35.5	0.0	0.0	5.3	5.7	0.3	0.0
39	1	118	22.3	1.7	0.0	0.3	0.7	0.2	0.0
39	1	196	22.2	0.0	0.0	7.8	0.7	0.7	0.0
39	2	42	0.0	0.0	0.0	0.3	0.2	3.5	0.0
39	2	68	0.5	0.0	0.0	0.5	0.5	0.8	0.0
39	2	118	43.7	0.3	0.0	0.3	1.3	0.7	0.0
39	2	196	0.5	0.0	0.0	0.0	0.0	0.2	0.0
40	1	50	46.5	0.0	0.0	14.0	0.5	1.0	0.0
40	1	82	1.2	41.3	0.0	1.3	0.3	0.0	0.0
40	1	119	32.3	6.3	0.0	0.2	0.0	0.2	0.0
40	1	175	2.7	0.0	0.0	4.0	0.0	0.0	0.0
40	2	119	4.8	0.0	0.0	0.0	0.0	0.0	0.0
40	3	50	27.0	0.0	0.0	7.5	0.0	0.5	0.0
40	4	50	12.0	0.0	0.0	5.5	0.0	0.0	0.0
41	1	62	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1	96	0.0	0.0	0.0	0.0	0.3	0.0	0.0
41	1	127	0.2	0.0	0.0	0.5	0.0	0.0	0.0
41	2	62	0.0	0.0	0.0	0.2	1.3	0.5	22.0
41	2	96	0.0	0.0	0.0	0.2	0.2	0.2	0.0
41	2	127	0.0	0.0	0.0	0.7	0.2	0.3	0.0
41	2	179	0.0	0.0	0.0	2.0	0.3	0.3	0.0
42	1	43	0.0	0.0	0.0	0.2	0.2	4.0	0.0
42	1	104	0.0	0.3	0.0	0.2	0.2	0.0	0.0
42	1	140	0.0	0.0	0.0	1.2	0.8	0.0	0.0
42	2	106	0.0	0.5	0.0	0.0	0.5	0.0	2.0
42	3	43	0.0	0.0	0.0	1.0	0.0	2.0	2.3
43	1	54	0.0	0.0	0.7	3.0	0.0	0.5	0.0
43	1	99	0.0	1.5	0.0	0.7	0.7	0.2	0.0
47	1	105	0.5	0.2	0.0	0.0	250.0	0.0	0.0
49	1	138	1.5	0.0	0.2	0.3	0.0	0.0	0.0
50	1	48	0.2	0.0	6.2	0.7	0.0	0.7	0.0
50	1	85	3.3	57.3	2.5	0.0	2.7	0.3	0.0
50	1	133	9.2	0.0	95.7	0.7	0.0	0.7	0.0
50	1	182	0.0	0.0	6.8	6.5	0.0	1.0	0.0
50	2	85	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	3	48	0.0	0.0	7.8	0.2	0.0	0.2	0.0
51	1	113	0.0	0.0	0.0	0.0	0.2	0.2	0.0
52	1	126	0.0	0.0	0.0	0.0	0.0	0.0	0.0
52	2	126	0.0	0.0	0.0	0.0	0.0	0.0	0.0
52	3	126	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 8B. 1994 crop dimensions and leaf defoliation. Mean data.

Site code	Plot code	Days after April 1st	% leaf holed	% leaf skeleton	Total % defol-iation	Stem circumf mm	Stem length cm	Canopy depth cm
9	1	158	5.9	4.8	10.6	39.7	284.3	119.1
9	2	158	3.7	1.8	5.6	19.2	171.3	91.8
11	1	159	6.1	2.0	8.1	26.4	197.1	127.2
11	2	159	3.8	5.8	9.7	25.4	173.8	98.1
11	3	159	12.6	8.9	21.5	24.3	170.4	109.0
17	1	160	7.6	0.0	7.6	63.3	370.0	160.0
19	1	76	2.5	0.0	2.5	.	80.3	80.3
19	2	76	10.6	0.0	10.6	.	82.6	82.6
19	3	76	2.4	0.1	2.5	.	50.4	50.4
22	1	75	2.3	0.3	2.5	59.4	331.9	168.1
22	2	75	2.9	0.0	2.9	51.0	291.0	143.2
23	1	74	4.8	0.0	4.8	44.4	281.4	106.8
27	1	90	1.3	7.5	8.8	.	98.9	98.9
27	2	90	6.0	0.0	6.0	.	93.9	93.9
30	1	91	1.3	14.9	16.2	52.8	272.8	158.3
31	1	111	0.8	0.1	0.8	.	125.2	125.2
31	2	111	1.3	0.0	1.3	.	166.6	166.6
32	1	112	4.8	0.4	5.2	48.0	247.0	161.3
39	1	42	3.9	0.0	3.9	.	260.0	226.7
39	1	68	4.1	4.2	8.3	51.9	283.1	170.6
39	1	118	4.0	9.5	13.5	83.7	388.4	144.9
39	1	196	5.0	5.4	10.4	57.2	340.4	150.1
39	2	42	10.0	0.0	10.0	.	456.7	233.3
39	2	68	8.2	3.2	11.4	68.1	405.9	152.2
39	2	118	7.1	4.4	11.4	65.4	384.2	119.8
39	2	196	.	.	.	74.6	394.0	0.0
40	1	50	3.2	3.2	6.4	59.7	269.0	213.3
40	1	82	2.6	25.0	27.6	46.3	232.3	177.0
40	1	119	0.6	12.6	13.2	54.0	269.7	146.3
40	1	175	1.4	8.9	10.3	59.0	289.1	160.5
40	2	119	2.5	5.7	8.3	16.2	114.4	114.4
40	3	50	1.7	1.7	3.3	56.3	265.7	193.7
40	4	50	1.3	1.3	2.5	.	264.7	234.7
41	1	62	0.5	0.5	1.0	42.1	197.0	173.3
41	1	96	0.6	0.0	0.6	54.2	246.1	205.2
41	1	127	3.8	0.0	3.9	53.1	259.1	176.2
41	2	62	0.4	0.4	0.9	46.1	273.0	205.3
41	2	96	0.9	0.4	1.3	51.4	317.7	229.3
41	2	127	11.3	0.0	11.3	54.6	333.6	249.0
41	2	179	7.8	0.0	7.8	68.8	373.3	202.8
42	1	43	2.1	0.0	2.1	.	320.0	277.5
42	1	104	2.9	0.6	3.6	67.3	331.7	245.8
42	1	140	6.3	0.0	6.3	57.2	305.6	241.0
42	2	106	1.4	0.0	1.4	53.6	320.9	138.4
42	3	43	1.9	0.0	1.9	.	426.7	316.7
43	1	54	1.1	1.1	2.2	36.7	254.8	138.0
43	1	99	2.1	0.3	2.5	35.9	255.0	136.0
47	1	105	18.1	1.2	19.3	56.9	235.9	181.2
49	1	138	0.8	0.7	1.4	31.1	160.0	160.0
50	1	48	2.5	2.5	4.9	.	193.9	100.4
50	1	85	3.0	1.9	5.0	29.0	197.9	94.1
50	1	133	1.9	66.5	68.3	31.0	214.6	129.2
50	1	182	5.0	43.1	48.2	35.4	217.4	96.9
50	2	85	1.5	0.1	1.5	.	61.4	61.4
50	3	48	5.7	5.7	11.5	.	179.3	131.3
51	1	113	2.9	0.0	2.9	47.6	299.9	197.7
52	1	126	0.0	0.0	0.0	.	.	.
52	2	126	6.0	6.0	11.9	.	.	.
52	3	126	0.5	0.5	1.0	.	.	.

9.0 NATURAL CONTROL AGENTS OF THE INSECT PESTS OF SRC

9.1 Summary

The main insect pests of SRC willow and poplar are chrysomelid leaf-eating beetles, stem aphids, caterpillars and and sawfly larvae.

The natural enemies of these pests were identified and investigated in the field and the laboratory. The carabid beetle, *Pterostichus niger*, was particularly abundant and was shown to predate the pupae and adults of *Phratora vulgatissima and Galerucella lineola*.

A range of hoverfly and ladybird species were demonstrated to predate the aphid, *Tuberolachnus salignus*. *T. salignus* was also shown to be parasitised by the Braconid wasp, *Praon volucre*. The presence of predator species within *T. salignus* colonies was shown to significantly reduce colony size.

Parasitism of chrysomelids was discovered in over-wintering adults with up to 12% being parasitised by the tachinid fly, *Medina separata.* The tachinid grub killed its host at the end of the hibernation period when it emerged from the host's abdomen.

Faecal samples were collected from the nestlings of songbirds in and around one SRC plantation and these were analysed to identify their contents. For all species, at least a third of identifiable items were from herbivorous arthropods. This figure was over 60% for willow warbler. Observations indicated that most of these items were obtained from the coppice canopy and included chrysomelids, caterpillars.

A large resource of natural enemies of insect pests present in SRC has been identified in the form of birds and arthropods. The activities of these species may be restricted to limited areas of the crop due to certain habitat requirements being absent. Provision of these features, mainly in the form of ground vegetation, shelter and nectar supply, would result in more effective natural control of invertebrate pests.

9.2 Introduction

A major element of any integrated pest management strategy (IPM) is the provision for pest control by natural means wherever possible. While this does not mean that chemical pesticides should never be used, their application should be part of a tactical and considered approach. IPM can include the use of pest resistant crop varieties (see Sections 11.0 & 13.0), and the avoidance of sites which may be particularly prone to attack (Sections 10.0 & 13.0). Knowledge of the biology and life cycle of the pest may make control at particular times more effective and less damaging to the wider crop ecosystem (Section 12.0 & 13.0). Managing pests at an acceptably low level by the use of natural control agents is a further possibility. A natural control agent can be a predator, a parasite, a parasitoid or a pathogen. These are described below;

- A predator is an organism which lives by killing and eating other organisms (Begon, Harper & Townsend, 1986). For example, a blue tit which feeds predominantly on aphids and caterpillars is as much a predator as is a bird of prey.

- A parasite is an organism which obtains its nutrients from one or a few host organisms, causing harm to its host but rarely immediate death, if at all (Begon, Harper & Townsend, 1986). Well known parasites include ticks, fleas and tapeworms on animals and various plants and fungi on other plants. Even aphids may be considered parasites as they are often tied to an individual host plant, consuming part of it without killing it. Parasites rely on their hosts throughout all their life stages, with usually only a short period away from the host species during the dispersal phase.

- Parasitoids possess many similarities to parasites but have a free living adult stage which is not dependent on a host. The adult female will often feed on nectar or pollen while she lays eggs on, in or near the host species. Larval development occurs in (or rarely on) the host, often causing little or no obvious effect until the parasitoid is nearly ready to emerge. At this stage the host is almost always killed. Only certain Hymenoptera (wasps) and Diptera (flies) practice parasitoidism and almost all host species are insects (a few are spiders and woodlice) (Begon, Harper & Townsend, 1986). Although this would seem to make for a very limited group of organisms being parasitoids, almost all insect species have at least one species-specific parasitoid and even parasitoids may be parasitised by hyper-parasitoids. As a consequence parasitoids are estimated to constitute 25% of the worlds species (Price, 1980).

- Pathogens are micro organisms including bacteria, viruses, fungi and protozoa which, once inside the host's body, multiply causing disease which is often fatal (Begon, Harper & Townsend, 1986). Although they do not actively seek their host, many pathogens cause symptoms which facilitate dispersal, so infecting new host individuals.

This section investigates which of these potential control agents, if any, are operating on the pests of SRC and which may be enhanced through suitable crop management. Very little of the work considers the actions of pathogens as this is a very specialised field. Most of this section is a synopsis of three reports written by M.Sc. students who undertook Game Conservancy Trust supervised projects as part of their post graduate degree course (Baxter, 1995; Sharples, 1997 and Vourdas, 1996).

It is known that predatory ground beetles can be important natural controls of the pests of cereal fields (Hill *et al.*, 1995 and Thomas, Wratten & Sotherton, 1991) and it is on this basis that Baxter (1995) instigated his study to investigate which species of ground beetle were inhabiting SRC. With the knowledge that predatory beetles were present in SRC, Vourdas (1996) investigated which of these and other species were preying on or parasitising willow aphids and phytophagous chrysomelids and at which point in the pests life cycle this occurred.

On a different tack, Sharples (1997) investigated the diet of the common bird species which nest in SRC to ascertain whether birds were taking significant numbers of pests.

This section also investigates the occurrence of parasitism in over-wintering chrysomelid beetles. The discussion brings together all these investigations in the context of a workable integrated crop management scheme and the part that natural pest control plays in this.

9.3 Methods

9.3.1 The predatory beetles of SRC (Baxter, 1995)

To identify potential pest predators, ground beetles inhabiting SRC were caught at three sites using pitfall traps. The three sites were;

- Alice Holt, Surrey. Five-year old poplar SRC on a poorly-drained, flat site of heavy clay with flints. Weed control was good and there was little ground vegetation but there were wide grassy headlands. The plot was surrounded by low hawthorn hedges, with adjacent fields mostly being in grass or under conifer forestry.
- Wishanger, Surrey. 4-year old willow and poplar stools planted in separate blocks adjacent to each other. The willow was on the valley flood plain adjacent to the river and tended to be very wet. The poplar was planted on alluvial sand slightly higher and further from the river. This was sharply draining and quite dry. Weed control was good with grassy headlands. Surrounding the site were pasture and arable fields, a Scots pine shelter belt on one side and the alder-fringed river on the other.
- Buckfast, Devon. 5-year old willow stools planted beside a stream on well-drained rich brown-earth soil. Surrounded by pasture and mature oak-ash woodland. Weed control was moderate to good with occasional patches of ground vegetation and grassy headlands.

Pitfall traps were set at each site to catch ground beetles and their design is illustrated in Figure 9.1. Each trap consisted of a 100 mm length of plastic down-pipe recessed into the ground with a plastic cup placed in the pipe supported by its lip resting on the lip of the pipe. The pipe's purpose was to keep the hole open whenever the cup was removed for emptying. The cup was part filled with a 33% alcohol solution and a few drops of detergent to reduce surface tension. The pipe and cup combination was positioned in the soil so that the lip of the cup sat flush with the soil surface.

The pitfall traps were arranged in transects at each site and beetles collected from them between 19th and 30th August 1994. There were four transects of thirteen traps each at Alice Holt, ten transects (five in willow and five in poplar) of five traps each at Wishanger and six transects of ten traps each at Buckfast - a total of 162 traps at the three sites. The number and length of transects (and the number of traps) was determined by the size and layout of the coppice plots. Each transect passed from a headland, through the crop edge into the heart of the coppice plot so that pitfall traps sampled headland, ride and coppice habitats. At the end of the trapping period the contents of the plastic cups were collected and taken back to the laboratory. There the beetles were identified using Joy (1932) and counted.

9.3.2 The insect predators of SRC pests (Vourdas, 1996)

Sections 7.0 & 8.0 indicate that the major pests of SRC were the phytophagous chrysomelid beetles and to a lesser extent the giant willow aphid (*Tuberolachnus salignus*). We studied predation of these at one site as it was host to *T. salignus* and the two willow beetles *Phratora vulgatissima* and *Galerucella lineola*. The site was at Friars Court Farm, Faringdon, Oxfordshire. Of the seven willow varieties grown there, four were selected for study, these being Dasyclados, Q83, SQ683 and Bowles Hybrid.

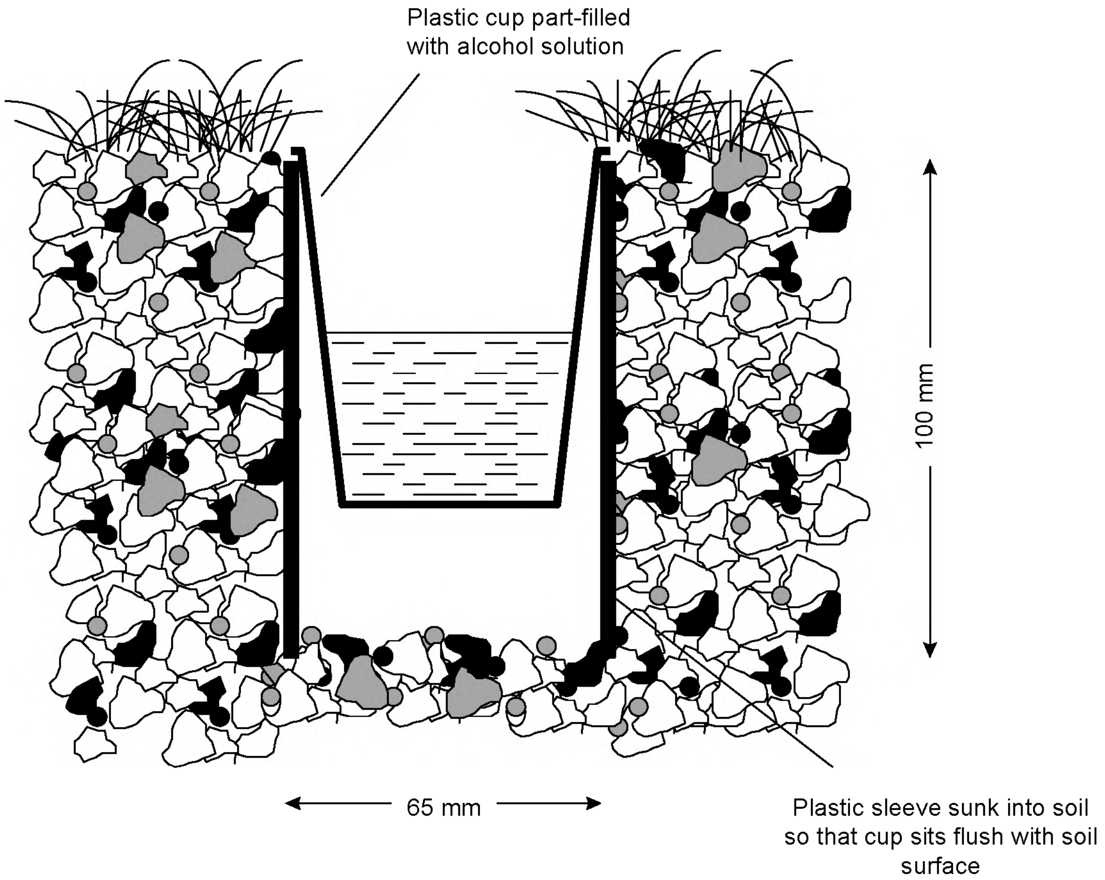

Figure 9.1 Design of pitfall trap for catching ground beetles

Ground Predators

To identify potential ground predators at the site, ten pitfall traps, as described in 9.3.1, were set to catch ground beetles in two lines of five at 2m and 27m from the crop edge and parallel to it in each of the four varieties. Seven samples were collected from each trap approximately one week apart from 11th June 1996 to 22nd July. Specimens were identified in accordance with Lindroth (1974).

Predator and Parasite Exclusion

To investigate the impact of different types of predation on phytophagous chrysomelid eggs and larvae, 45 stools were randomly selected, 15 each of SQ683, Q83 and Dasyclados. On each stool, three branches of roughly equal length and height were selected and marked. Each branch supported a small number of larvae or eggs of one or both of the two pest chrysomelids present at the site. Percent defoliation and the number of eggs and larvae present was recorded. For each stool one of the marked stems was bagged with a nylon mesh bag, closed at each end to exclude all predators and parasites. Another branch was bagged similarly but the bag was left open at the apical end so that bird predators and predators which reached their prey by climbing the stem were excluded. On the third the branch was left untreated and so was open to all natural enemies. The experiment was started on 19th June 1996 and terminated after pupation of the larvae, five weeks later. At the end of the experiment, the percent defoliation was recorded for each branch as an indirect measure of pest burden.

Predation Bioassays

The potential predators of the willow aphid, *T. salignus*, the larvae and pupae of the two chrysomelids and the pupae and the newly emerged adults of *Phratora vulgatissima* were investigated using bioassays in the laboratory of five different predatory insect species. These are described below:

1. Adults and larvae of the ladybirds *Adalia bipunctata* (two-spot ladybird), *Coccinela septempunctata* (seven-spot ladybird), adults only of *Coccinela 11-punctata* (11-spot ladybird) and *Propylea 14-punctata* (14-spot ladybird) and larvae only of Syrphus *ribesii* and *Dasysyrphus albostriatus* (two common hoverfly species) were introduced to petri dishes containing individuals of *T. salignus*. The petri dishes were 90mm diameter and lined with moist filter paper. Into each were placed ten aphids above 1.5mm long, a 50mm section of willow stem (to concentrate the movements of the aphids) and one individual of one of the predators listed above. Numbers of alive, eaten and dead aphids were recorded after 2, 4, 6, 8, 10, 12 and 24 hours. A similar number of control treatments were also set up in the same manner but without a predator.

2. *Dasysyrphus albostriatus* larvae were also observed on small willows in pots. Twenty aphids were released on each of ten potted willows and allowed to settle for 12 hours. Single *D. albostriatus* larvae were then introduced to four of the willows. The six remaining willows acted as controls. Sticky tape was placed around the edges of the pots to stop the aphids from escaping and the pots were kept far enough apart so as to avoid movement from one plant to another. White paper was placed at the base of each willow to facilitate the counting of eaten or dead aphids which had fallen. Every 12 hours at 0800 and 2000 hours the number of dead and alive aphids were counted and the positions of the aphids and the predator were recorded. The timing of the count allowed differences in nocturnal and diurnal feeding to be observed.

3. The procedure described in point 1 above was repeated replacing the aphids with five *Phratora vulgatissima* or five *Galerucella lineola* larvae with two willow leaves instead of the section of willow stem. The introduced predators were larvae or adult seven-spot ladybirds. Numbers of chrysomelid larvae alive, dead and eaten were recorded after 24 and 48 hours.

4. *P. vulgatissima* pupae were collected from the SQ683 plot and placed, ten at a time on damp filter paper in petri dishes. These were then exposed to one or other of the ground beetles *Pterosticus niger* and *Harpalus rufipes*. Dead and live pupae were recorded after 3, 6 and 24 hours.

5. Five newly emerged *P. vulgatissima* were placed in plastic containers part-filled with soil and one *P. niger* was introduced. The number of alive, dead and eaten beetles was recorded after 2, 4 and 6 hours.

Aphid Surveys

A survey of *T. salignus* colonies was conducted at the field site to record colony size, colony behaviour and the presence of natural enemies. Forty randomly located colonies were observed on two occasions one week apart (9th and 16th July). The size of each colony was ranked and categorised using the criteria in Table 9.1.

Table 9.1 Criteria used to categorise size of *T. salignus* colonies.

Colony size category	Description
1	Small colony. Less than 20 aphids with none or few nymphs. Colony occupying up to 2cm length of stem
2	Moderate colony. More than 20 aphids with nymphs. Colony length 2-5cm
3	Moderate colony. Nymphs and adults present in large numbers. Length 5-10cm
4	Large colony. Adults and nymphs present. Length 10-15cm
5	Very large colony. Several hundred aphid adults and nymphs. Length over 15cm

Chrysomelid pupation

It is known that the chrysomelid pests of willow pupate in the soil. It is not, however, know how deep the larvae go to pupate, or their availability to predators. To determine this, six soil samples were collected from each of three soil-depth zones in each of the four willow varieties involved in the investigation. The soil depth zones were 0-1cm, 1-2cm and 2-3cm and each soil sample for each depth zone covered 100cm^2 (10x10cm). The samples were collected from the base of randomly selected stools towards the centre of each plot. The number of pupae and emerged adults were counted regardless of species (*P. vulgatissima* or *G. lineola*) as the early pupal stages were difficult to identify specifically.

Parasitism

To identify parasitism of eggs, eggs of *P. vulgatissima* and *G. lineola* were collected from all four willow varieties and kept in petri dishes at 25°C. A total of 674 *P. vulgatissima* eggs and 798 *G. lineola* eggs were cultured through to hatching to assess the prevalence of egg parasitism. *T. salignus* parasitism was investigated by looking for and collecting aphid mummies from colonies. Aphid mummies are the distinctive, discoloured dead bodies of aphids which have been parasitised (e.g. see Thacker & Hopkins, 1998).

Field Observations

Some time was dedicated to field observations, looking for possible natural enemies and recording the behaviour of the pests and possible natural enemies.

9.3.3 The avian predators of SRC pests (Sharples, 1997)

Study species and nest location

To see if birds predate the pests of SRC, the invertebrate diet of the nestlings of five bird species were studied. These species represented all those for which active nests were discovered during fieldwork and are representative of some of the more abundant species which breed in SRC willow (Section 16.0). The basic breeding ecology of the five species is presented in Table 9.2.

Nests were located in and around the willow SRC at Friars Court Farm, Oxfordshire. They were discovered by watching foraging birds back to the nest and by exploring suitable areas within territories. To facilitate this a deer high-seat was positioned in the crop so that the movement of birds through and over the canopy could be observed. This method gave approximate locations of nests which could then be searched for on the ground. Most nests were extremely well hidden and only a small proportion of the total number present must have been found.

Once located, each nest was labelled using species name, nest number and date. The number of eggs or young was also recorded.

Nest observation

Whenever time permitted, observations were made of nests from a safe distance so that the birds were not deterred from visiting. This enabled some record of the food brought to the nest to be made. It also permitted identification of the areas from which the birds were obtaining their prey.

Table 9.2 Ecological summaries of the five bird species investigated in this study (from Cramp *et al.*, 1992 & 1994).

	Reed Bunting (*Emberiza schoeniclus)*	**Willow Warbler** *(Phylloscopus trochillus)*	**Garden Warbler** *(Sylvia borin)*	**Sedge Warbler** *(Acrocephalus schoenobaenus)*	**Reed Warbler** *(Acrocephalus scirpaceus)*
Nest site	Dense, low-growing vegetation. Nest on or near the ground	Scrub, damp willow and alder. Nest almost always on the ground.	Often brambles and bushes. Nest low but off the ground.	Dense vegetation often near water. Nest up to 60cm off the ground	Reeds but also other vegetation near water. Low but off the ground
N$^{o.}$ eggs	4-5	6-7	4-5	5-6	4
Breeding Period	Late April-May. 2nd brood June-July	Late April-May. 2nd brood June-July	Late May-June	May-June	Late May-June
Adult Diet	Mostly seeds, 30% invertebrates	Invertebrates, some berries late in season	Invertebrates, some berries late in season	Invertebrates	Invertebrates
Nestling Diet	Invertebrates (mostly insects)	Invertebrates, mainly Diptera, Homoptera and caterpillars	Invertebrates, mainly Diptera and caterpillars	Invertebrates, particularly Lepidoptera	Invertebrates
Foraging Niche	Mainly in low vegetation	Mainly in the shrub canopy	Mainly in medium to high canopy	Low in ground vegetation and underscrub	High in ground vegetation and low in scrub

Faecal sample collection

Faecal samples, from which invertebrate remains could be identified (see below), were collected from the nestlings in each nest up to twice weekly until the young birds had fledged. Faecal sacs were placed in glass tubes and labelled with species name, nest number and date of collection. The samples were frozen until analysis at a later date.

Invertebrates in the canopy

Twenty $2m^2$ sheet beats (see Section 7.3.2) were taken from the canopy in two broad areas around nest sites. From these samples abundances of different arthropods in the canopy were calculated with particular reference to defoliating (i.e. pest) species. These sheet beats were also used as a means of collecting reference material for use in the laboratory in comparison to faecal sample fragments and segments.

Faecal analysis in the laboratory

Each faecal sac was analysed for invertebrate remains separately using a method developed by The GCT (Moreby 1987). Once defrosted, the sample was rinsed though a 180μm technical sieve using water. This washed away the uric acid in the sample. Large aggregations of particles were broken down to facilitate identification of individual items. The sample was then rinsed with alcohol and washed into a sample tube.

Each sample was then examined in a 9cm petri dish with a 1cm grid scored on its base. This aided the division of the sample into sections to avoid counting the same particles twice. Examination was undertaken using a binocular microscope at 120x magnification and the number of identifiable items, such as legs and mandibles, were counted and recorded. Table 9.3 is a list of the structures identified from the faecal samples in this study and used to determine nestling diet. The items are illustrated in Moreby (1987). From the number of similar items it is possible to estimate the number of individuals of that species or genus which were consumed, however, often the items were too fragmented for this to be possible.

Invertebrates identified from the faecal matter were categorised in terms of their feeding strategy so as to consider the proportion of pests eaten by each species. Thus the categories were as follows:

Defoliators - Coleoptera: Chrysomelidae
Lepidoptera (larvae)
Hymenoptera: Symphyta (larvae)

Other herbivores - Homoptera: Aphidae
(i.e. sapsuckers) Homoptera: Cercopidae
Homoptera: Cicadellidae

Predators - Arachnida: Araneae
Arachnida: Opiliones
Coleoptera: Carabidae
Diptera: Syrphidae (larvae)
Neuroptera: Chrysopidae (larvae)
Neuroptera: Hemerobiidae (larvae)

Other - All other groups such as Odonata and Diptera

9.3.4 Parasitism and other causes of mortality in over-wintering chrysomelids

During the winter of 1995-6 over-wintering chrysomelids were collected from Long Ashton, near Bristol and Friars Court Farm, Oxfordshire. The species involved were *P. vulgatissima* and a small number of *G. lineola*. A sample of 49 *P. vulgatissima* were killed and dissected. The remainder were placed in 9cm petri dishes in groups of up to 25 and kept in a cool outbuilding until spring. The beetles were observed regularly. The beetles were fed every two days with fresh willow leaves once they had broken diapause and begun moving about. At each feeding, counts of dead and alive beetles were made and notes made of any evidence of parasitism.

9.4 Results

9.4.1 The predatory beetles of SRC (Baxter, 1995)

A total of 2834 Carabid beetles of 30 species and 59 Staphylinid beetles of 15 species were collected from the pitfall traps at Alice Holt, Wishanger and Buckfast over the trapping period (see Table 9.4). Of these, one Carabid species and seven Staphalynid species were not identified due to the complexities of specific identification presented by these groups (Joy, 1932). There were greater numbers of beetles in ptifalls at the edge of the coppice plots than in the interior. This appeared to be due to an association with increased ground cover at the crop edges although this effect was not analysed for statistical significance.

9.4.2 The insect predators of SRC pests (Vourdas, 1996)

Ground Predators

The most common predatory arthropods collected from the pitfall traps set at Friars Court Farm were the two Carabid beetles, *Pterostichus niger*, and *Harpalus rufipes*. Both beetles were found in all the traps in varying numbers with *H. rufipes* being the most frequent. Both species were least common in Q83 and most common in Bowles Hybrid (Figures 9.2 and 9.3). *P. niger* was considerably more frequent in the traps located at the edge of the crop than in those toward the centre for SQ683, Dasyclados and Bowles Hybrid and this difference was significant at $p<0.01$ (Figure 9.2). Greater numbers of *H. rufipes* were caught at the crop edge in SQ683, Q83 and Dasyclados and this was significant at $p<0.001$. In Bowles hybrid significantly more individuals were caught in the crop interior (Figure 9.3).

Table 9.3 Invertebrate remains identified from faecal samples of the nestlings of five bird species nesting in SRC.

Class/Order/ Family	**Structure (N^o from 1 individual)**	**Notes**
INSECTA		
COLEOPTERA:		
Carabidae	Mandible (2) Elytra (2 or many fragments)	Triangular mandible with pointed tip Striated elytra
Carabidae larvae	Mandible (2)	Usually sickle shaped with pointed or serrated tooth near base
Staphylinidae	Mandible (2)	Curved with forked apex
Elateridae	Peg (1)	
Curculionidae	Leg (6)	Characteristic shaped femur and tibia
Chrysomelidae	Mandible (2)	Cone-shaped with serrated top (ref.)
Chrysomelidae larvae	Mandible (2)	Similar to adult, less scleriterization (ref.)
Coccinelidae larvae	Mandible (2)	Small with fine, curved, forked tip (ref.)
DIPTERA:	Wings (2 or many fragments) Legs (6 or many small fragments)	
Tipulidae	Legs (6) Wings (2) Eggs (>100)	Long and fine Characteristic venation Black and elliptical
LEPIDOPTERA:		
Larvae	Mandible (2)	Like a cupped hand, fingers and thumb *in one plane* (ref.)
HYMENOPTERA: SYMPHYTA		
Adult	Mandible (2)	Curved and pointed with large serrations along one edge (ref)
Larvae	Mandible (2)	Similar to Lepidoptera, cupped hand with thumb *held forward* (ref)
ODONATA: ZYGOPTERA	Mandible (2)	(ref.)
HOMOPTERA:		
Aphidae	Tibia (6)	Characteristic, fine with curved dark tip (ref.)
Cercopidae	Hind tibia (2, often fragmented)	2 rows of small spines (ref.)
Cicadellidae	Hind tibia (2)	Many spines along outer edge
NEUROPTERA:		
Larvae	Mandible (4)	Flat, curved, sickle-shaped and usually found paired (but can be

		single)
ARACHNIDA		
ARANEAE:	Chelicera (2)	Conical with a row of spines down the edge. Fang often attached
	Fang (2)	Characteristic, like curved horn
OPILIONE:	Jaw (2)	Sac-like with fang attached
	Fang (2)	Black, pointed with serrated inner edge
GASTROPODA		
(small snails)	shell fragments (1 central whorl)	

Predator and Parasite Exclusion

The results of the predator exclusion are shown in Figure 9.4. There were significant differences in defoliation between all three varieties ($p<0.001$). There was significantly more defoliation in the closed bag treatments than in the no bag treatments ($p<0.001$) and there was significantly more defoliation in open bag than in no bag treatments (<0.001). No significant difference existed between closed bag and open bag treatments.

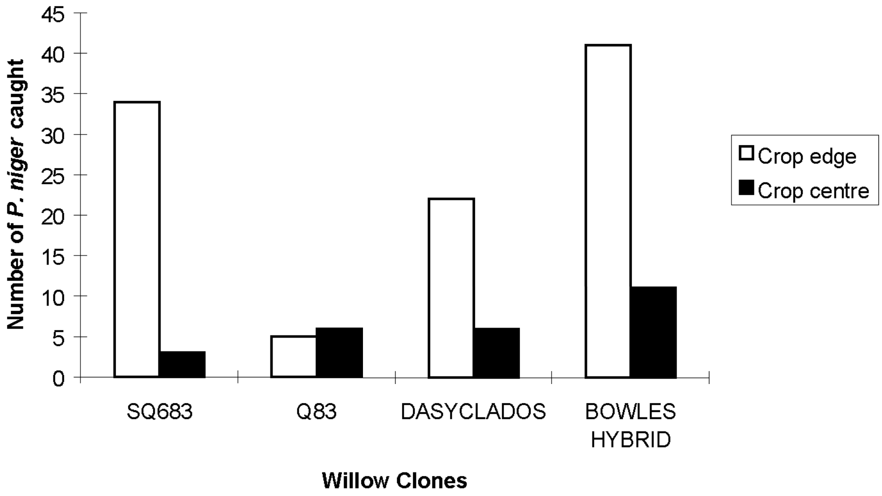

Figure 9.2 The distribution of *P. niger* between and within willow varieties at Friars Court Farm, Oxfordshire

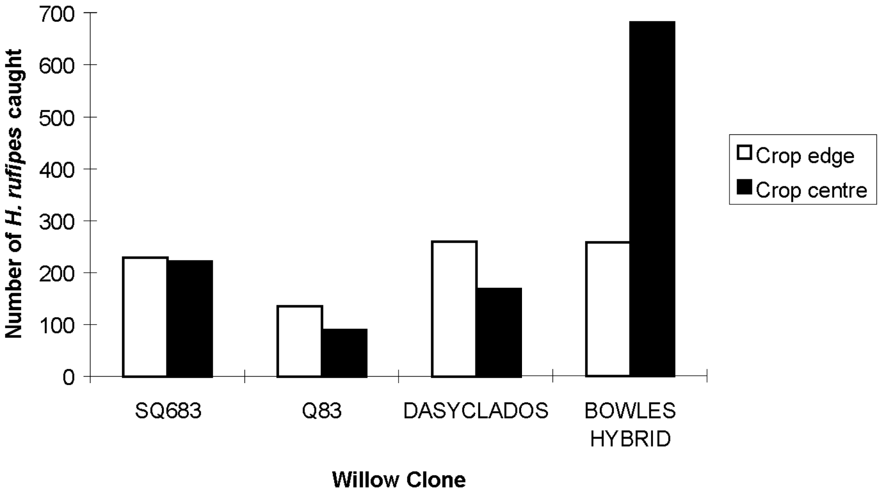

Figure 9.3 The distribution of *H. rufipes* between and within willow varieties at Friars Court Farm, Oxfordshire

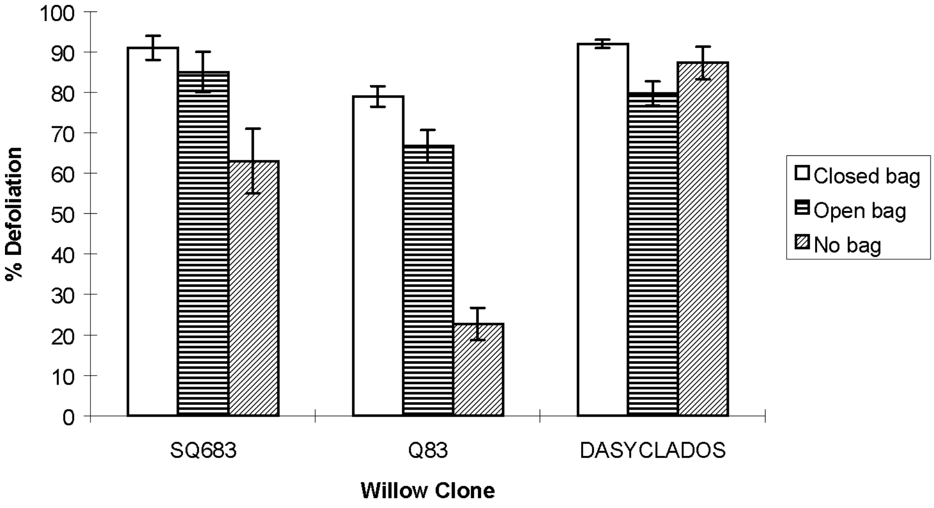

Figure 9.4 The effect of predator exclusion using closed and open bags on the defoliation of willow branches in the field

Predation Bioassays

1. Predation of *T. salignus* by ladybirds and hoverfly larvae. All the predator species tested against aphids in petri dishes produced significantly more dead aphids than the control treatments ($p<0.01$). There were differences in aphid mortality between predators and the results of each predator species are presented in Figure 9.5.
2. Predation of *T. salignus* by *D. albostriatus* on potted willows in the laboratory. The aphid colonies on trees onto which *D. albostriatus* were released were significantly smaller ($p<0.001$) than on the control trees and

significantly more dead aphids (p<0.001) were recorded than on control trees. No difference was recorded between nocturnal and diurnal feeding rate of the hoverfly.

3. Predation of larval *P. vulgatissima* and *G. lineola* by *A. bipunctata* and *C. septempunctata*. Neither ladybird species was observed to predate either Chrysomelid species in the laboratory.
4. Predation of chrysomelid pupae by ground beetles. *H. rufipes* was not recorded to kill or eat pupae but *P. niger* was observed to feed on pupae of both chrysomelid species.
5. Predation of adult *P. vulgatissima* by ground beetles. *H. rufipes* was not recorded to kill or eat the newly emerged adult *P. vulgatissima* but *P. niger* was.

Table 9.4 Table of Carabidae and Staphylinidae recovered from pitfall traps at three SRC sites in the south of England

CARABIDAE		STAPHYLINIDAE	
Carabinae	*Carabus violaceus*	Micropeplinae	*Micropeplinus fulvus*
	Carabus nemoralis		
	Carabus glabratus	Tachyporinae	*Tachinus marginellus*
	Cychrus rostratus		*Tachinus sp.*
	Leistus ferrugineus		
	Notiophilus biguttatus	Omaliinae	*Metopsia clypeata*
Harpalinae	*Loricera pilicornis*	Steninae	*Stenus sp.*
	Clivina fossor		*Stenus brunnipes*
	Bembidion sp.		
	Tachys sp.	Aleocharinae	*Oxypoda sp.*
	Ophonus sp.		
	Harpalus sp.	Staphilininae	*Staphylinus sp.*
	Pseudophonus pubescens		*Staphylinus olens*
	Patrobus sp.		*Gabrius sp.*
	Patrobus excavatus		*Philonthus sp.*
	Abax ater		*Quedius sp.*
	Amara sp.		*Xantholinus sp.*
	Calathus sp.		*Oxytelus sp.*
	Calathus fuscipes		*Neobisnius sp.*
	Calathus piceus		
	Calathus melanocephalus		7 unidentified species
	Cyrtonotus fulvus		
	Cyrtonotus aulicus		
	Poecilus cupreus		
	Poecilus coerulescens		
	Pterostichus madidus		
	Pterostichus macer		

Pterostichus niger
Pterostichus vulgaris
Olisthopus rotundatus

1 unidentified species

Aphid surveys

Three species of hoverfly larvae were discovered from observation of *T. salignus* colonies in the field. These were *Syrphus ribesii, Dasysyrphus albostriatus* and *Episyrphus balteatus*. *S. ribesii* larvae were encountered from 23rd June usually located feeding in or around *T. salignus* colonies with up to five individuals at the same colony. From 18th July *D. albostriatus* were frequently seen and seemed to be more abundant than the previous species, despite *D. albostriatus* larvae being better camouflaged. They were usually encountered lying horizontally on the main willow stems. The third hoverfly species was observed in the egg stage laid individually inside or next to small *T. salignus* colonies toward the base of stools from 24th July. One newly hatched individual was collected on 26th July and fed *T. salignus ad libitum* through until pupation on 2nd August. In this time it consumed 67 aphids and grew from 1mm to 13mm length (see Figure 9.6).

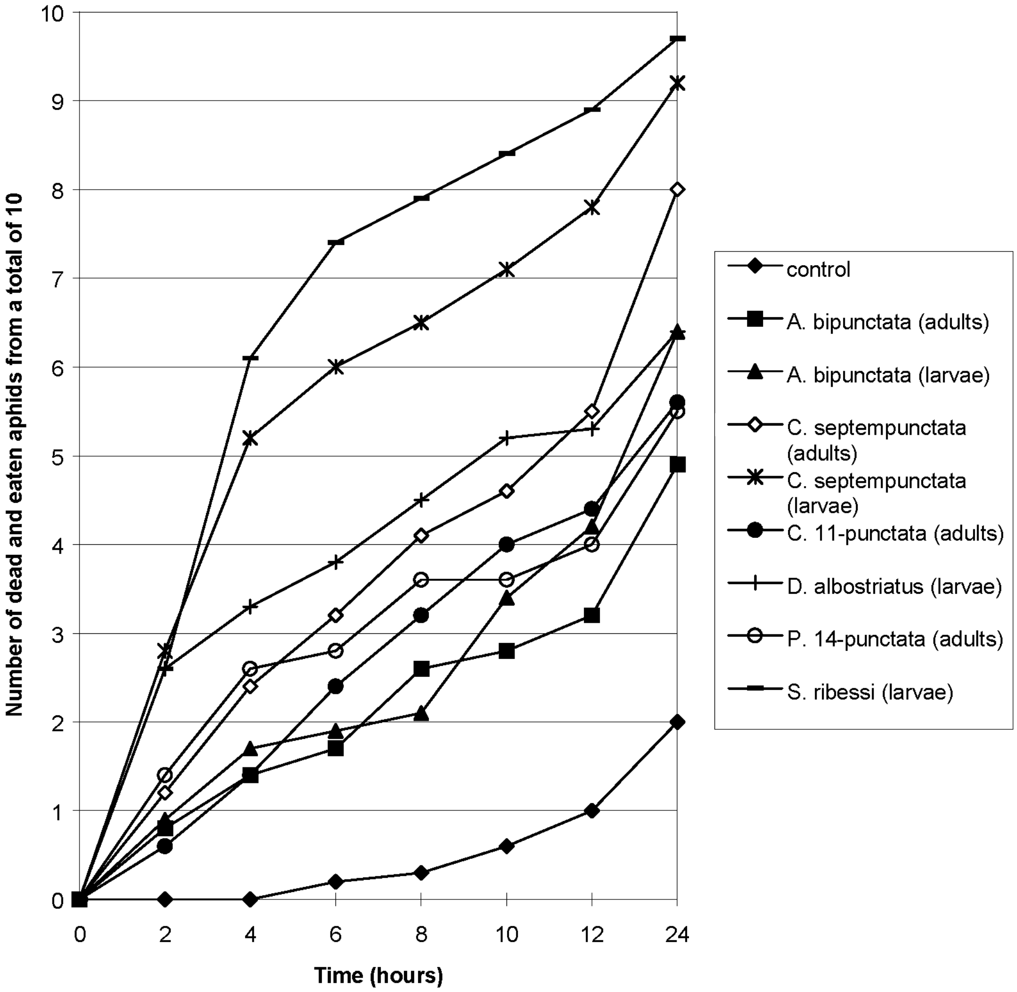

Figure 9.5 Results of bioassay comparing predation of *T. salignus* by four ladybird species (adults and larvae) and two hoverfly species (larvae)

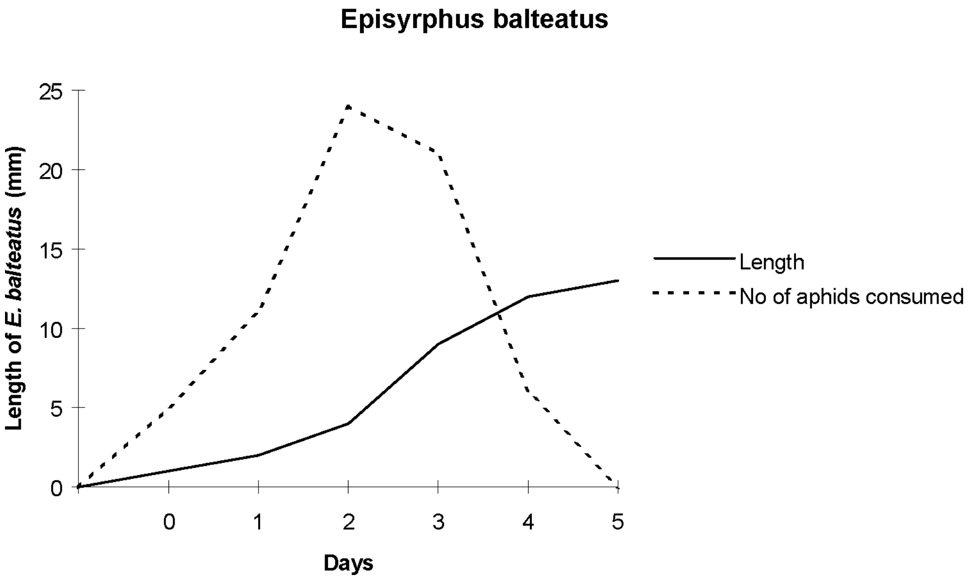

Figure 9.6 Growth of a single larvae of the hoverfly *Episyrphus balteatus* fed *ad libitum* with *T. salignus* until it pupated

The commonest predator observed feeding at aphid colonies was *A. bipunctata* larvae. Other invertebrates observed feeding on *T. salignus* in the field were *A. bipunctata* adults, *C. septempunctata* adults and larvae, and larvae of *Chrysopa perla* (a green lacewing) and *Hemerobius humulinus* (a brown lacewing).

The number of predators present at a colony showed a significant positive correlation with the colony size (Spearman's rank correlation coefficient = 0.4739, $p<0.05$). Most of these predators were *A. bipunctata* larvae and these too were significantly correlated with colony size (0.4705, $p<0.05$). Mean colony size decreased from 2.45±0.16 on 9th July to 0.95±0.18 16th July (the dates of the survey) and this decrease showed a significant positive correlation with the number of predators (0.3104, $p<0.05$).

Chrysomelid pupation

Chrysomelid pupae were discovered in the soil samples collected from the field site. The density of records varied with variety as the varieties were not colonised evenly. The results are presented in Table 9.5. There were significantly ($p<0.001$) more pupae in the top 1cm of soil compared with soil at both depths of 1-2cm and of 2-3cm. There were no differences between the lower two soil layers.

Table 9.5 Distribution within the soil of chrysomelid pupae

Layer	Total	%	Mean N° Pupae per 100cm^3 soil
1st cm	241	73.0	10.04
2nd cm	63	19.0	2.62
3rd cm	26	7.8	1.08
Total	**330**	**100.00**	

Parasitism

No evidence of parasitism was found for *P. vulgatissima* or *G. lineola* egg or larval stages in the field or in the laboratory by Vourdas.

Five aphid mummies were collected from the field indicating a low incidence of parasitism. A Braconid wasp which specialises in parasitising aphids (*Praon volucre*) was raised from one of these.

9.4.3 The avian predators of SRC pests (Sharples, 1997)

Study species, nest location and faecal sample collection

A total of 17 birds occupied nests were located at the study site, mainly of two species; reed bunting (six nests) and willow warbler (six nests). Other nests discovered were garden warbler (one), reed warbler (one), sedge warbler (two) and dunnock (*Prunella modularis*) (one). Four of these nests were lost to predation or bad weather before faecal samples could be collected and so consequently thirteen nests were sampled yielding 69 individual faecal sacs. A breakdown of nest location, sampling dates and sampling success is given in Table 9.6a-c.

Nests were well concealed and difficult to find. All were located low down in the willow crop amongst ground vegetation, willow warblers choosing grass tussocks and reed buntings in grass and thistles. The dunnock nest was in nettles within the crop as was that of the garden warbler and the reed warbler nest was in small reeds at the edge of the crop. Both sedge warbler nests were built into the lower branches of small willow stools amongst tall grass.

Nest observation

Few feeding observations were made of reed buntings, the birds being very cautious on approach to the nest. Observation was possible of nest 5 from the deer-seat and mayflies and damselflies were identified being fed to the nestlings. Birds could not be seen feeding within the coppice canopy but it seemed likely that they were feeding within the coppice as few birds were observed to move out of the coppice.

All willow warbler pairs were observed to bring green caterpillars to the nest. Mayflies and damselflies were also identified. This species was very vocal whilst foraging and were easily followed. Almost all foraging occurred within the coppice canopy although not always immediately adjacent to the nest site.

Feeding observations were not made on the garden warbler pair. Sedge warblers were observed feeding in the coppice canopy close to the nest site as were reed warblers which could be seen bringing many winged insects to the nest.

Invertebrates in the canopy

Mean numbers of invertebrates per 1m^2 plan of SRC (from sheet beats) in the two broad areas surveyed are presented in Table 9.7.

Faecal analysis in the laboratory

Solid material from the faecal samples was found to be extremely fragmented and made identification of species and quantification of numbers consumed very difficult. However, a rough estimate of the numbers of individuals eaten was arrived at by counting the identifiable fragments (see Table 9.3).

A total of 543 items were identified from all the samples combined. The mean proportion of each invertebrate type and each invertebrate feeding strategy (i.e. defoliators, other herbivores, predators, other) in the faecal samples from each of the bird species studied are presented in Figures 9.7a-l. These proportions are derived from estimates of the number of individuals consumed, not mass of invertebrates.

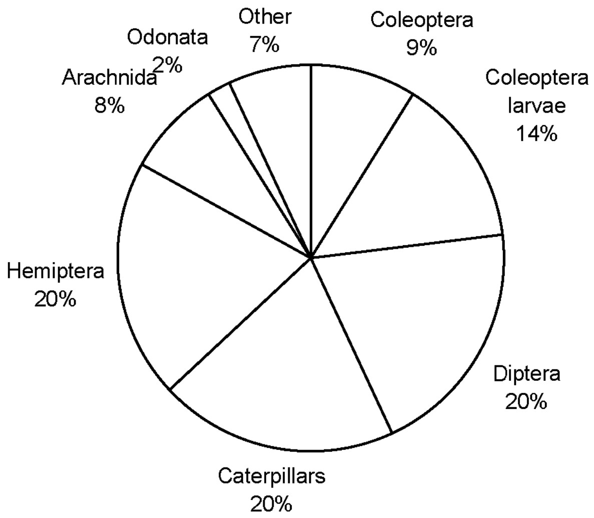

Figure 9.7a Proportion of identifiable items in faecal samples from all bird species belonging to each of the different invertebrate groups identified

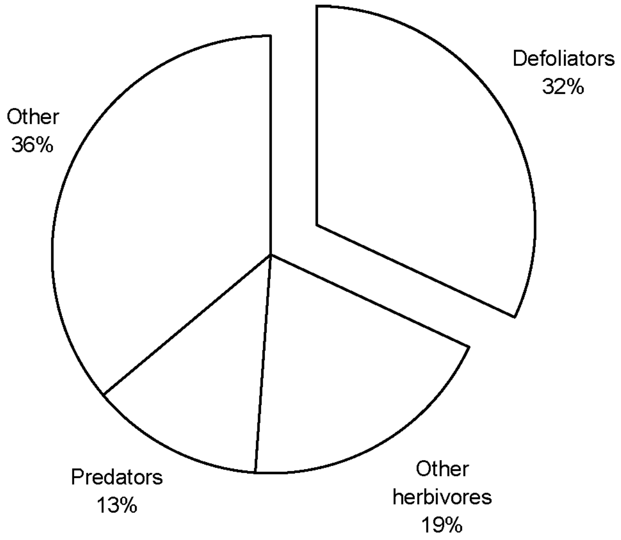

Figure 9.7b Proportion of identifiable items in faecal samples from all bird species belonging to defoliators and other identified invertebrate niches

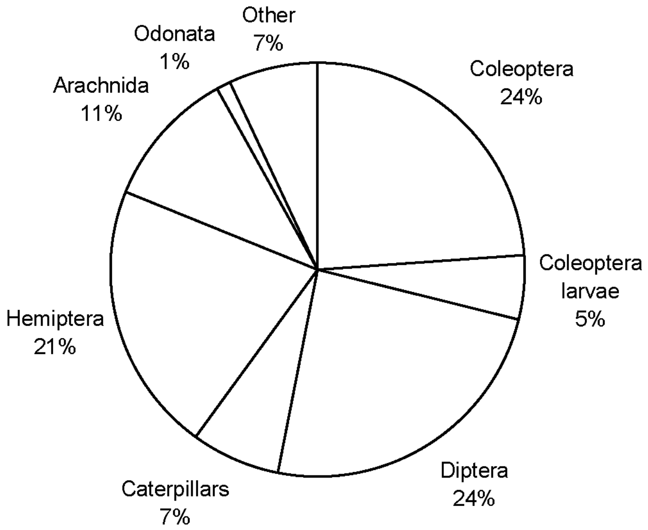

Figure 9.7c Proportion of identifiable items in faecal samples of reed bunting belonging to each of the different invertebrate groups identified

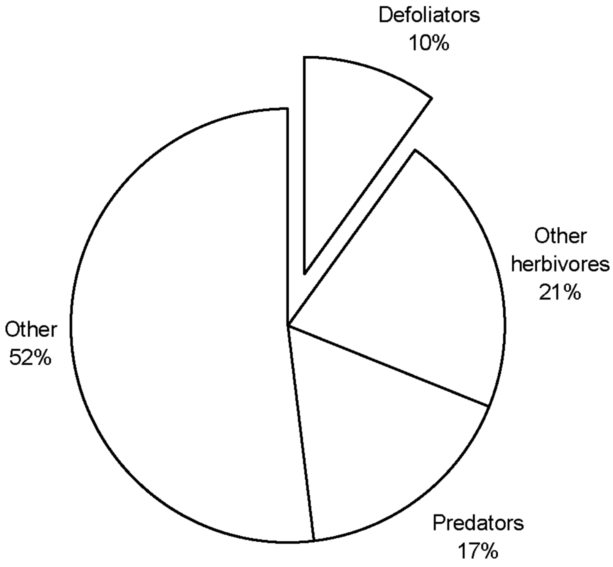

Figure 9.7d Proportion of identifiable items in faecal samples of reed bunting belonging to defoliators and other identified invertebrate niches

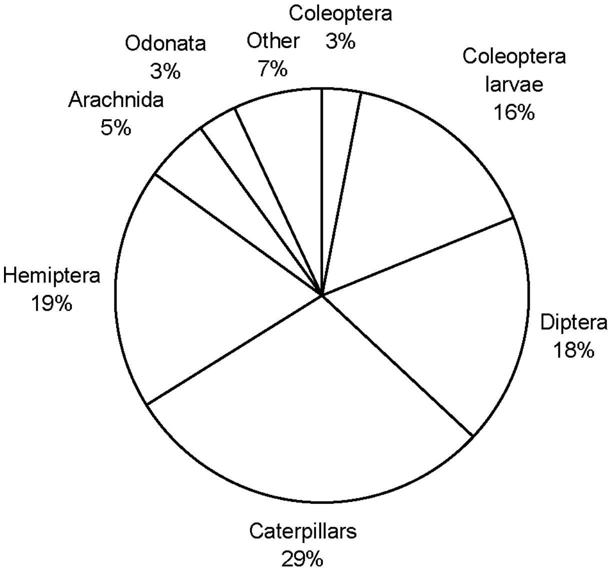

Figure 9.7e Proportion of identifiable items in faecal samples of willow warbler belonging to each of the different invertebrate groups identified

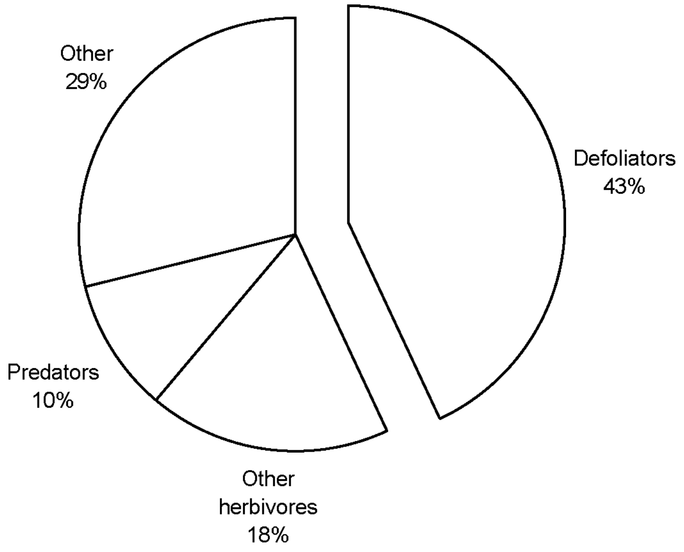

Figure 9.7f Proportion of identifiable items in faecal samples of willow warbler belonging to defoliators and other identified invertebrate niches

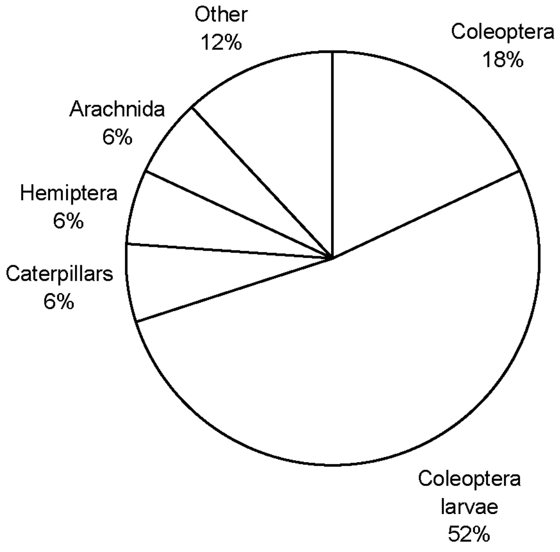

Figure 9.7g Proportion of identifiable items in faecal samples of garden warbler belonging to each of the different invertebrate groups identified

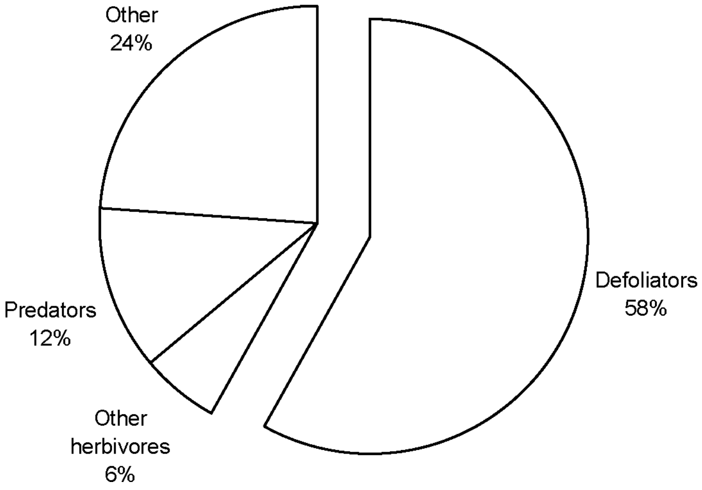

Figure 9.7h Proportion of identifiable items in faecal samples of garden warbler belonging to defoliators and other identified invertebrate niches

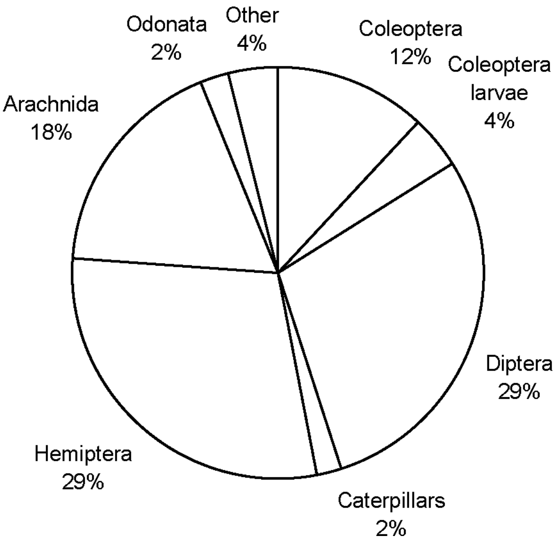

Figure 9.7i Proportion of identifiable items in faecal samples of reed warbler belonging to each of the different invertebrate groups identified

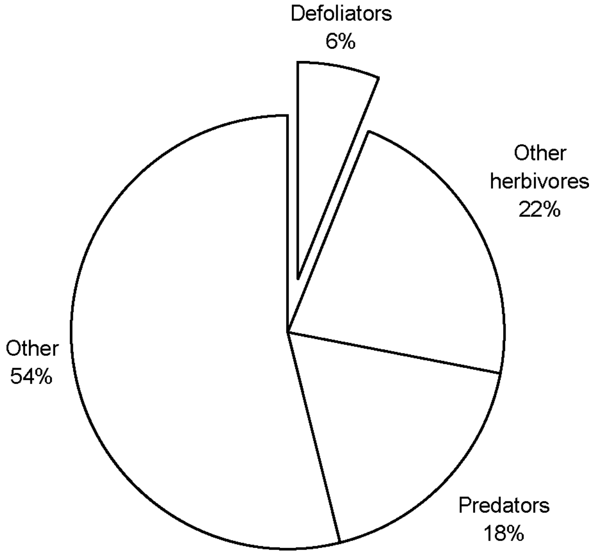

Figure 9.7j Proportion of identifiable items in faecal samples of reed warbler belonging to defoliators and other identified invertebrate niches

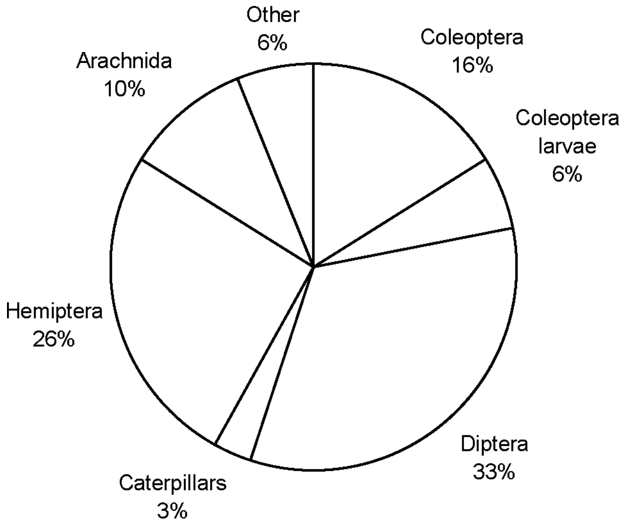

Figure 9.7k Proportion of identifiable items in faecal samples of sedge warbler belonging to each of the different invertebrate groups identified

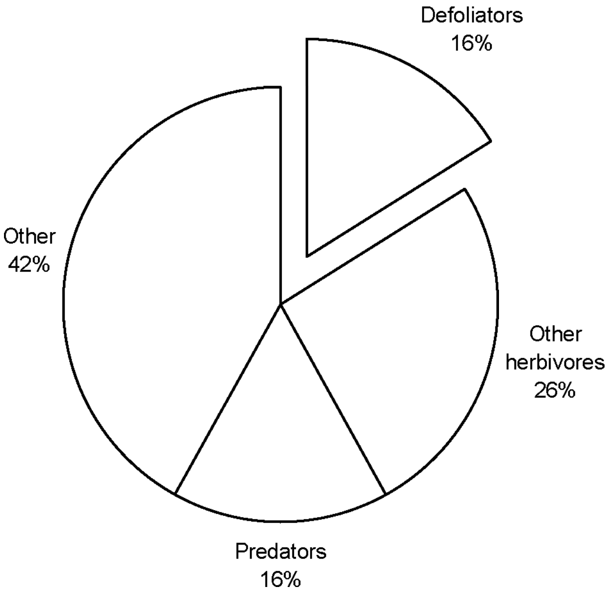

Figure 9.7l Proportion of identifiable items in faecal samples of sedge warbler belonging to defoliators and other identified invertebrate niches

Table 9.6 A breakdown of nest location, sampling dates and sampling success for the nests sampled in this study

a. Reed bunting

	Nest 1	**Nest 2**	**Nest 3**	**Nest 4**	**Nest 5**	**Nest 6**
Date located	15/5	22/5	22/5	27/5	12/6	15/6
N° eggs (e) or chicks (c)	5e	5e	5e	5e	4e	4c
Hatch date	?	Lost	6/6	lost	30/6	?
N° faecal sacs	4	0	4	0	2	4
Fledging date	3/6		17/6		5/7	22/6
Cause of failure	-	Predated	-	-	-	predated

b. Willow warbler

	Nest 1	**Nest 2**	**Nest 3**	**Nest 4**	**Nest 5**	**Nest 6**
Date located	27/5	27/5	27/5	28/5	13/6	15/6
N° eggs (e) or chicks (c)	6c	6c	6c	6c	4e	4e
Hatch date	?	?	?	?	26/6	26/6
N° faecal sacs	4	7	7	7	13	5
Fledging date	6/6	3/6	6/6	10/6	10/7	10/7
Cause of failure	-	-	-	-	-	-

c. Other species

	Dunnock 1	**Garden Warb. 1**	**Reed Warb. 1**	**Sedge Warb. 1**	**Sedge Warb. 2**
Date located	22/5	10/6	22/6	17/6	22/6
N° eggs (e) or chicks (c)	5e	5c	4e	5c	4e
Hatch date	6/6	?	29/6	?	10/7
N° faecal sacs	0	2	6	4	0
Fledging date	-	17/6	10/7	26/6	10/7
Failure	weather	-	-	-	predated

Table 9.7 Mean numbers of individuals of different insect groups collected from sheet-beat samples in two areas of SRC frequented by foraging birds

Invertebrate	Area 1		Area 2	
Homopterans	5.80	(3.0%)	7.50	(8.0%)
Adult Coccinelid	0.35	(0.2%)	0.08	(0.1%)
Larval Coccinelid	2.23	(1.2%)	1.08	(1.2%)
Caterpillars	0.23	(0.1%)	0.33	(0.4%)
Chrysomelid: *Phratora vulgatissima* adults	0.40	(0.2%)	0.63	(0.7%)
Chrysomelid: *Phratora vulgatissima* larvae	139.2	(73.1)	56.9	(61.1%)
Chrysomelid: *Galerucella lineola* adults	2.30	(1.2%)	0.23	(0.2%)
Chrysomelid: *Galerucella lineola* larvae	39.80	(20.9%)	26.45	(28.4%)

9.4.4 Parasitism and other causes of mortality in over-wintering chrysomelids

A summary of the results from the dissection of the sample of *P. vulgatissima* is presented in Table 9.8. Those recorded as parasitised contained a white grub up to 2mm in length within the body cavity. Of the two beetles recorded under “other foreign body”, one contained a large egg-like object or cyst within it which could not be identified. The other appeared to have been attacked by a fungus and possessed fungal hyphae running through it.

Table 9.8 Summary of the results of the dissection of *P. vulgatissima* obtained from the wintering population at Friars Court Farm, Oxfordshire

	Males	**Females**	**Total**
Total number dissected	28 (57%)	21 (43%)	49 (100%)
Number parasitised	4 (14%)	2 (10%)	6 (12%)
Other foreign body	1 (4%)	1 (5%)	2 (4%)

Only 11 *P. vulgatissima* were collected from Long Ashton. None of these were parasitised but two were dead when collected and infected with a mould fungus. This appeared as a white floss coming from beneath and between the elytra.

A summary of the observations obtained from another sample of beetles collected at Friars Court Farm is presented in Table 9.9. Few *G. lineola* were obtained and none were parasitised. A proportion of both the *P. vulgatissima* (6.4%) and *G. lineola* (8.1%) collected were dead and infected with a mould fungus. A smaller proportion (4.1% and 2.7% respectively) were dead with no obvious cause. Some of these appeared to have been predated by other arthropods as often merely a husk remained but this is speculative. Of the live *P. vulgatissima* reared through until the spring, 6.9% were parasitised. This became apparent as the beetles broke diapause from 21st April onwards. The parasitised beetle would die and a red-brown pupa would be observed protruding from under the elytra or beside the body. Although not observed the parasitoid grub would have emerged from the host, killing it in the process, and then pupated outside the hosts body. The tachinid fly, *Medina separata*, was identified from the adults which emerged from the pupae using the key in Belshaw (1993).

Table 9.9 Observations of willow beetles obtained from Friars Court Farm, Oxfordshire and over-wintered in the laboratory

	Total	**Alive**		**Dead**	
		Not Parasitised	Parasitised	Mould	Other
P.vulgatissima	534	445 (93.1%)	33 (6.9%)	34 (60.7%)	22 (39.3%)
G.lineola	37	33 (100%)	0	3 (75.0%)	1 (25.0%)

9.5 Discussion

From the initial pitfall trapping at three coppice sites across the south of England (Baxter, 1995) it is apparent that a great range of Carabid and Staphylinid beetle species are to be found in SRC crops. These species groups have been identified as important predators of farmland arthropods, including some agricultural pests (Thomas, Wratten & Sotherton, 1991). Studying the two most numerous species at Friars Court Farm revealed that their occurrence was not uniform throughout the crop. Although the situation was reversed in one variety for reasons unknown, both *H. rufipes* and *P. niger* tended to be more numerous towards the crop edge. This was to be expected as ground beetles tend to inhabit areas of ground vegetation, tussocky grasses for example (Forsythe, 1987). This habitat was found more towards the crop edge under the influence of the grassy headlands which were present at the site.

In studies of the distribution of the predatory arthropods of cereal fields they are also found to be more frequent at the field margin. This information led to the development of beetle banks by The GCT (Thomas *et al.*, 1991). Beetle banks are earth banks established through the centre of large cereal fields and sown with a mixture of tussocky grasses (predominantly cocksfoot (*Dactylis glomerata*) and Yorkshire fog (*Holcus lanatus*). By this method predatory ground beetles and spiders are encouraged into the heart of the crop where they may help control the numbers of crop pests. If Carabids numbers are to be maximised a similar means of encouraging them away from the crop edges will be necessary.

That Carabids may be an important control agent of the major willow pest, *Phratora vulgatissima*, was demonstrated in the laboratory for *P. niger*. This species was observed to consume adult and pupal forms of *P. vulgatissima*. It is likely that it will also consume *P. vulgatissima* larvae which were not tested against *P. niger* in this study. Although *H. rufipes* did not consume any form of *P. vulgatissima*, it is highly likely that several of the other ground beetle species, including some of those recorded by Baxter, will also be predators of this species. Furthermore, the investigation of the soil depth at which *P. vulgatissima* pupated indicates that pupae are readily available to terrestrial predators, which most ground beetle species are, most pupae being within the top 1cm of the soil.

Vourdas (1996) also shows here that other arthropods predate willow pests, both in the field and in the laboratory. Four ladybird, three hoverfly and two lacewing species were shown to consume the willow aphid *Tuberolachnus salignus* (but none consumed *P. vulgatissima*). Observations in the field and in the laboratory also suggest that natural enemies of this aphid may be having some effect on its numbers. Aphid colonies were noted to decrease in size with time and that this decrease was greatest when predators were present. This may be due to the aphids being eaten or to the aphids moving off to avoid predation. This latter possibility would still result in fewer aphids merely due to the disturbance which interrupts their feeding and reproduction. The study of the effect of *Dasysyrphus albostriatus* on aphids on potted willows in the laboratory does strongly suggest that aphid numbers decreased due to predation. Considering the willow beetles *P. vulgatissima* and *Galerucella lineola* in the predator and parasite exclusion experiment, their numbers would also appear to be reduced by exposure to natural enemies as more defoliation (indicating greater pest abundance) was observed on branches from which natural enemies were excluded.

Parasitoids were discovered infecting over-wintering adult *P. vulgatissima* at Friars Court Farm in moderate numbers. The Tachinid responsible, *Medina separata*, has only recently been recognised as occurring in the UK, but this is due to the difficulty in separating this species from its congeners (Belshaw, 1993). Its hosts are recorded as ladybirds and chrysomelids and it has been recorded in the UK from *P. vitellinae*, closely related to *P. vulgatissima* (Belshaw, 1993). Other evidence of parasitoid activity during this study includes the shrivelled larval skins of *P. vulgatissima*, which were discovered adhering to willow leaves at several SRC sites in Northern Ireland and in England in 1995 and 1996 (*pers obs.*). These are highly suggestive of parasitoid activity.

Parasitoid activity was also recorded for *T. salignus* and the insect responsible was identified as *Praon volucre.* This is a small braconid wasp with a large number of similar species found in the UK. Their activities can be recognised by the mummified aphids they leave behind (Gauld & Boulton, 1988).

Both these parasitoid species require nectar food sources as adults and in the case of Hymenoptera (the group to which braconid wasps belong) it has been shown that the provision of nectar sources increases the fecundity and foraging distance of the adult female i.e. she infects more host individuals over a larger area (Altieri & Letourneau, 1982; Powell, 1986; Leius, 1967; Van Emden, 1962 and Jervis *et al.*, 1993).

The work of Sharples (1997) dealt with birds and showed that these species too could conceivably have a beneficial effect within SRC. Although the species investigated were restricted and the number of nests studied was few, interesting results were obtained. For all species, at least a third of the identified faecal items were from herbivorous arthropods. For willow warbler and garden warbler the figure was over 60% with Coleoptera larvae (i.e. willow beetles) featuring highly. The impact of these birds when pest numbers could be significant, especially in areas where the habitat allows them to nest at high density. Observations indicated that most food items for all species except the garden warbler (which was not observed) were obtained with the SRC crop.

The studies reported in this section show that there is a large resource of natural enemies of insect pests present within SRC in the form of arthropods and birds. Their activity distribution may, however, be restricted to limited areas of the crop. For example, the ground beetles are likely to be associated with rides and headlands where suitable vegetation occurs. Birds also require suitable vegetation in which to nest and although they may range away from the nest when foraging, limited nesting habitat limits the number of territories and so limits the number of pests consumed. Hoverflies, parasitoid flies and wasps all need nectar sources as adults and so may be restricted to the edges of the crop where suitable flowers are available (Powell, 1986; Leius, 1967; Van Emden, 1962 and Jervis *et al.*, 1993). Only ladybirds, which are carnivorous as adults and as larvae, can complete their whole life cycle within the heart of the crop, feeding on aphids. These too, however, may be restricted somewhat, this time by their need to find over-wintering sites which will lie largely outside of the crop.

Initial attempts around the world at using biological control of pests tended to centre on introducing alien species to control the pest (Grenier, 1988 and Powell, 1986). More recently attention has turned to naturally occurring predators/parasitoids by enhancing the crop environment to encourage and increase the effectiveness of these species (Powell, 1986; Sage & Tucker, 1995). Several studies of such biological pest control suggest that biomass crops like SRC are ideal subjects for this sort of pest management (Murdoch, 1975; Powell, 1986 and Price & Martinsen, 1996; Sage & Tucker, 1995; Tucker & Sage and Buckley, 1997). These state that in order to support predator and parasite numbers from year to year, low numbers of pests must be maintained throughout the life of the crop. For annual crops which may rotate around a field system, some method of supporting the natural control in the absence of the crop and its associated pest must be provided. This might be in the form of a sacrificial area of the crop or by supplying an alternative host/prey species. This stability is needed to provide a continuation of the control species and so avoid local extinctions. Perennial crops like SRC circumvent this problem by being present continuously providing habitat for pest and predator from one year to the next. Also, the continuous presence of a pest may not be possible in a food crop where even slight damage may be unacceptable (i.e. fruits which must be cosmetically appealing). This problem does not exist in SRC where economic thresholds are higher and slight damage does not reduce the value of the crop (section 1.0).

The mechanisms which sustain continuous, but low numbers of pests and their enemies are not straight forward. Powell (1986) suggests that diversity of habitats is important so mimicking natural systems resulting in a diversity of natural control methods. Food in the form of pollen and nectar for adult parasitoids and refugia for over-wintering and maintaining small numbers of pests or providing alternative hosts when the pest is scarce are the main opportunities cited. Murdoch (1975) states that stability is the key. This might be achieved through diversity of habitats in the farmland ecosystem but Murdoch argues that this is not the case. Natural ecosystems are more stable than agricultural ones because agricultural ecosystems are subjected to frequent and severe disturbance (not so in SRC, Section 1.0). Species develop together in nature but not in agriculture and that the natural component of agricultural systems is vastly simplified. In this last respect farmland ecosystems are more like laboratory based experiments. Stability is in direct conflict with traditional pest control which uses pesticides to produce wild swings in pest numbers in an attempt to create local extinctions. A major drawback of stability of pest numbers is that in some systems, stability may only be achieved at high pest density which is not a desirable situation.

Price and Martinsen (1994) also state that SRC has the potential to benefit from natural pest control methods. It can sustain moderate levels of defoliation without significant yield losses. Defoliation does, however, have an economic effect which needs to be quantified but it is likely that the damage threshold is high (Sage and Tucker 1995). There is a warning that practices, such as providing over-wintering sites, may benefit pest as well as enemy. Establishing a ground vegetation may increase winter survival by the pest or may stress the crop so making it more susceptible to pest attack.

SRC is a good candidate for pest control using natural enemies and the reasons include the following;

- The stability of SRC crops is intermediate between agricultural crops and forestry crops. This has advantages for natural pest controls.
- Vigorous growth means damage compensation is high and foliage will be recycled into the crop.
- High economic thresholds mean that control actions will be rarely required.
- Natural regulation of pests is likely to be high The rotation times allow beneficial insect communities to colonise and develop especially if they over-winter out of the trees.

- Early harvest is an option if pest numbers become unacceptable.
- Natural pest control can be combined with other IPM methods, based on genotype selection and plant breeding, cultural control and cultivation practices. These have a high probability of success together with significant environmental benefits.

As part of IPM, to encourage natural enemies within the crop, there is a strong argument for encouraging the growth of a ground flora beneath the coppice canopy. This would provide suitable conditions for ground beetles, provide nesting cover for birds and nectar sources for predatory and parasitic insects all of which would help keep pest numbers at an acceptable level. The effect of a ground flora on the crop requires investigation and this is done to some extent in Section 21.0. The viability of establishing a ground flora in SRC and the species likely to be successful and beneficial are discussed in Section 20.0.

9.6 References

Baxter, D.A. (1995) *Design and management of short rotation coppice plantations - a case study of tiger and ground beetles*. Report submitted for the M.Sc. in Landscape Ecology, Design and Management, Wye College, University of London.

Begon, M., Harper, J.L. and Townsend, C.R. (1986) *Ecology: Individuals, populations and communities*. Blackwell Scientific Publications, Oxford.

Belshaw, R. (1993) Tachinid flies, Diptera: Tachinidae. *Handbooks for the identification of British Insects.* Volume 10, part 4a(i). Royal Entomological Society of London, London.

Cramp, S. and Perrins, C.M. (1994) *Handbook of the Birds of Europe, the Middle East and North Africa: The Birds of the Western Palearctic*, Volume 6, Warblers. Oxford University Press, Oxford.

Cramp, S. and Simmons, K.E.L. (1992) *Handbook of the Birds of Europe, the Middle East and North Africa: The Birds of the Western Palearctic*, Volume 9, Buntings and New World Warblers. Oxford University Press, Oxford.

Forsythe, T.G. (1987) *Common ground beetles.* Naturalists' Handbook 8. Richmond Publishing Co. Ltd., Richmond.

Gauld, I. And Boulton, B. (1988) *The Hymenoptera.* Oxford University Press, Oxford.

Grenier, S. (1988) Applied biological control with Tachinid flies (Diptera, Tachinidae): A review. *Anz. Schädlingskde., Pflanzenschutz, Umweltschutz,* 61, 49-56.

Hill, D.A., Andrews, J., Sotherton, N.W. and Hawkins, J. (1995) In *Managing habitats for conservation*, pp. 230-266. Eds W J. Sutherland and D A. Hill. Cambridge University Press, Cambridge.

Jervis, M.A., Kidd, N.A.C., Fitton, M.G., Huddleston, T. and Dawah, H.A. (1993) Flower-visiting by hymenopteran parasitoids. *Journal of Natural History,* 27, 67-105.

Joy, N.H. (1932, reprinted 1976) *A practical handbook of British Beetles.* E.W. Classey Ltd, Faringdon.

Leius, K. (1967) Influence of wild flowers on parasitism of tent caterpillar and codling moth. *The Canadian Entomologist,* 99, 444-446.

Lindroth, C.H. (1974) *Handbooks for the identification of British insects: Coleoptera: Carabidae*. The Royal Entomological Society, London.

Moreby, S.J. (1987) An aid to the identification of arthropod fragments in the faeces of gamebird chicks (Gallifomes). *Ibis* 130. 519-526.

Murdoch, W.W. (1975). Diversity, complexity, stability and pest control. *Journal of Applied Ecology*. 12, 795-807.

Powell, W. (1986). Enhancing parasitoid activity in crops. In *Insect parasitoids,* Editors: Waage, J., and Greathead, D. Academic publishing.
Price, P.W. (1980) *Evolutionary biology of parasites.* Princeton.

Price, P.W. & Martinsen, G.D. (1994) Biological pest control. In *Biomass and Bioenergy*. Pergamon.

Sage, R.B. & Tucker, K (1995) Integrated flora management and pest control in short rotation coppice. In: *Wood fuel - The Green Debate, The Old Palace, Hatfield, 1994.* Harwell Laboratories, Oxford.

Sharples, A. (1997) *A preliminary investigation into the diets of five songbird species frequenting short rotation coppice in the UK: with specific interest in bird predation on defoliating insect pests.* Report submitted for the M.Sc. in Pest Management (Applied Entomology), University College of London and for the Diploma of Imperial College.

Thacker, J. and Hopkins, G. (1998) British tree aphids - natural history and conservation. *British Wildlife*, 9. 154-163.

Thomas, M.B., Wratten, S.D., Sotherton, N.W. (1991) Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: Predator densities and emigration. *Journal of Applied Ecology* 28. 906-917.

Tucker, K., Sage, R.B. & Buckley, G.P. (1997) Introducing other plants into short rotation coppice willow. *Aspects of Applied Biology* 49.

Van Emden, H.F. (1962) Observations on the effect of flowers on the activity of parasitic Hymenoptera. *Entomologist's Monthly Magazine*, 98, 265-270.

Vourdas, M. (1996) *A preliminary investigation into the natural enemies of herbivore pests of short rotation coppice willow.* Report submitted for the M.Sc. in Pest Management (Applied Entomology), University College of London and for the Diploma of Imperial College.

10.0 THE ABUNDANCE AND DISTRIBUTION OF CHRYSOMELIDS BETWEEN SITES

10.1 Summary

Here we look at the abundance and distribution of chrysomelids at a sample of 29 well-established SRC sites in Britain and Ireland during 1994 - 1997. The dataset enabled us to identify trends in chrysomelid presence and abundance over time.

By collecting data on various environmental site factors in 1995, we were also able to investigate, using regression analysis, whether sites particularly prone to colonisation by chrysomelids had certain features in common.

We found that while there were fluctuations in the presence and abundance of chrysomelids at some sites between years, for *Galerucella lineola* and *Phratora vitellinae* there were no overall trends over the period (for example towards increasing populations). The distribution of *P. vulgatissima* however, did increase over the period.

In the regression analysis, geographic location was not significant in the analysis of chrysomelid distribution although the maps suggest that sites in Scotland and in East Anglia were generally not colonised by these species.

***Phratora vulgatissima* were more abundant at the older willow plantations in the sample and in plantations growing on clay soils. The analysis also indicated that the presence of certain wild willow species in the vicinity of plantations probably act as a colonisation source for this beetle.**

The presence of *Galerucella lineola* in the SRC survey plots was significantly related to the presence of rivers or other waterways nearby.

Wild poplars *Populus* spp. and certain willow species probably act as colonisation sources for *Phratora vitellinae* on poplar SRC although this was not shown.

These results indicate that certain sites are more likely to be colonised by and to support a damaging population of chrysomelid beetles and that these sites may be avoided at the planning stage.

10.2 Introduction

In Section 8.0 we identified three leaf-eating beetles (Coleoptera: Chrysomelidae) *Phratora vulgatissima*, *P. vitellinae* and *Galerucella lineola* as the most widespread and abundant herbivorous insects on short rotation willow or poplar coppices (SRC) in the UK and Eire in 1994 and 1995. We added to these data by continuing to sample chrysomelids at the 1994 and 1995 sampling sites in both 1996 and in 1997. This provided a four-year dataset of chrysomelid presence and abundance. This enabled us to look at trends in the presence and abundance of each of the three chrysomelid species over time.

We then look at external factors that may influence the likelihood of a damaging pest population occurring. Data from 1995 on chrysomelids is compared with other datasets containing information on a wide range of site factors which, conceivably might influence the abundance and distribution of the beetles. By siting SRC plantations in locations that for some reason are not located or are avoided by the pests is a first step in any integrated pest management strategy, i.e. pest avoidance.

10.3 Methods

10.3.1 Quantifying beetle abundance

Data on the presence and abundance of *P. vulgatissima, P. vitellinae* and *G. lineola* in SRC crops in Britain and Ireland were collected from 29 SRC sites in each year 1994 - 1997. Twenty-four of these sites contained willow SRC and 11 of them contained poplar SRC (several sites contained both willow and poplar). The sample constituted almost all sites known to the authors to be over 0.5 ha in area and at least two years old (the exceptions were unmanaged or overgrown sites). Insect assessments were undertaken during the period May - September in each year. Most sites contained several plots with a range of varieties present and of these, insect sampling was confined to those varieties recommended for commercial SRC (Tabbush & Parfitt, 1996). At some sites with beetles and a range of varieties, all commercial SRC varieties were sampled to provide a between-variety comparison (Section 11.0) and at others samples were collected several times during the summer. While this was done primarily to monitor population dynamics and is reported elsewhere, occasionally sites were re-sampled when sampling was first undertaken during the beetle larval or pupae stage.

Adult and larval beetles were collected from within the canopy of SRC plots by beating the coppice stems, and allowing the insects to fall into a cotton sheet laid out on the ground between the coppice stools (the method is described in detail in Section 7.0). Beat samples were taken at three randomly selected locations within a sample plot, to provide a mean with variance for beetle numbers per m^2. The sheet beat method enabled rapid assessments to be made and hence many sites to be sampled in one season.

The chrysomelids have one generation per year and usually appear as larvae in mid June/early July (e.g. Kendall *et al.*, 1996). If samples contained chrysomelid larvae but few (< 10) or no adults, we usually re-sampled the site at a later date. Adult chrysomelids tended to disappear following egg laying in spring resulting in an dip in numbers until the new generation emerges (Section 9.0) and larvae numbers did not provide a stable estimate of chrysomelid abundance due to rapidly changing numbers. Similarly, a small number of late larval instars suggested that a proportion of the beetle population at the site would be pupating in the soil. Sample date was used as a potential explanatory variable in the site analysis to account for other trends in beetle abundance through time that may exist in the sample.

The chrysomelid data for the four years were used to calculate a categorical abundance index for the population of *P. vulgatissima* in each sample plot for each year:

0 - Species not present
1 - Species present but in low numbers
2 - More than 10 adults per m^2 on the sheet

The index was based on the three samples of adult numbers taken per plot and was used to ameliorate the effect of variations in the abundance of *P. vulgatissima* that exist in SRC plantations both during the season and spatially within plots.

10.3.2 The distribution of beetles between sites and years

The environmental factors that may influence the abundance of the three beetle species between sites and which were included in the analysis are listed in Table 10.1.

The index of abundance of each beetle for 1995 was treated as the dependent variable in a linear step-wise multiple regression analysis, with the environmental factors as explanatory variables. Linear regression analysis was then used to confirm the statistical significance of any selected variables. All analyses were carried out using SYSTAT (Wilkinson, 1990). 1995 was used in this part of the analysis as this was the year in which data on most of the environmental factors were collected. Where different samples were collected from more than one plot, the index of beetle abundance was based on the variety sample containing most pests. At the sites from which samples were taken on several occasions during the season, the index was calculated using a mean value.

Some free-living willows are thought to be preferred by (i.e. are more palatable to) *P. vulgatissima* and *G. lineola* (e.g. Tahvanainen *et al.*, 1985) and are categorised in this study accordingly. Sections 7.0 and 11.0 indicate that *P. vitellinae* only occurs on poplar SRC. Some willows are however palatable to this species. These tend to be those that are unpalatable to *P. vulgatissima* so the same categories were used in the analysis (the details and causes of species and clonal selection by these chrysomelids is discussed in Section 11.0). The presence chrysomelids on the free-living willows was also recorded

10.3.3 The distribution of other common herbivores between sites and years

We also calculated an abundance index for sawfly larvae and caterpillars using the 1995 dataset (Section 7.0) using the above method and tested this against the same list of environmental variables. Note that samples of moth and sawfly larvae were collected from a reduced sample of 19 sites.

Table 10.1. Site specific environmental variables included in the analysis database

SRC species	Willow or poplar
NGRN	National grid reference north
NGRW	National grid reference west
Soil type	Clayey, loamy, sandy or organic
Altitude	Metres above sea level
Site age	Year of planting, before or after 1991
Nearby woodland	Proportion of woodland or scrub within 400 m
Nearby water	Presence of rivers or other water bodies within 400m
Previous land-use	Cropland, grassland, woodland
Exposure	Five point scale
Cut-back year	Year of last cut
Preferred wild willows*	Presence or absence within 400 m
Other wild willows*	Presence or absence within 400 m
Wild poplars	Presence or absence within 400 m
Sample date	Days from April 1 1994

* Wild willows preferred by *P. vulgatissima* were *S. viminalis, S. caprea*, and *S. cinerea* (Tahvanainen *et al.*, 1985). Other wild willows were other free-living willows encountered in the surveys - *S. fragalis, S. alba, S. purpurea.*

10.4 Results

10.4.1 the abundance and distribution of chrysomelids

The distribution and relative abundance of the three chrysomelids at the UK SRC survey sites in each year are shown in Tables (10.2 - 10.4). Note that by the end of the four year period, six of the 29 sites were abandoned, reducing the overall sample size to 23, the willow sample to 18 and the poplar sample to nine.

The proportion of sites from which *P. vulgatissima* were recorded increased steadily over the period 1994 - 1996, colonising over half of all sites in the sample and over two-thirds of all willow sites by 1996. Over the four year period the species increased (from an index of 0 to 1 or 1 to 2) at six sites and decreased at two. *P. vitellinae* occurred at over half the poplar sites throughout the period but no overall trend was apparent. The greatest distribution was in 1995 when the species was recorded from all but one of the 11 poplar sites. An overall increase (index 0 to 1 or 1 to 2) occurred at two sites and a decrease at one site over the period. In 1997, the species was abundant (index=2) at five sites. *G. lineola* was less widespread than the other two species although it occurred at one third of the willow sites in 1994 and 1996. In 1997 the species was recorded from just three (17 %) of the remaining 18 willow sites in the sample and was abundant at one.

10.4.2 Factors affecting the distribution of chrysomelids between sites

Chrysomelids were generally not recorded from SRC sites in the far north and in the East Anglia region of England. Despite this, Easting or Northing were not significant in the regression analyses of chrysomelid abundance and the environmental factors.

In the regression analyses for the index of beetle abundance and environmental site variables (Table 10.1), the presence of *P. vulgatissima* was positively related to site age (more beetles at sites planted before 1991, $F_{1,19}=11.22$, $P<0.005$), soil type (more beetles on clay soils, $F_{2,19}=4.15$, $P<0.05$) (Figure 10.2) and to the presence of preferred free-living willows ($F_{1,19}=17.25$, $P<0.005$). These three variables explained 63% of the variance in the beetle abundance index. At three of the 13 SRC sites that had *P. vulgatissima*, no preferred free-living willows were found within the 400m survey area (or within an extended search area of up to 1 km) but the species was recorded from the canopy of preferred free-living willows at seven of the remaining 10 sites. Four of the five sites that contained more than 10 adult beetles / m^2 contained preferred free-living willows adjacent to the SRC plots. The beetle was not recorded from the other free-living willows in the sample.

Table 10.2. *Galerucella lineola* - abundance index at the SRC sites over the four year study. There were 24 sites with willow and 11 with poplar in 1994 and 18 with willow and 10 with poplar in 1997.

NGR - National grid reference Easting and Northing
Tree spp. - Willow or poplar or both

Abundance index: 0 - No *G. lineola* at site
1 - One to 10 *G. lineola* /m2
2 - More than 10 *G. lineola* /m2
a - Site abandoned (grubbed up etc.).

Site name	NGReast	NGRnrth	Tree spp.	1994	1995	1996	1997
Brahan	251	855	w	0	0	0	0
Guisichan	231	827	w	0	0	0	a
Kincardin	294	816	w	0	0	a	a
Shotts	286	660	w	0	0	1	a
Florence	26	503	w	1	0	0	0
Loughall	98	510	w	0	0	0	0
Castlarch	29	521	w	2	0	0	0
Johnston	91	278	w	0	0	0	1
Clonrche	74	293	w	0	0	0	0
Dublin	125	411	w	0	0	0	0
Ingerthrp	428	466	w & p	1	1	1	0
Parbold	347	413	w	1	1	1	1
Broadlaw	414	580	w	0	0	0	0
Haydon	383	565	w	0	0	0	0
Dunstall	401	262	w & p	1	0	1	0
Bardolph	465	343	w	0	0	a	a
Swanbrne	479	228	p	0	0	0	0
Castlerise	567	324	p	0	0	0	0
Mepal	545	285	p	0	0	0	0
Ashton	354	169	w & p	1	1	1	a
Alice	481	143	p	0	0	0	0
Wishngr	491	139	w & p	0	1	0	0
Buckfast	275	68	w	0	0	0	0
Henley	479	184	w & p	1	1	a	a
Michael	187	43	p	0	0	0	0
Compton	365	163	w & p	0	0	0	0
Friars	430	201	w	2	2	2	2
Ashmans	586	217	w	0	0	0	0
Roves	423	191	w	0	0	1	0
% presence at all sites in sample				28 %	21 %	27 %	13 %
% presence at willow sites in sample				33 %	25 %	33 %	17 %

Table 10.3. *Phratora vitellinae* - abundance index at the 29 SRC sites from 1994 to 1997 inclusive.

NGR - National grid reference Easting and Northing
Tree spp. - Willow or poplar or both

Abundance index:
0 - No *P. vitellinae* at site
1 - One to 10 *P. vitellinae* /m^2
2 - More than 10 *P. vitellinae* /m^2
a - Site abandoned (grubbed up etc.). Sampling no longer possible.

Site name	NGReast	NGRnrth	Tree spp.	Brassy 94	Brassy 95	Brassy 96	Brassy 97
Brahan	251	855	w	0	0	0	0
Guisichan	231	827	w	0	0	0	a
Kincardin	294	816	w	0	0	a	a
Shotts	286	660	w	0	0	0	a
Florence	26	503	w	0	0	0	0
Loughall	98	510	w	0	0	0	0
Castlarch	29	521	w	0	0	0	0
Johnston	91	278	w	0	0	0	0
Clonrche	74	293	w	0	0	0	0
Dublin	125	411	w	0	0	0	0
Ingerthrp	428	466	w & p	1	1	1	1
Parbold	347	413	w	0	0	0	0
Broadlaw	414	580	w	0	0	0	0
Haydon	383	565	w	0	0	0	0
Dunstall	401	262	w & p	1	2	2	2
Bardolph	465	343	w	0	0	a	a
Swanbrne	479	228	p	2	2	1	1
Castlerise	567	324	p	0	1	0	0
Mepal	545	285	p	0	1	0	0
Ashton	354	169	w & p	2	2	2	2
Alice	481	143	p	2	2	2	2
Wishngr	491	139	w & p	0	0	0	0
Buckfast	275	68	w	0	0	0	0
Henley	479	184	w & p	0	1	a	a
Michael	187	43	p	1	1	1	2
Compton	365	163	w & p	2	2	2	2
Friars	430	201	w	0	0	0	0
Ashmans	586	217	w	0	0	0	0
Roves	423	191	w	0	0	0	0
% presence at all sites in sample				24 %	42 %	27 %	30 %
% presence at poplar sites in sample				63 %	91 %	70 %	70 %

Table 10.4. *Phratora vulgatissima* abundance and distribution at the 29 SRC sites.

NGR - National grid reference Easting and Northing
Tree spp. - Willow or poplar or both

Abundance index: 0 - No *P. vulgatissima* at site
1 - One to 10 *P. vulgatissima* /m^2
2 - More than 10 *P. vulgatissima* /m^2
a - Site abandoned (grubbed up etc.). Sampling no longer possible.

Site name	NGReast	NGRnrth	Tree spp.	Blue 94	Blue 95	Blue 96	Blue 97
Brahan	251	855	w	0	0	0	0
Guisichan	231	827	w	0	0	1	a
Kincardin	294	816	w	0	0	a	a
Shotts	286	660	w	1	1	1	a
Florence	26	503	w	0	0	0	1
Loughall	98	510	w	2	2	2	1
Castlarch	29	521	w	2	2	2	2
Johnston	91	278	w	2	1	2	2
Clonrche	74	293	w	1	0	0	0
Dublin	125	411	w	1	1	0	0
Ingerthrp	428	466	w & p	1	1	1	1
Parbold	347	413	w	1	1	2	2
Broadlaw	414	580	w	2	2	2	2
Haydon	383	565	w	0	1	1	1
Dunstall	401	262	w & p	0	0	1	1
Bardolph	465	343	w	0	0	a	a
Swanbrne	479	228	p	0	0	0	0
Castlerise	567	324	p	0	0	0	0
Mepal	545	285	p	0	0	0	0
Ashton	354	169	w & p	2	2	2	a
Alice	481	143	p	0	0	0	0
Wishngr	491	139	w & p	0	0	0	0
Buckfast	275	68	w	0	0	1	1
Henley	479	184	w & p	0	1	a	a
Michael	187	43	p	0	0	0	0
Compton	365	163	w & p	0	1	0	0
Friars	430	201	w	2	2	2	2
Ashmans	586	217	w	0	0	0	0
Roves	423	191	w	0	0	1	1
% presence at all sites in sample				34 %	45 %	54 %	52 %
% presence at willow sites in sample				46 %	54 %	67 %	67 %

The presence and abundance of *G. lineola* was found to be related to the presence of water nearby (ANOVA, n=23, $F_{1,21}$=12.14, P=0.002, r^2=0.37). No other variable was important and *G. lineola* was not recorded at any site in Scotland. Referring back to the original site maps indicated the presence of a stream or river course within around 200m of the SRC plantings at seven of these eight sites while the eighth contained two ponds fed by ditches. A two-way chi-square test of *G. lineola* presence and absence and water-way presence or absence was also significant (Table 10.5, this test excludes Scottish sites as these are beyond the normal range of this species, Kendall *et. al*. 1996). *G. lineola* were occasionally recorded from the same free-living wild willow species as *P. vulgatissima*.

Table 10.5. Contingency table and Pearson chi-square test statistic for *G. lineola* occurrence at the sub-sample of willow SRC sites (outside Scotland) with and without water-ways nearby.

	With waterway	Without waterway
With beetles	8	0
Without beetles	5	7
Total	13	7

Pearson chi-square test statistic = 7.179, DF=1, P<0.01. sites with water-ways nearby were significantly more likely to have beetles than those without.

P. vitellinae was not significantly related to any of the environmental factors in Table 10.1. The species was recorded from free-living poplar trees in the vicinity of plantations at several sites and from free-living willows (S. purpurea and on two occasions).

10.4.3 Factors affecting the distribution of other common herbivores between sites

In 1995, sawfly larvae were recorded from the canopy at 18 of the 19 SRC sites where intensive collection methods were used and was abundant at one (Section 7.0). Moth (and butterfly) larvae were recorded from 10 of the 19 sites but never in large numbers (abundance index 2). The three point index of abundance for both these species groups therefore showed relatively little variance across sites and were not related to any environmental factors listed in Table 10.1.

10.5 Discussion

Comparing the abundance of chrysomelids between sites and years was complicated by the variability in the number of chrysomelids on the coppice during the year, and by their variable distribution within the plots. We know for example that most chrysomelid adults over-winter in crevices outside of the coppice field (e.g. bark of mature trees, see Section 12.0) and following colonisation of the SRC in late April/ early May, the beetles concentrate around the coppice edges. The adults spread into the fields to lay eggs in mid to late May. By the time the young larvae emerge in June, adult numbers have significantly reduced. The larvae take 7 - 10 days to pupate in the soil and by late July the new generation of adults emerge (see Section 9.0 and e.g. Kendall *et al.*, 1996).

We accounted for these variations in this study in several ways. First, through sampling methodology, by avoiding the initial colonisation, by sampling away from the crop edge and by not relying on adult samples collected during the mid-summer pupal period before the emergence of the second generation adults. Second, by including as many sites as possible in the sample and by using an index of abundance to create a categorical variable for the regression. A site received an index of 0 only if no adults or larvae were found. Most other sites contained many more (index=2) or many less (index=1) than 10 adults. Furthermore, date was not significant in the analysis, suggesting no trend or major step change through time consistent across sites. In other studies, late summer populations can be more than, similar or to less than colonising ones (Sections 9.0 & 12.0 and e.g. Kendall *et al.* 1996).

This study confirms the widespread distribution of *P. vulgatissima* on willow SRC at UK SRC plantations in the 1990's, and its avoidance of poplar (see also Sage & Tucker, 1997 and Section 11.0). It also indicates that this species has steadily increased in its distribution and abundance over the period 1994 to 1997. Note that the sample did not include sites that were in their establishment year, so this trend does not include the initial colonisation phase of those sites most prone to attack (we have observed on several occasions, newly planted sites being colonised by chrysomelids within weeks of being planted). *G. lineola* was less widespread and populations were more variable between years with a reduction from 33 % to 17 % between 1996 to 1997. Like *P. vulgatissima*, *P. vitellinae* was also widespread, occurring at all but one poplar site in 1995 and over two thirds of sites since.

The datasets for the two *Phratora* spp. suggest that at some sites populations of beetles that have become established remain at high levels between years (both species had an index of 2 at five sites each for most of the period). At other sites, beetle numbers stay a low densities or even come and go. These processes indicate that there are features of some SRC sites (or their environment) which make them prone to colonisation by chrysomelids, and/or encourage populations to grow once beetles have arrived.

The comparison between the beetle abundance index and the site factors provides evidence that site location has an important influence on the chances of damaging pest populations developing in willow SRC plantations. The wild willow species on which beetles were found appear to be a source of colonisation by *P. vulgatissima*. The occurrence of *P. vulgatissima* adults and larvae on free-living *S. viminalis, S. caprea* and *S. cinerea* and not on *S. alba* and *S. fragalis* (despite these two species being generally more abundant at several sites that contained the beetle) is consistent with the findings of laboratory studies on willow palatability (e.g. Rowell-Rahier, 1984, Tahvanainen *et al.*, 1985).

We also found that the chance of a SRC plantation being colonised by *P. vulgatissima* increases with its age. The beetle may take longer to colonise SRC plantations that do not contain wild willow hosts in the immediate vicinity. Four of the five plantations that contained more than ten *P. vulgatissima* per m^2 were bordered by free-living willows that also contained the beetle. Conversely, three of the 24 plantations in this study were colonised despite the lack of wild willows within at least 1 km of the site. The significance of soil type in the regression may also reflect the importance of colonisation sources. Free-living willows occurring in the British Isles and Ireland are common on poorly drained but nutrient rich soils in the lowlands such as clay loams (Brendall, 1985).

The presence of over-wintering areas, primarily under the bark of mature trees or other crevices, is known to be an important, and possibly limiting, component of the habitat requirements of *P. vulgatissima* (Sections 9.0 and 12.0). Kendall *et al.* (1996) found that most *P. vulgatissima* adults occupying an SRC plot over-wintered in crevices within 200 metres of the plantation. The presence of woodland, scrub or hedges nearby however was not significantly related to the indices of beetle abundance in this analysis. The variables used, however, did not quantify the quality of these areas as over-wintering habitat and it is likely that certain types of woody habitats are not suitable. Similarly, beetles found at sites with no woody habitats nearby over-wintered in fence posts, buildings, wood piles etc. (Sage *et. al.*, in press), and in the crop itself when it contains sufficient debris or at one site, where stem cankering by a rust pathogen *Melampsora* spp. provided suitable crevices (Kendall *et al.*, 1996).

For *P. vitellinae* a similar effect is likely with wild poplars or certain willow species acting as colonisation sources and an increased risk of colonisation over the first few years after planting. The lack of significant variables in the analysis probably reflects the low sample of poplar sites (11). In 1995, *P. vitellinae* were found on wild poplar or willows in the vicinity of most poplar SRC plots that also contained the beetle. *Galerucella lineola* was recorded from eight *Salix* SRC sites in England and Ireland. All eight had nearby water courses. This suggests that this species colonises willows along water courses. The relationship between damp sites, and *G. lineola* has been referred to by others. For example, a recent study in Sweden found that *G. lineola* were influenced by humidity in their feeding behaviour (Larsson *et. al.*, 1997).

Many shrub and tree willow species (and to a lesser extent poplars) are associated with watery places in the UK (Brendall, 1985). It is then perhaps intuitive that the insects associated with these trees, such as the chrysomelid species investigated here, are also linked with wet places. While this was demonstrated in the analysis for *G. lineola*, the analysis may have overlooked a similar relationship for the *Phratora* spp. For *P. vulgatissima* at least, all but one of the sites that contained a high abundance of this species (Index=2) in

1995 had water-ways nearby. Anecdotally, we observed two willow plantings established since 1993 on sites adjacent to willow-lined rivers (and therefore not included in this study, see Methods), which were colonised immediately by *P. vulgatissima*.

Another chrysomelid, the broader willow beetle *Plagiodera versicolora* was occasionally recorded at some willow sites. While we have no data on, for example, clonal selection by this species, it was recorded in fairly large numbers on a wild *S. alba* at one site.

Although further work is required on the scale at which chrysomelid colonisation processes of SRC crops occur, it is likely that the regularity and severity of colonising populations decreases with distance from the plot. These results suggest that there is scope for avoiding severe infestations of this beetle by undertaking a risk assessment study when considering the location of a new plantation. The presence of *S. viminalis, S. caprea* and *S. cinerea*, adjacent to proposed planting sites is likely to lead to damaging populations of *P. vulgatissima* and possibly *G. lineola*, particularly near water-ways. Although not shown, *P. vitellinae* are likely to colonise poplar SRC plantations planted in the vicinity of wild poplar trees. If such sites are selected for SRC plantations, the use of species or varieties unpalatable to these beetles would be an important consideration. This study confirms the unpalatability of poplar SRC to *P. vulgatissima* and *G. lineola* and of (most) willow SRC to *P. vitellinae*. Clonal selection within species by the three chrysomelids is explored in detail in Section 11.0.

Pest avoidance can be an important component of an IPM strategy, and this paper provides evidence that appropriate site selection can reduce the likelihood of a SRC plantation being colonised by these chrysomelids.

10.7 References

Brendell, T., (1985) *Willows of the British Isles*. Shire Natural History, Aylesbury, UK, pp. 24.

Hutchinson, H. P.; Kearns, H. G. H., (1930) *The control of Phyllodecta vitellinae. L. (Chrysomelidae).* Annual Report Agricultural and Horticultural Research Station, Long Ashton, pp. 112-126.

Kendall, D. A.; Wiltshire, C. W.; Butcher, M., (1996) *Phenology and population dynamics of willow beetles (Coleoptera: Chrysomelidae) in SRC willows at Long Ashton.* ETSU B/M4/00487/14/REP, Harwell Laboratories, Oxford, pp. 44.

Larsson, S., Haggstrom, H.E. Denno, R.F. (1997) Preference for protected feeding sites by larvae of the willow-feeding leaf beetle *Galerucella lineola*. *Ecological Entomology* **22**, 445-452.

Price, P. W.; Martisen, G. D., (1994) Biological pest control. *Biomass & Bioenergy,* **6**, 93-102.

Rowell-Rahier, M.; Pasteels, J. M., (1982) The significance of salicin for a *Salix* feeder, *Phratora vitellinae.* In: *Proceedings of the fifth international symposium on insect plant relationships.* Eds. J.H. Visser and A.K. Minks Pudoc, Wageningen, The Netherlands.

Rowell-Rahier, M., (1984) The presence or absence of phenolglycosides in *Salix* (Salicaceae) leaves and the level of dietary specialisation of some of their herbivorous insects. *Oecologia* **62**, 26-30.

Sage, R. B.; Tucker, K., (1995) Integrated flora management and pest control in short rotation coppice. In: *Wood Fuel - The Green Debate.* The Old Palace, Hatfield. Harwell Laboratories, Oxford, pp. 21-29.

Sage, R. B.; Tucker, K., (1997) Invertebrates in the canopy of willow and poplar short rotation coppices. *Aspects of Applied Biology* **49**, 105-111.

Sage, R. B. & Tucker, R. B. (In press) The distribution of *Phratora vulgatissima* (Coleoptera: Chrysomelidae) on cultivated willows in Britain and Ireland. *European Journal of Forest Pathology.*

Sage, R. B.; Tucker, K.; Sotherton N. W., (In press) Integrated crop management of SRC plantations to maximise crop value, wildlife benefits and other added value opportunites. *ETSU B/W2/00400/00/00.* Harwell Laboratories, Oxford.

Sage, R.B., Robertson, P.A., & Poulson, J.G. (1994) Enhancing the conservation value of short rotation coppice - Phase 1, the identification of wildlife conservation potential. *ETSU B/W5/00277/REP.* Harwell Laboratories, Oxford.

Southwood, T.R.E., (1978) *Ecological Methods*, 2nd edition. Chapman and Hall, London.

Tabbush, P.; Parfitt, R., (1996) Poplar and willow clones for short rotation coppice. *Forestry Commission Research Information Note 278.* Alice Holt Research Station, Farnham, Surrey.

Tahvanainen, J. R.; Julkunen-Tiitta, Lavola, A., (1985) Phenolic glycosides govern the food selection pattern of willow-feeding leaf beetles. *Oecologia* **67**, 52-56.

Wilkinson, L., (1990) *SYSTAT, The System for Statistics.* Systat Inc. Evanstan, Illinois, USA.

11.0 PREFERENCES EXHIBITED BY CHRYSOMELIDS FOR DIFFERENT VARIETIES

11.1 Summary

When comparing the numbers of chrysomelid beetles from different willow and poplar varieties in the same plots, we found that both *Phratora vulgatissima* and *Galerucella lineola* were more abundant on some willow varieties that others. Neither species were found on poplar varieties growing alongside infested willow. Of the commonly planted varieties, 'Germany' and 'Q83' were both avoided by *P. vulgatissima* and 'Germany' by *G. lineola*.

The third common chrysomelid in UK SRC plantations, *P. vitellinae* was recorded from all (five) poplar varieties sampled, and while it was occasionally recorded from some of the more unusual willow varieties, it avoided all commonly planted ones.

Another group of (much smaller) chrysomelids, the flea beetles (Chalcoides spp.) were not identified to species in this study. As a group, they were found on all willow and poplar varieties sampled.

These field data on varietal selection occurred with limited choices (in terms of available varieties). Nevertheless, the selection patterns found reflect the findings of controlled studies. The patterns are interpreted in the context of studies on the chemical characteristics of willow and poplar leaves, and the ability of the different chrysomelids to deal with or use these chemicals.

We also compared chrysomelid numbers in an intimately mixed plot of five willow varieties, with numbers in monovarietal blocks of each of the same varieties. Three were preferred by *P. vulgatissima* and *G. lineola* at other sites and two were usually avoided. We found that while there were significantly fewer of both species in the mixed plot, this reflected only the reduced abundance of the preferred varieties in this plot.

A knowledge of varietal resistance and susceptibility in the field can be used as part of an integrated pest management strategy for chrysomelids by either planting the most resistant varieties (and hence possibly compromising yield potential), or by using sacrificial areas of the most

susceptible varieties. Mixing susceptible and resistant varieties may not be useful in limiting chrysomelid damage.

The use of varietal choice is however complicated by the fact that most species avoided by one chrysomelid tend to be susceptible to another. A survey of free-living willows and poplars and chrysomelids in the vicinity of a proposed plantation can provide guidance.

11.2 Introduction

Differences in the susceptibility of willow and poplar species and varieties to feeding damage by *P. vulgatissima*, *P. vitellinae* and *G . lineola* have been noted for many years. Hutchinson and Kearns (1930) at the Long Ashton Research Station listed those willow species, based on field observations, that were attacked by chrysomelids and those that were not. Since then the literature on chrysomelid beetles includes several papers describing laboratory based and other studies on this subject, particularly for willows (e.g. Tahvanainen 1985; Kendall *et al.* 1996). It is clear from this work that different species and varieties within the genus display a range of levels of susceptibility, with willow varieties in particular ranging from susceptible to completely resistant.

In this section we report selection and avoidance of varieties by chrysomelids at a range of SRC plantations in Britain and Ireland in the field. We compare chrysomelid numbers from varieties growing in the same plots. In a case study at one site, numbers of defoliating insect and measurements of crop phenology were recorded at mixed and monovarietal *Salix* plots and compared. The null hypothesis was that there were no differences in pest abundance, defoliation and crop growth statistics between similar varieties in the two plot types. The field work was undertaken in summer 1994 and 1995.

In the discussion we consider the literature related to varietal selection by chrysomelids, usually based on laboratory studies, and compare this information with the field findings presented here. This enables us to make an assessment of the scope for including differential varietal resistance and susceptibility in a management strategy for chrysomelids.

11.3 Methods

11.3.1 Comparisons between varieties at a range of sites

Invertebrate numbers were assessed at a large number of sites in both 1994 and 1995 in accordance with the methods described in section 7.0. As indicated in section 7.0 and 10.0, several varieties were sampled at many of these sites during these quantitative surveys. These data allow comparisons in the abundance of chrysomelids to be made between varieties in the same plots and sampled on the same day.

Data are presented and significant differences identified for sites that contained beetles and where at least three varieties were sampled for comparison. Most sites contained several plots with a range of willow varieties present and of these, insect sampling was confined to those varieties recommended for commercial SRC (Tabbush and Parfitt, 1996). Comparisons were not made where varieties were separated by other habitats or where one-sided colonisation by beetles could bias numbers in particular varieties for other reasons (see Sections 9.0 and 12.0 for patterns of colonisation and dispersal). Comparisons were also avoided between different age-classes of coppice even where they occurred within the same plot.

11.3.2 A comparison between mixed and monovarietal blocks

At one site, a case study comparison between monovarietal plots and a plot containing an intimate mixture of the same varieties was undertaken. The plot contained six adjacent blocks of coppice, five of which were monovarietal and the sixth contained an intimate mix of the five varieties in the monovarietal block.

Comparisons in insect abundance were made between the five monovarietal blocks and the mixed block. Percentage loss of leaf area (defoliation) and crop height were also measured in two of the monovarietal blocks (SQ683 and Dasyclados) and for the same two varieties in the mixed block itself. Observations indicated that the three plots were similar in terms of exposure, soil type and adjacent habitat but the possibility of un-recorded factors causing differences between plots cannot be discounted.

The abundance of the two chrysomelid species in each of the six sample blocks, and measurements of defoliation and stem length in the selected plots, were collected in accordance with the methods described in Sections 7.0 and 8.0. Within the mixed block, 18 stems were measured, nine of S. dasyclados and nine SQ683.

11.4 Results

11.4.1 Species selection

Regular sampling of SRC plots in 1994 at a range of sites indicated that *Phratora vulgatissima* were confined almost exclusively to willow SRC sites in Britain and Ireland while *P. vitellinae* was recorded from the poplar plots. This result is described in Section 10.4.1 and was not necessarily expected as *P. vitellinae* was the main pest of withy bed willows in the past. G*alerucella lineola* was also recorded from willow sites only.

11.4.2 Varietal selection

P. vulgatissima and G. lineola on willow

At site A, four Salix species were intensively sampled for chrysomelids SQ683, Dasyclados, Q83 and Bowles Hybrid (Figure 11.1, bowles Hybrid not shown). The varieties Dasyclados, Bowles hybrid and SQ683 contained populations of both *P. vulgatissima* and *G. lineola* adults from spring emergence until late June and then larvae until early August. The Q83 however, bordered by the *S. viminalis* SQ683 varieties and the Dasyclados, also contained *G. lineola* in high abundance but no *P. vulgatissima*. (*G. lineola* were also found on Q83 at site H in Figure 11.7, along with Dasyclados). The other varieties at the site that contained numerous *P. vulgatissima* and *G. lineola* were Calodendron, Delamare and Bowles Hybrid (by observation only, these varieties were not sampled). Strips of *S. alba vitellinae*, and the poplar varieties Boelare and Trichobel contained virtually no beetles at the site (again by observation only).

Both Bowles Hybrid and Dasyclados occurred in two separated fields of SRC at site B in Northern Ireland (Figure 11.2). There were no differences in the abundance of *P. vulgatissima* between these two varieties in either plot although numbers differed between the two plots.

At site C in Southern Scotland (Figure 11.3), *P. vulgatissima* was abundant in Dasyclados, Mullatin and SQ683. No individuals were found in a plot of Germany and defoliation was less in this variety than the other three. Flea beetles were equally common in all four varieties. At a similar site in NW England (Site D, Figure 11.4), Germany was again avoided by *P. vulgatissima* compared to the Bowles Hybrid and Dasyclados. This result was repeated for *G. lineola* which also occurred at this site while flea beetles were recorded from all three varieties. Defoliation was lower in the Germany variety at both site C and D than the other varieties. At a further two sites (E and F) sampled for *P. vulgatissima*, Bowles Hybrid, SQ683 and Dasyclados again contained beetles along with another variety Cambells while Germany and Q83 did not (Figure 11.5). At another site not shown in the Figures, *P. vulgatissima* was found at high densities on Bowles Hybrid. In an adjacent plot of Korso (*S. burjicata*), the beetles were present but at much lower densities.

P. vitellinae at poplar and mixed sites

Similarly high numbers of *P. vitellinae* were sampled from two poplar varieties at site G in southern England (Figure 11.6). Both Beaupre and Trichobel contained around 45 beetles per m^2 when sampled and around 14 flea beetles per m^2. A further two varieties at the site, Boelare and Rap, although not sampled apparently contained similar numbers of beetles.

FIGURES 11.1, 11.2, 11.3, 11.4, 11.5, 11.6 NOT AVAILABLE ELECTRONICALLY

At site H, Beaupre, Boelare and Trichobel all contained *P. vitellinae* (Figure 11.7). Adjacent willow plots (Dasyclados, Bowles Hybrid and Q83) did not contain this beetle. Flea beetles at this site were found in varying abundance in all varieties. Defoliation at this site tended to be higher in the poplar plots than the willow plots. The two poplar varieties sampled at site I (Figure 11.8), Beaupre and Rap, again both contained *P. vitellinae* whereas adjacent willow varieties did not.

At the poplar site described in Section 12.0, Boelare, Beaupre and Trichobel all contained a high abundance *of P. vitellinae* and no *P. vulgatissima*. Conversely, a strip of just two rows of the willow variety Dasyclados within the poplar SRC contained no *P. vitellinae*, but did contain *P. vulgatissima*.

11.4.3 Mixed v monovarietal

The two varieties Dasyclados and SQ683 in the monovarietal blocks at the Castlearchdale site contained between 10 and 20 *Phratora vulgatissima* and between 5 and 10 *Galerucella lineola* per m^2 (Figures 11.9 & 11.10). The other two varieties Germany and Q83 contained significantly fewer of both species (except G. lineola in Q83 see 11.4.2 above). The mixed plot contained significantly fewer beetles than the two infested monovarieties (Figures 11.9 and 11.10, except *P. vulgatissima* in Dasyclados), but more than the Germany and Q83 monovarieties (except *G. lineola* in Q83).

Percentage defoliation in the Dasyclados was significantly higher in the monovarietal block than the same variety in the mixed block. For SQ683, the mean percentage defoliation was again higher in the monovarietal block but the difference was not significant. The mean stem length, canopy height and stem circumference of each variety were greater in the mixed plots but the differences were not significant (Figures 11.9 to 11.10). However, by combining varieties (to increase sample size) and comparing data between blocks, indicated that the willow stems from the mixed block were significantly taller and had a greater canopy height than the stems from the monovarietal blocks (Table 11.1).

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Table 11.1. Growth measurements for both hybrids combined in both plot types. DF=32.

Plot	Stem Length, cm	Difference to mixed	Stem Circumf, mm	Difference to mixed	Canopy height, cm	Difference to mixed
Mixed	197.1		26.4		127.2	
Monovarietal	172.1	T=2.45 P=0.020	24.9	T=0.61 P=0.55	103.6	T=2.55 P=0.015

FIGURE 11.7, 11.8, 11.9 AND 11.10 NOT AVAILABLE ELECTRONICALLY

11.5 Discussion

11.5.1 Varietal selection by chrysomelids

Data on host plant selection in the field by chrysomelids is difficult to interpret because selection by the beetles is affected by the presence and by the absence of optimal or sub-optimal plant species or varieties. Beetle colonisation of sub-optimal varieties may be due to the absence of, or complete defoliation of, a highly suitable one. Also, in our experience, any of the three main chrysomelid species considered in this study could, on occasion, be found on any nearby willow or poplar species or variety for a short period of time. An example of this was found during the intensive monitoring programme at site A (Figure 11.1). The Q83 variety was in fact extensively colonised by *P. vulgatissima* for the first few days following spring emergence, before being rejected. In another example at the same site, *G. lineola*, usually reported as feeding exclusively on willows, began to appear on a strip of the poplar variety Trichobel adjacent to the main willow plots, during late summer 1995 (this chrysomelid is not usually associated with poplars at all). A possible explanation was that the willow plots had become severely defoliated with little leaf replacement due to drought stress.

Interpretation of host plant selection data may also be complicated when certain adult beetles show different preferences for feeding and for egg laying. For *P. vitellinae* in particular, adults would be expected to lay eggs on varieties that provide maximum protection for the eggs and larvae from predation, i.e. those that contain the optimum type and level of the phenolglycoside salicin, which the eggs and larvae use as a deterrent (see below). The adults themselves may well feed on the most palatable variety. Seasonal changes in leaf chemistry or physical factors can also change preferences. Despite these reservations, useful interpretations can be made of species and varietal selection by adult chrysomelids when considering the results presented here in conjunction with the results of other research studies and the causes of varietal selection.

11.5.2 Varietal selection

At most sites that contained chrysomelids in this study, certain varieties contained significantly more beetles than others and for several commonly planted varieties these differences were consistent between sites. This indicates first that chrysomelids can readily discriminate between different varieties in the field. The colonisation of a sub-optimal variety Q83 by *P. vulgatissima* in the spring described above indicates the beetles initially cannot distinguish the different varieties before settling on them, at least when few other beetles are present (it has been suggested that chrysomelid colonisation is stimulated by the feeding activities of other individuals already on the plant).

The results also indicate that the different varieties show different levels of susceptibility and resistance to attack and that the different chrysomelid species do not necessarily select the same varieties. *Phratora vulgatissima* selected most *S. viminalis* varieties sampled (Bowles Hybrid, Mullatin, SQ683, Cambells) with the exception of the *S. triandra* cross Q83 (Table 11.2) and *S. dasyclados* (Wimm.) Apart from Q83, it also avoided *S. aquatica gigantea* (e.g. Germany). As indicated in the previous section of this report the beetle also avoided all the common poplar varieties. *Galerucella lineola* tended to occur on the same species and also avoided *S. aquatica gigantea* variety 'Germany' but unlike *P. vulgatissima* was commonly recorded on Q83.

In a recent study, using both field and laboratory procedures, 24 SRC varieties were compared for susceptibility to damage by *P. vulgatissima* and *G. lineola* (Kendall *et. al.*, 1996). This indicated similar results to those found here Varieties were given an index of resistance based on the amount of defoliation. *S. eriocephala* was consistently the most resistant variety, followed by *S. purpurea, S. burjatica* (Germany)*, S. dasyclados* (Swe, see Table 11.2) *and S. triandra* Q83 varieties. Of these only the first two were consistently avoided by both beetles. Least resistant were *S. viminalis, S. aurita, S. caprea, S. cinerea, S. stipularis* and *S. dasyclados* (Wimm.).

P. vitellinae was found in equal numbers on all poplar varieties sampled in this study (Beaupre, Trichobel, Boelare, Rap). It did not select any of the willow varieties sampled, despite the presence of the beetle on adjacent poplar varieties. Anecdotally however, we have found this beetle on some more unusual willow SRC varieties such as an *Salix purperea* variety at Site I (Figure 11.8). In a study of *P. vitellinae* conducted in the 1930's in the old basket willow beds of Lancashire, Leicestershire, Berkshire and Gloucestershire, the beetle was found to attack *S. purpurea*, *S. alba*, *S. alba vitellinae*, *S. nigricans*, *S. repens* and to a lesser extent *S. fragilis* and S. *purperea x viminalis*. They did not attack S. *viminalis*, *S. triandra*, *S. americana* and *S. coerulea* (Hutchinson and Kearns(1930). On wild growing willows, *P. vulgatissima* is associated with *S. viminalis* amongst others while *P. vitellinae* with *S. nigricans*, *S. purperea* and *S. fragilis* (Rowell-Rahier and Pasteels, 1992).

Flea beetles did not appear to show selectivity but individual species were not separated in this study. It is however very likely that different species of flea beetles are associated with different willows and poplars. While they are much smaller than the *Phratora* spp., in large numbers they could cause significant defoliation. Up until now however, the numbers recorded for flea beetles have not been as high as for the larger Phratora spp. and consequently flea beetles have not been a focus for this study.

11.5.3 Mixed v monovarietal

Two of the five willow varieties were avoided by both beetle species in the monovarietal blocks. In the mixed block, the abundance of beetles was approximately half that found in the three preferred varieties in the monovarietal blocks. This suggests that the level of beetle abundance for each variety in the mixed block reflects that found in the monovarietal blocks. The results of the beetle surveys indicate that mixing susceptible willow varieties with sub-optimal ones may not reduce the colonisation by beetles of the susceptible varieties. However, percentage defoliation of at least one of the susceptible varieties through insect herbivory was also less in the mixed plot while defoliation of the avoided varieties was similarly low in both plot types. Measurements of stem growth indicated that the Dasyclados and SQ683 stems were larger in the mixed plot.

It is perhaps surprising then that percentage defoliation of susceptible varieties in the mixed block were significantly lower than that found for the same varieties in the monovarietal blocks. The reason for this maybe that the records of percentage defoliation may not in fact reflect the levels of herbivory by the insects. The growth measurements of the varieties in 1994 do suggest that the mixed plot was growing more vigorously than the varieties in the monovarietal blocks and hence compensation for herbivory is also greater. The reason for this difference in growth is unclear although there is some evidence that the reduced rust attack on the mixed plot compared to the monovarietal blocks documented elsewhere is at least in part responsible.

In other crop ecosystems it has been shown that monocultures tend to support larger populations of insect pests and diseases and suffer greater damage than mixed planting. It has already been demonstrated that the rust pathogen spreads less quickly through a susceptible hybrid in a mixed willow SRC plantation than the same hybrid in a monovarietal block (Royle et al 1993), the results of this survey do not indicate a similar effect for chrysomelids.

11.5.4 Plant traits that influence varietal selection

The explanation for differences in the willow and poplar feeding preferences of chrysomelids identified in Section 10.5.2, may lie with the various chemical and morphological differences that exist in these tree species groups. In particular the chemical composition of willow and poplar leaves has been clearly linked with the feeding preferences of the two *Phratora* spp.. Kendall et al. (1996) provide a recent overview.

Many willow and poplar species produce high concentrations of certain chemicals collectively known as phenolglycosides, in their leaves. These are usually sub-lethal compounds which reduce the palatability of the plant and hence the amount of herbivory from most generalist herbivorous feeders. These include the chrysomelids *P. vulgatissima* and *G. lineola.* The 'specialist' feeders such as *P. vitellinae* have however evolved to use the commonest phenolglycoside in willow leaves salicin, to produce through hydrolysis a special salicylaldehyde defensive secretions as larvae (Rowell-Rahier and Pasteels 1982, 1986). This secretion is thought to be effective and relatively easy for the beetle to produce. The disadvantage is that the beetle is unable to produce a defensive secretion when feeding on plants that do not contain the appropriate phenolglycosides. Defensive secretions are very important to these chrysomelids as they are vulnerable to predation for several weeks, both as egg clusters and as cohorts of relatively immobile larvae.

P. vulgatissima and *G. lineola*, while unable to hydrolyse the phenolglycosides do produce their own (methylcyclopentanoide) monoterpene defensive secretions that do not depend directly on the chemical composition of the host plant. While this is likely to use more of the beetles resources than the salicylaldehyde secretions of *P. vitellinae*, the beetles can eat a wider range of plants including herb species. Generally then, Salicin acts as a deterrent for *P. vulgatissima* and *G. lineola*, and as an attractant for *P. vitellinae*.

Usually then, willows and poplars that contain high levels of phenolglycosides (Table 11.2) such as salicin deter feeding and ovipositing by *P. vulgatissima* and *G. lineola* (willow only) as these chemicals inhibit larval development, increase mortality through predation (Haggstrom and Larsson 1995) and confer no benefit in terms of defensive secretions. These beetles would not be expected to breed well on willows or poplars that contain medium or high concentrations of these chemicals, although as suggested they may occur on them from time to time. Conversely, *P. vitellinae* is attracted to the willows and poplars that contain the phenolglycoside salicin. Adults and larvae of this beetle feeding on species or varieties that do not contain these chemicals are unable to produce defensive secretions and are more vulnerable to predation.

The physical characteristics of willow leaves have also been found to influence feeding preferences by chrysomelids. Non-glabrous (i.e. pubescent) leaves, tough leaves and leaves from old trees have all been cited as causing reduced egg production and/or larval growth (Rowell-Rahier & Pasteels, 1982, Raupp, 1985). However it is likely that pubescence is not a deciding factor. *S. viminalis* leaves tend to be densely pubescent yet are preferred by *P. vulgatissima*. Conversely Germany and Q83 both tend to be glabrous yet are both avoided by this species.

S. nigricans, *S. purperea* and *S. fragilis* all contain relatively high concentrations of phenolglycosides such as salicin (Table 11.2) and are fed on by *P. vitellinae* adults and larvae. These *Salix* spp. also contain few condensed tannins, proanthocyanidins, and have glabrous leaf surfaces. *S. cinerea* and *S. caprea* do not contain phenolglycosides (but do contain proanthocyanidins and have hairy leaves) and *S. viminalis* has low concentrations of a wide range of phenolglycosides. These species are avoided by *P. vitellinae* but are colonised by *P. vulgatissima*. *S. alba* has low glycoside but hairy leaves. *S. triandra* contains an unusual phenolglycoside, salidroside (Tahvainen et al, 1995) and is avoided by both *Phratora* spp. but not by *G. lineola*. Q83 is avoided by both *Phratora* spp., probably because it consists of S. triandra.

Table 11.2. Willow varieties, parentage and glycosides

Parentage	Variety name
caprea x *cinerea* x *viminalis*	*calodendron*, *dasyclados* (Wimm)
Aquatica Gigantea	*burjatica* Germany, Korso, *dasyclados* (Swe)*
triandra	Black Maul
aurita x *viminalis* x *caprea*	*stipularis*
triandra x *viminalis*	Q83
caprea x *viminalis*	*serican* Coles
viminalis	Bowles hybrid, Mullatin, Swedish viminalis, Ulv, Orm, SQ683

High glycosides	*purperea, nigricans, fragilis, gigantea*
Low glycosides	*viminalis, cinerea, caprea, alba*
Low salicin glycosides but high salidroside	*triandra*

* 'Swe' refers to several varieties named *dasyclados* recently released by Swedish breeding programme and is used here to distinguish them from Dasyclados Wimm.

In a detailed study in Sweden, *S. dasyclados* (Swe) has been found to be a sub-optimal host plant for *G. lineola* compared to *S. viminalis* (as expected from leaf chemistry) with substantially longer larval development times and lower larval survival (Denno et al 1990, Haggstrom and Larsson 1995). While this suggests that adults should select *S. viminalis* this was not necessarily the case (the *S. dasyclados* Wimm. sampled in this study differs from Swe in this respect, see Table 11.2). This use of a sub-optimal variety by this beetle has been observed in this study, for example Korso. A suggested explanation for this is that evolutionary selection pressure on *G. lineola* to avoid *S. dasyclados* (Swe) and other sub-optimal varieties that lead to reduced breeding success has not yet occurred. Many *Salix* varieties used in SRC like *S. dasyclados* have not been around for very long. Generalist feeders like *G. lineola*, may not distinguish between these subtly different varieties. There may therefore be an increase in the specialisation of chrysomelids to certain willow and poplar varieties.

In summary, the selection by the three chrysomelids of varieties in UK SRC plantations described in this study are consistent with these interpretations of leaf chemistry. Willows (and poplars) that contain high levels of phenolglycosides such as salicin (i.e. those grown for basket making in the past) deter feeding and ovipositing by *P. vulgatissima* and *G. lineola* but attract *P. vitellinae*. *P. vitellinae* was a widespread pest of cultivated willows earlier this century when coppiced willows were grown in withy beds for making baskets (Hutchinson & Kearns, 1930). *P. vitellinae* is not common in modern willow SRC plantations (Sage & Tucker, 1997). This is probably due to the change in the varieties used.

The avoidance of poplars, and certain willow varieties by *P. vulgatissima* observed is also consistent with laboratory based experiments on varietal selection by this beetle and by studies of the chemical composition of willows and poplars (e.g. Tahvainen *et al.*, 1985). Most modern SRC willows have been bred without insect resistance in mind and are based on *S. viminalis,* a species low in phenolglycosides, and therefore available to generalist feeders like *P. vulgatissima* (e.g. 'Bowles Hybrid' and 'SQ683'). There are exceptions to these rules, possibly due to lag times in the evolution of the expected response to a recently released variety.

The implications of these are very important. While varietal resistance could dramatically reduce the potential for damage by chrysomelids in commercial SRC plantations, varieties identified by this and other studies that appear consistently resistant to *P. vulgatissima* and *G. lineola*, tend to be varieties that are particularly susceptible to *P. vitellinae*. For example while varieties such as *S. eriocephala* and *S. purperea* could be of value in plant breeding for resistance to *P. vulgatissima* (Kendall *et al.* 1996), the susceptibility of *S. purperea* to *P. vitellinae* reduces this value (whether *S. eriocephala* is also susceptible to *P. vitellinae* is not known). There are however exceptions and most notably here, Q83 (*S. triandra* cross) which appears to be resistant to both *Phratora* spp. (but not *G. lineola*), and 'Aqautica gigantea' e.g. Germany, which may be particularly useful as a widely planted variety that appears to be resistant to all three chrysomelids.

A knowledge of varietal resistance and susceptibility in the field can be used as part of an integrated pest management strategy for chrysomelids by either planting the most resistant varieties (and hence possibly compromising yield potential), or by using sacrificial areas of the most susceptible varieties. Mixing susceptible and resistant varieties may not be useful in limiting chrysomelid damage. A survey of free-living willows and poplars and chrysomelids in the vicinity of a proposed plantation could help in deciding which varieties to plant, particularly if only one chrysomelid species is present.

11.6 References

Bach, C. E., (1994) Effects of herbivory and genotype on growth and survivorship of sand-dune willow (*Salix cordata*). *Ecological Entomology*, **19:** 303-309.

Brendell, T., (1985) *Willows of the British Isles.* Shire Natural History, Aylesbury, UK, pp. 24.

Denno, R. F., Larsson, S. and Olmstead, K. L. (1990) Role of enemy-free space and plant quality in host-plant selection by willow beetles. *Ecology* **71**: 124-137.

Haggstrom, H., Larsson, S., (1995) Slow larval growth on a suboptimal willow results in high predation mortalitym in the leaf beetle *Galerucella lineola*. *Oecologia*, **104**: 308-315.

Hutchinson, H. P.; Kearns, H. G. H., (1930) The control of *Phyllodecta vitellinae.* L. (Chrysomelidae). *Annual Report Agricultural and Horticultural Research Station, Long Ashton.* pp. 112-126.

Kendall, D. A.; Wiltshire, C. W.; Butcher, M., (1996) Phenology and population dynamics of willow beetles (Coleoptera: Chrysomelidae) in SRC willows at Long Ashton. *ETSU B/M4/00487/14/REP*, Harwell Laboratories, Oxford, pp. 44.

Kendall, D. A.; Hunter, T., Arnold, J., Morris, T., Wiltshire, C. W., (1996) Susceptibility of willow varieties (salix spp.) to Herbivory by *Phyllodecta vulgatissima* (l.) and *Galerucella lineola* (Fab.) (Coleoptera, Chrysomelidae). *Annals of Applied biology* **129**: 379-390.

Larsson, S., (1983) Effects of artificial defoliation on stem growth in *Salix smithiana* grown under intensive culture. *Oecologica applicata*. **4**: 343-349.

Price, P. W.; Martisen, G. D., (1994) Biological pest control. *Biomass & Bioenergy,* **6**: 93-102.

Raupp, M.J. (1985) Effect of leaf toughness on mandibular wear of the leaf beetle *Plagiodera verisocolora*. *Ecological Entomology* **10**: 73-79.

Rowell-Rahier, M.; Pasteels, J. M., (1982) The significance of salicin for a *Salix* feeder, *Phratora vitellinae*. In: *Proceedings of the fifth international symposium on insect plant relationships*. Eds. J.H. Visser and A.K. Minks Pudoc, Wageningen, The Netherlands.

Rowell-Rahier, M., (1984) The presence or absence of phenolglycosides in *Salix* (Salicaceae) leaves and the level of dietary specialisation of some of their herbivorous insects. *Oecologia* **62**: 26-30.

Sage, R. B.; Tucker, K., (1995) Integrated flora management and pest control in short rotation coppice. In: *Wood Fuel - The Green Debate,* The Old Palace, Hatfield. Harwell Laboratories, Oxford, pp. 21-29.

Sage, R. B.; Tucker, K., (1997) Invertebrates in the canopy of willow and poplar short rotation coppices. *Aspects of Applied Biology* **49**: 105-111.

Sage, R.B. & Tucker, K. (In press) The distribution of *Phratora vulgatissima* (Coleoptera: Chrysomelidae) on cultivated willows in Britain and Ireland. *European Journal of Forest Pathology* ??: 00-00.

Southwood, T.R.E., (1978) *Ecological Methods*, 2nd edition. Chapman and Hall, London.

Tabbush, P.; Parfitt, R., (1996) Poplar and willow varieties for short rotation coppice. *Forestry Commission Research Information Note 278.* Alice Holt Research Station, Farnham, Surrey.

Tahvanainen, J. R.; Julkunen-Tiitta, Lavola, A., (1985) Phenolic glycosides govern the food selection pattern of willow-feeding leaf beetles. *Oecologia* **67**, 52-56.

Wilkinson, L., (1990) *SYSTAT, The System for Statistics.* Systat Inc. Evanstan,

12.0 OVERWINTERING AND DISPERSAL OF CHRYSOMELIDS INTO SRC - AN OPPORTUNITY FOR CONTROL

12.1 Summary

We studied the spring dispersal of the three common chrysomelid species from overwintering habitats into cultivated willow and poplar coppices at four sites in southern England over two years.

Adult *Galerucella lineola*, *Phratora vulgatissima* and *P. vitellinae* overwintered under the bark of mature trees within a few hundred metres of the coppice plantation, or in other niches that simulated this habitat. Relatively few beetles remained in the coppice fields during the winter.

Adult emergence coincided approximately with initial leaf emergence of their food plants. *P. vitellinae* on poplar therefore emerged several weeks later than *G. lineola* and *P. vulgatissima* on willows. Dispersal was by flight, with most activity during warm periods. Dispersal continued for several weeks for the willow species but was shorter for *P. vitellinae*. At one site, around 17500 adult *P. vitellinae* dispersed from a single oak tree.

All three species initially colonised the edge of the coppice field. Typically, 80 % or more of the beetles colonising a plantation were within 8 m of the edge. Both *Phratora* spp. accumulated in the plantation edge zone for several weeks before leaving this area and colonising the crop interior. Beetles also avoided recently cut stool if standing coppice existed nearby.

The patterns of dispersal and colonisation identified by this study may facilitate chrysomelid management practices in infested short rotation coppice that avoid the need for insecticide applications over the entire plantation. Instead, by monitoring colonisation at the crop edge in the spring, a local insecticide application could be applied from the field headlands which would reach most beetles in the field.

12.2 Introduction

As already indicated in section 10.0 and Sage & Tucker (1997b), SRC sites that contain free-living willow and poplar trees nearby are more likely to be colonised by chrysomelids than other sites. This information could be useful in an Integrated pest management strategy as it enables high risk sites to be avoided. In the winter, chrysomelids are not commonly found within SRC plantations (although there exceptions to this as we shall see). Instead, they overwinter in or near the coppice fields as adults and then re-colonise the crop canopy in the spring. When or how they do this is not known but an understanding of these colonisation processes may also help as part of integrated pest management strategy for these pests (Kendall *et al.*, 1996; Griffiths, 1997

In this study, we first identified where chrysomelids were spending the winter at several SRC sites, and then investigated the spring movements of adult beetles into and through the coppice canopy. To do this we used a variety of beetle traps to identify the timing and mode of movements from the overwintering sites into the coppice. We undertook this work at three sites and involved all three main chrysomelid species. As we started to collect beetles in these traps, we recorded the abundance of beetles in the coppice canopy, using the beating methods described in section 7.3.2, from strategic range of locations within the coppice field. These sampling and monitoring programmes enabled us to identify any patterns of chrysomelid colonisation and crop infestation in the SRC plantations that may help in managing these insects at sites where they have become pests.

Like the Colorado potato beetle in North America, an understanding of these movements may help to develop methods to manage or control these potential pests.

12.3 Methods

12.3.1 Study sites and overwintering surveys

Three SRC sites in southern England, two willow plantations (Pearces Farm at Long Ashton, and Friars Court, section 2.0) and one poplar plantation (Alice Holt) were selected for this study in 1994 (Table 1). The willow sites contained *P. vulgatissima* and *G. lineola* and the poplar site contained *P. vitellinae* (section 11.) In late 1995, the coppices at Pearces Farm and at Alice Holt were removed so in 1996, to keep the sample size up, we continued this study at Friars Court and added another site that contained *P. vitellinae* at Compton Dando in Avon. Temperature data were obtained from a weather station 5 km north of the Oxfordshire site in both years. The date of leaf emergence in the coppices was noted each year.

Table 1. Study sites in southern England used for this study.

Site	Site code	Tree species	Area (ha)	Date planted	County
Long Ashton	Willow1	willow	1.8	1986	Avon
Friars Court	Willow2	willow	5.0	1990	Oxfordshire
Alice Holt	Poplar1	poplar	0.6	1990	Surrey
Compton Dando	Poplar2	poplar	5.0	1990	Avon

Searches for overwintering chrysomelids were conducted between December and February 1994/95 and 1995/96 at each site. Within the crop, crevices on coppice stems and stools, dead herbage and the soil surface were searched. Trees, hedgerows, fence posts, wood piles, buildings etc. up to 400 m from the coppice were also examined. The aim of these searches was primarily to provide guidance for subsequent trapping of emerging adults in the spring.

12.3.2 Trapping emerging chrysomelids

In March 1995, three window traps and three gutter traps were placed around the perimeter of the Friars court (willow2), Long Ashton (willow1) and Alice Holt (poplar1) sites. All traps were constructed in our workshops at the Game conservancy HQ. The window trap (Owen, 1993) consisted of a wooden frame (1 m x 2 m) with strong clear plastic sheeting stretched over each face. This was supported by two 3-m tall posts that were driven into the ground and steadied with guy ropes. The frame was orientated vertically with the bottom edge 0.5 m above the ground. A 1-m length of plastic guttering, 0.1-m wide and with sealed end pieces was attached to the bottom edge of the screen on each side and filled with a water and 50 % preservative (car anti-freeze) solution to collect beetles. In preliminary trials, we found that most chrysomelids projected towards the screen bounced beyond the guttering and were not collected. However, by smearing the plastic sheeting with clear petroleum jelly to dampen impacts, we improved the catch rate to nearly 100 %. The window traps were located mid-way between the coppice and previously identified beetle overwintering sites and orientated parallel to the coppice edge. The two faces indicated the approximate direction of movement of beetles when caught (towards or away from the coppice). Each window trap had a gutter trap placed nearby, similarly orientated. A gutter trap consisted of two 1-m lengths of guttering with end pieces, laid in a trench side by side, again to indicate direction. A plastic cup half filled with the solution used in the window traps, was placed in a hole at one end to collect invertebrates.

Eight emergence traps were placed within the coppice at each site. Emergence traps were located randomly within the plots and placed over areas of bare soil, cut stools or dead vegetation. The traps consisted of four plywood ‘walls’ attached to corner posts to make an open ended box 1-m long by 0.5-m wide and 0.5-m tall. The corner posts were pushed into the ground so that the lower edges of the walls formed a gap-free fit with the soil surface. A pitfall trap and yellow dish trap, both filled with the water preservative solution used above, were placed inside the box before sealing the top with a fine plastic mesh.

All traps were set up in mid March with preliminary catches collected for the week to 27 March (week 0). Each trap was visited on the same day each week, but each site was visited on different days. At the Poplar1 site, week 1 refers to the seven days to 4 April, at Willow2 week 1 refers to 5 April and the Willow1 to 6 April. When occasionally a sample was not collected on the appropriate day, a correction was made to adjust the sample to provide a 7-day equivalent. Samples were collected and returned to the laboratory for sorting until 18 May (week 7 at Willow1).

12.3.3 Chrysomelids in the coppice canopy (1995)

Invertebrate sampling from the crop canopy began on 12 April (week 2) at site Willow2. Invertebrates were collected from within the coppice canopy using the beating method described in Section 7.3.2. Chrysomelids were immediately counted on the sheet to avoid collection and storage. The two superficially similar *Phratora* spp. can often be separated in the hand by colour and body shape, although this method is not considered reliable due to some overlap (Kendall *et al.*, 1996). However, collection sampling to estimate population size (reported elsewhere) confirmed species at all four sites (Section 10).

The location of beat samples changed during the spring as the distribution of the colonising beetles in the coppice became apparent. Initially two samples were collected near to the coppice edge but by May, at site Willow2 (the largest 1995 site), six beat samples were collected each week, at 5-m intervals along a transect perpendicular to the crop edge.

12.3.4 Chrysomelids in the coppice canopy (1996)

In 1996, invertebrate beat samples were collected from the coppice canopy throughout the spring at site Willow2 and Poplar2. Samples from both sites were collected on the same day each week starting with week 1, covering the 7 days from 28 March to 4 April (and hence equivalent to week 1 in 1995 at site P1) and finishing on week 10, to 6 June. Both sites were sufficiently large to collect several independent samples up to 30 m into the coppice and at least 30 m from other edges. At site Willow2, four edge transects were sampled in four different varieties or age classes, with beats taken at six points along each; at the edge, edge +2 m, +4 m, +8 m, +15 m, and +30 m. Each transect ran from the crop edge facing a belt of mature trees and scrub 10 m away. The first was in a block of 3-year-old SQ683 *S. viminalis* on 4-year-old stools approximately 4 m tall. The second and third transects were in blocks 3-year-old Q83 *S. triandra* x *S. viminalis* and Dasyclados *S. caprea* x *S. cinerea* x *S. viminalis*. The fourth was in a 3-m tall block of 1-year-old

Bowles *S. viminalis* on 2-year-old stools. This fourth transect included an area of recently cut (year 0) coppice, approximately 20 m deep, between the overwintering areas and the standing coppice. The six sampling points were located within the standing coppice, while a further six samples were collected from the cut area. This was done to assess whether beetles avoided cut coppice, when colonising the crop.

At site Poplar2, a similar number of beat samples were collected from each of two transects. The first was in a 3-m tall plot of 2-year-old Beaupre *P. trichocarpa* x *P. deltoides* on 3-year-old stools which faced an area of mature mixed ash *Fraxinus excelsior* and oak *Quercus* spp. woodland approximately 50 m away. The second was in a plot of 4-year-old Boelare *P. trichocarpa* x *P. deltoides* stems on 5-year-old stools which in places exceeded 6 m in height. The sampling ran from the base of a single oak tree *Quercus* spp., located 6 m from the crop edge. The tree was a mature stag-headed oak, around 10 m tall, with a short main trunk, approximately 1.5 m in diameter, and relatively few upper branches due to die-back. The bark was heavily fissured and apparently provide abundant overwintering opportunities for chrysomelids. Two further beat sampling transects were collected along the coppice edge, in either direction, from the base of the tree. This was done to assess whether beetles radiated from the tree base in an even manner, and enabled an estimate of the total number of beetles colonising the coppice from this single source.

12.3.5 Analyses

The numbers of beetles caught in the three window traps compared to the three gutter traps in 1995 were compared using repeated measures analysis of variance (ANOVA) over the seven-week sampling period. The total catch for each trap was calculated and these data were log-transformed (ln(x+1)) to normalise distributions. Trap location was included as a factor in the analysis to account for the pairing of traps. The three site/beetle combinations, *P. vulgatissima* at site Willow1, *G. lineola* at site Willow2 and *P. vulgatissima* at Willow2 were considered separately. The analysis considered the significance of any difference between the two types of trap over the whole sampling period. Almost all dispersal activity by *P. vitellinae* at site Poplar1 occurred during week 6, so the comparison in this case was made using a paired *t*-test for that one week.

A comparison was then made of beetle numbers caught by the two window trap faces, also using repeated measures analysis of variance over time. The 'in' and 'out' faces (towards and away from the plantation respectively) were paired in the analysis by including trap location in the model. The data were log-transformed and each site/beetle combination considered separately as before. A *t*-test was again used for *P. vitellinae* at site Poplar1. Data from the eight emergence traps at each of the three sites in 1995 were used to calculate the mean number of beetles emerging per m^2 of ground. This enabled a numerical comparison with densities recorded from the crop canopy. Within each site, a *t*-test was used to test any differences between beetle numbers from emergence traps covering patches of vegetation or cut coppice stools, with those over mainly bare soil or leaf litter.

Beetle abundance data from the 1996 within-crop beat samples for the four transects at site Willow2 and the two transects at Poplar2 were analysed in a similar way to the 1995 window and gutter trap data. The six sampling points along each transect line were considered as separate treatments within the transect. Repeated measures ANOVA over time was used on the log-transformed data, with transect as a factor. Each site/beetle combination was considered separately. In Figures, the mean for all four transects at site Willow2 and both transects and Poplar2 are shown for clarity. All statistical analyses were carried out using Systat (Wilkinson 1990).

12.4 Results

12.4.1 Overwintering

At site Poplar1, adult *P. vitellinae* were found under the bark of conifer trees 40 m from the coppice and in cracks in nearby wooden fence posts. At site Poplar2, *P. vitellinae* filled every crevice in the trunk of mature oaks (*Quercus* spp.) 5 - 10 m from the coppice. Trees with flaking bark in a belt of mature woodland up to 250 m from the coppice contained aggregations of up to 500 beetles. At site Willow1, *P. vulgatissima* were common under the bark of hedgerow trees and in a row of disintegrating concrete fence posts up to 200 m from the coppice. Individuals and small aggregations were also found within the coppice at this site, amongst dead herbage and in coppice shoot lesions caused by rust cankers (see Kendall *et al.*, 1996). At site Willow2, aggregations of up to 200 adult *P. vulgatissima* and 20 *G. lineola* were found under the loose bark of mature willows *S. fragalis* and *S. alba* and of elder *Sambucus nigra*, within 20 m of the coppice. Smaller numbers were recorded under the bark of fallen branches and willow logs. *G. lineola* in particular were also found in the hollow stems of dead standing herbage, particularly Umbellifers *Umbelliferae* spp. and willowherb *Epilobium* spp.

12.4.2 Beetle trapping

Beetles were recorded in traps throughout the seven-week sampling period at sites Willow1 and Willow2 in 1995 (Figure 12.1).

FIGURE 12.1 NOT AVAILABLE ELECTRONICALLY

Significantly greater numbers were caught in the window traps than the gutter traps over the whole period (repeated measures ANOVA: site Willow2, *P. vulgatissima*, $F_{1,2}$=29.10, P<0.05 and *G. lineola*, $F_{1,2}$=422.8, P<0.005; site Willow1, *P. vulgatissima*, $F_{1,2}$=42.14, P<0.05). Towards the end of the period, the difference between traps decreased as beetle flight activity decreased and the window trap catches tended to zero. The reduced activity in the middle of the sampling period coincided with a period of cold daytime temperatures (Figure 12.2)

At site P1, almost all *P. vitellinae* activity was confined to week 6 (Figure 12.1). Many more beetles were caught in window traps than the gutter traps in that week (*t*-test, t=130.4, P<0.001). Relatively few beetles were caught in the ground emergence traps at all three sites. (site Willow2, 0.6 beetles per m^2 per week; site Willow1, 1.8; site Poplar1, 0.5). There were no differences in numbers from emergence traps covering cut stools or dead herbage compared with those over bare earth or leaf litter. At site Willow1 and Willow2, it was apparent that some beetles actually entered the emergence traps from outside by crawling under the netting stapled around the trap sides, inflating these samples as beetles colonised the coppice from outside.

More *P. vulgatissima* were captured by the outward-facing sides of the window traps (away from the coppice) than the inward sides at site Willow1 over the whole period (repeated measures ANOVA, between subjects, $F_{1,2}$=36.95, P<0.05). At site Poplar1, more *P. vitellinae* were caught on the 'out' faces than the 'in' faces in week 6 (*t*-test, t=4.849, P<0.05). At site Willow2, Figure 12.1 indicates a similar trend at site Willow1 for *P. vulgatissima* for most of the sampling period but the overall difference for both *P. vulgatissima* and *G. lineola* was not significant ($F_{1,2}$=11.60, n.s. and $F_{1,2}$=0.041, n.s. respectively). This is because of the trend, apparent at all sites but particularly at Willow1, towards more beetles on the trap inward faces at the end of the sampling period. This reflects the movement of the beetle population from the overwintering areas into the coppice, and the subsequent general flight activity at the coppice edge.

In 1995, *P. vulgatissima* were first recorded in window trap samples at site Willow2 and Willow1 in week 1 (to 5 and 6 April respectively). From week 2, ending 12 and 13 April, significant beetle flight activity (in proportion to the whole sampling period) was recorded each week until mid May (week 6, Figure 12.1). *G. lineola* were active a week earlier at site Willow2, with a few records in the preliminary samples during week 0 (to 28 March) and proportionally large numbers in samples for week 1 until week 6 (10 May). As already indicated, virtually no dispersal activity by *P. vitellinae* at the site Poplar1, was recorded before or after week 6.

FIGURE 12.2 NOT AVAILABLE ELECTRONICALLY

12.4.3 Canopy beat sampling (1995)

The chrysomelid samples collected from the crop canopy at site Willow2 in 1995 recorded colonisation by *G. lineola* during week 2 (to 12 April) and *P. vulgatissima* during the following week (to 19 April). Over the following two or three weeks, this sampling indicated that following initial colonisation, most beetles of both species accumulated in the crop canopy at the very edge of the coppice (Figure 12.3, these data are compared with daytime maximum temperatures). Samples collected 10 m or more into the crop contained relatively few beetles. By week 6 however (to 10 May 1995), most beetles had left the crop edge zone and moved further into the coppice. The 1996 sampling programme investigated these trends in more detail.

12.4.4 Canopy beat sampling (1996)

G. lineola and *P. vulgatissima* at site Willow2, colonised the coppice edge two to three weeks later in the season than in 1995, with a significant number of *P. vulgatissima* at the edge in three of the four transects (up to 120/m^2 of crop canopy) for the first time during week 5, ending 2 May (Figure 12.4 & 12.5, compare Figure 12.3). The variety Q83 was initially colonised by a small number of both species during week 4 (to 25 April), but there were virtually no further records of *P. vulgatissima* in this variety in subsequent samples (section 10.0). At site Poplar2, significant numbers of *P. vitellinae* (200/m^2 of canopy at the edge) were first recorded colonising the crop canopy in transect 1 in week 6 and transect 2 in week 7 (to 16 May), one or two weeks after the willow feeding species at site Willow2 (Figure 12.6, compare 12.4 and 12.5).

The abundance of *P. vulgatissima* at site willow2 and *P. vitellinae* at P2 decreased with distance from the crop edge along all transects (except 2 at Willow2, see above) for several weeks following initial colonisation (Figure 12.4 and 12.6). The repeated measures ANOVA indicated that this trend was significant over the whole sampling period for both beetles (*P. vitellinae* site Poplar2, $F_{5,5}$=113.58, P<0.001; *P. vulgatissima* site Willow2, $F_{5,10}$=36.54, P<0.001), although the Figures show a change towards fewer beetles at the edge and more within the coppice field towards the end of the sampling period.

For *G. lineola* at site W2, no significant trend was apparent for the whole sampling period (between subjects, $F_{5,15}$=0.540, P>0.1). however, like the *Phratora* spp., Figure 12.3 and 12.4 indicates that *G. lineola* still initially colonised the edge in both years but for a shorter period.

At site W2, virtually no beetles colonised the area of year 0 (cut) coppice between the overwintering areas and the standing coppice (<1 / m^2 *P. vulgatissima* and < 1 / m^2 *Galerucella lineola*). The edge of the standing coppice in this transect were colonised by over 20 / m^2 *P. vulgatissima* and 30 / m^2 *G. lineola*.

FIGURE 12.3, 12.4, 12.5 AND 12.6 NOT AVAILABLE ELECTRONICALLY

The number of *P. vitellinae* collected from the secondary transects along the coppice edge, reduced with distance from the single tree source, in a similar manner to the main transect perpendicular from the coppice edge. The number of beetles from the three equi-distant beat sample locations, provided a mean value for each concentric ring of coppice radiating from the base of the tree. Using these data, we estimate that the single oak tree produced 17500 colonising *P. vitellinae* individuals. The number of overwintering *P. vitellinae* would have been more than this due to mortality over the period.

12.4.5 Temperature and leafing times

The hourly mean daily maximum temperatures recorded at a location near site Willow2 are shown in Figure 2 and alongside the beetle data in Figures 12.4 to 12.6. At site Willow2, initial leaf emergence on the willows occurred on 3 April 1995, and on 11 April 1996. The poplar leaf first emerged on 26 April 1995 at site Poplar1 and 2 May 1996 at site Poplar2.

Statistically we cannot demonstrate a link with the beetle colonisation data but interpretations can be made by comparing temperature data and changes in the distribution of beetles in the coppice field. Beetles initially colonising the crop edge coincided with increasing temperatures during the early part of spring at each site, and movements into the main body of the coppice from the coppice edge tended to coincide with further increases in temperature in late spring.

12.5 Discussion

12.5.1 Overwintering

While many chrysomelid species overwinter in soil there is no evidence that these arboreal feeding species do (see also Hutchinson & Kearns, 1930a, 1930b). Relatively few chrysomelids were found within the coppice plantations during overwintering searches at three of the four study sites, and the numbers captured by the emergence traps at all four did not account for the numbers and distribution of beetles subsequently recorded in the coppice canopy. On old willows and poplar trees, they do have the opportunity to overwinter on their food plants but in frequently cut SRC, appropriate crevices are limited. Most chrysomelids feeding on SRC crops are therefore obliged to find alternatives outside the coppice itself, under the bark of nearby mature trees or in crevices that effectively simulate this habitat. There are however occasions when overwintering chrysomelids have been recorded within SRC. For example when crevices in the coppice stems that are similar to the bark of mature trees have been created by for example rust cankering (Kendall *et al.* 1996) or where dead standing weeds or perennial herbage is prolific.

In most case then, chrysomelid pests of SRC have to recolonise the coppice fields from overwintering areas around the field edges. This requirement suggests that coppice fields that do not have appropriate overwintering habitats nearby will not support large and hence damaging populations of these pests. While this may be the case, it is in most situations impractical to organise this, with other economic demands on plantation location. Similarly it would be impractical, uneconomic and environmentally damaging to attempt to remove chrysomelid overwintering habitats. Instead, it is potentially extremely useful to know where populations are overwintering, as we shall see.

12.5.2 Emergence and dispersal

The trapping data accumulated in this study in 1995 indicate clearly that for all three species chrysomelids, flight is the primary mode of dispersal from overwintering habitats to the SRC crops. Similarly, the differences in beetle catches from the two window trap faces, consistent between species and sites, indicates that these traps were not simply recording random flight activity in and around the coppice plantations. Instead, they recorded a net movement of beetles from the overwintering habitats towards the coppice. This confirms the lack of overwintering in the coppice fields themselves.

While this movement was confined to a period of less than one week for *P. vitellinae* in 1995, *G. lineola* and *P. vulgatissima* continued to emerge and fly into the coppice over a four to five week period. The change to more beetles caught on the inward trap faces in week 6 (to 10 May at the Friars court site, Willow2), marked the end of the dispersal period for these two species. The short dispersal period for *P. vitellinae* observed in this study may be a function of the late leafing of poplars. In the past, many of the willow varieties cultivated in withy beds were palatable to *P. vitellinae* (Section 11.0) and Hutchinson & Kearns (1930a) found that dispersal by this beetle into these willows lasted from April to late May.

For each site and year combination, beetle emergence coincided with, or occurred soon after, initial leaf emergence in their food plants. At site Willow2, leaf emergence on 3 April 1995 coincided with a warm period (Figure 4) and was followed immediately by large numbers of *G. lineola* recorded in the window traps during week 1 (to 5 April) and *P. vulgatissima* a week later. After this, temperatures fell and catches of both beetles reduced (weeks 3 and 4) before increasing again in week 5 (to 3 May). At site P1, poplar leaf emergence occurred on 25 April, 3 weeks later than the willow at site W2 and the emergence of *P. vitellinae* reflected this. In 1996, the temperature rose slowly during the first half of April, delaying leaf emergence (11 April at W2, 8 days later than in 1995), and beetle emergence (3 weeks later than in 1996). Leaf emergence in most trees is triggered by a combination of increasing daytime temperatures and day length. These factors are also known to break diapause in some chrysomelids (Lefevere & Kort 1989; Fujiyama *et al.*, 1996).

12.5.3 Colonising the crop edge

In both years, the majority of *P. vulgatissima* and *G. lineola* initially colonised the crop canopy within a few metres of the coppice edge at site W2. At site P2 in 1996, a similar pattern of colonisation was even more apparent for *P. vitellinae*. This extreme edge distribution suggests a reluctance by (most) overwintered beetles to fly any further than necessary and a tendency to aggregate where beetles already occur (Bach & Carr, 1990). The exception to this pattern of edge colonisation, was *P. vulgatissima* along transect 2 at site W2, where the resistance of the Q83 variety to this beetle prevented it from colonising it at all. This resistance is related to the presence of certain phenolglycoside compounds in the leaves of *S. triandra*, (Tahvainen *et al.*, 1985).

By 9 May 1996 (week 6), more than 80% of all *P. vulgatissima* in the field at site W2 were within 10 m of the standing coppice edge. This proportion was even greater for *P. vitellinae* at site P2 by 23 May (week 8). For *P. vulgatissima* and *P. vitellinae*, these edge distributions remained for at least 3 weeks in 1996. At the poplar site, if dispersal by *P. vitellinae* was confined to a short period (as in 1995), the individuals recorded in the edge zone in week 8 at site P2 would have been the same as those recorded in week 5 and 6. The consistently low numbers further into the crop at this site indicate this was the case. For *P. vulgatissima*, numbers within the crop interior increased steadily over the period suggesting a turnover of beetles as dispersal progressed or an avoidance of the edge by later emerging beetles. During these periods, beetles of all three species were observed to feed on the young coppice leaf, rapidly defoliating the coppice canopy within the edge zone, and mating.

12.5.4 Dispersing to the crop interior

In 1996 *G.lineola* at site W2 had moved into the crop interior within a week or two of colonising the crop edge, and by week 6 (to 9 May), had spread evenly through the coppice. Both *Phratora* spp. delayed this secondary dispersal for several weeks following colonisation of the edge. For *P. vitellinae* at P2, virtually all beetles settled within the first 10 m of crop in both edge lines in week 6, left this area during week 9 (to 30 May) and spread through the main body of the field (Figure 3c). For *P. vulgatissima* at W2, a similar secondary dispersal was observed, also at the end of May. This secondary movement occurred earlier in 1995 for *P. vulgatissima*, and was also apparent for *G. lineola*. In both years, dispersal from the edge zone coincided with warm weather at the end of May in 1996 and at the beginning of May in 1995.

A consequence of this staged movement is that most females would not have laid their eggs in the crop edge zone, which by mid May in 1996 had become severely defoliated. In an ongoing study at site W2, Griffiths (1997) found that egg laying in both species commenced as adult numbers in the edges began to decline. This clearly is of benefit to the relatively immobile larvae when the availability of food may affect survival. Most adult beetles then left the study area (or died), by early June for *G. lineola* and late June for *P. vulgatissima*, preventing competition for food between larval and adult stages.

12.5.5 An opportunity to control chrysomelids

Phratora vulgatissima, P. vitellinae and *G. lineola* have been the principal defoliating invertebrate pests of SRC crops in Britain and Ireland each year since 1993 (Sage & Tucker, 1997a, 1997b, Section 8.0). *P. vulgatissima* accumulated rapidly at site Willow2 during the course of this and in 1997 it became the third UK site in which areas of willow coppice suffered die-back as a direct consequence of repeated defoliation episodes over several years (Kendall *et al.*, 1996).

The potential therefore exists for biomass plantations to suffer economic losses following infestations. A principal aim of the study described in this report is to develop an integrated pest management strategy for these crops. While an IPM strategy does not preclude insecticides, the use of overall insecticide applications in standing coppice has severe practical and economic limitations and such applications may also affect many non-target invertebrate species and other wildlife groups (Sage & Robertson, 1996, Sage & Tucker, 1997a, Sections 7.0 and 14.0 - 18.0).

However the ability to predict patterns of dispersal by these three chrysomelid species into and through coppices described here, and in particular the temporary accumulations of beetles along edges, and the avoidance of recently cut stools, may provide an opportunity to control damaging populations using relatively small quantities of an insecticide applied from the plantation headland. This then could provide an emergency measure for when other management practices for these pests fail. The method may provide a practical emergency control measure, which could be used as part of an Integrated Pest Management strategy for biomass crops, when other pest management strategies fail. This is discussed in greater detail in Section 13.0.

12.6 References

Bach, C.E. & Carr, D.S. (1990). Aggregation behaviour of a willow flea beetle, Altica subplicata (Coleoptera: Chrysomelidae). *Great Lakes Entomologist*, **23**, 65-76.

Bates, J. (1995) *Alternatives in agriculture - growing crops for industrial, energy and other non-food purposes*. Parliamentary Office of Science and Technology, London.

Forsberg, J., Johansson, H., Ramstedt, M. & Ahman, I. (1991) *Skadegorare i energiskog av Salix*. Sveriges Lantbruksuniversitet, Speciella skrifter 47, Uppsala.

Fujiyama, S., Yammanoi, A. & Hasebe, T. (1996) The effects of temperature and photoperiod on adult diapause of two geogeraphic populations *in Chrysolina aurichalcea* (Mannerheim) (Coleoptera: Chrysomelidae). *Environmental Control in Biology*, **34**, 215-222.

Griffiths, J. (1997) *Population structure and damage potential of two Chrysomelid pests of willow grown under short rotation arable energy coppice production*. Unpublished D. Phil. report, pp 76. Imperial College, London.

Hutchinson H.P. & Kearns H.G.H. 1930a. The control of *Phyllodecta vitellinae.* L. (Chrysomelidae) a major pest of willows. Annual Report Agricultural and Horticultural Research Station, Long Ashton 112-126.

Hutchinson H.P., & Kearns H.G.H. 1930b. The control of *Galerucella lineola* - a major pest of willows. Annual Report Agricultural and Horticultural Research Station, Long Ashton 108-111.

Kendall, D.A., Wiltshire, C.W. & Butcher, M. (1996) *Phenology and population dynamics of willow beetles (Coleoptera: Chrysomelidae) in short rotation coppice willows at Long Ashton*. ETSU B/M4/00487/14/REP, Harwell Laboratories, Harwell.

Kennedy, C.E.J. & Southwood, T.R.E. (1984) The number of species of insects associated with British trees: a re-analysis. *Journal of Animal Ecology,* **53,** 455-478.

Kreslavsky, A.G., Solomatin, V.M., Mikheev, A.V. & Gritzenko, V.V. (1996) Migrations, dispersions and population structure in three species of leaf beetle (Coleoptera, Chrysomelidae). *Zoologicheskii Zhurnal*, **75**, 1021-1033.

Ministry of Agriculture, Fisheries and Food (1994) *Alternative Crops: New Markets*. MAFF.

Owen, J.A. (1993) Use of a flight interception trap in studying the beetle fauna of a Surrey wood over a three year period. *The Entomologist*, **112**, 141-160.

Sage, R.B. (1994) *A review of the status and control strategies of known and perceived insect pests on* Salix *and* Populus *in North West Europe*. ETSU B/M3/00388/10/REP. Harwell Laboratories, Oxford.

Sage, R.B. & Tucker, K. (1995) Integrated flora management and pest control in short rotation coppice. *In: Wood fuel - The green debate,* pp. 21-29. Harwell Laboratories, Oxford.

Sage, R.B. & Robertson P.A. (1996) Factors affecting songbird communities using new short rotation coppice habitats in spring. *Bird Study,* **43**, 201-213.

Sage, R.B. & Tucker, K. (1997a) Invertebrates in the canopy of willow and poplar short rotation coppices. *Aspects of Applied Biology* **49**, 105-111.

Sage, R.B. & Tucker, K. (1997b) The distribution of *Phratora vulgatissima* (Coleoptera: Chrysomelidae) on cultivated willows in Britain and Ireland. *European Journal of Forest Pathology* (In press).

Southwood, T.R.E. (1978) *Ecological Methods, 2nd edition.* Chapman and Hall, London.

Tahvainen. J.R., Julkunen-Tiitto & Lavola, A. (1985) Phenolic glycosides govern the food selection pattern of willow-feeding leaf beetles. *Oecologia,* **67**, 52-56.

Wilkinson, L. (1990) *SYSTAT, The System for Statistics.* Systat Inc. Evanstan, Illinois, USA.

13.0 INTEGRATED PEST MANAGEMENT - INSECTS

13.1 Summary

This section draws primarily on the findings of the previous six sections (7.0 – 12.0 inclusive), which investigate the abundance and diversity of insects in SRC, the main pest species and aspects of their ecology.

This information is used here to develop an integrated pest management (IPM) strategy, primarily for leaf eating beetles (chrysomelids), the main group of pest species of SRC in Britain.

Chrysomelid beetles were resposible for the majority of defoliation in UK SRC plantationsf and have caused economic damage at several SRC sites in the UK.

The abundance and diversity of insects in SRC crops, particularly willow, and the existence of potentially beneficial species, means that the environmental cost of overall insecticide applications in these crops would be very high.

SRC sites that are planted near to certain free-living willow or poplar trees, particularly willows along waterways, have a high risk of repeated colonisation by chrysomelids. These sites can either be avoided, or plantations designed to minimise the impact of chrysomelid attack.

High risk sites can be planted with species or varieties that are not susceptible to a locally abundant beetle species. For example poplars could be used in areas where certain wild willow species are abundant. Alternatively, the strategic use of highly suscetible willows could be used as sacrificial plantings (see below).

The activities of naturally occurring predators and parasites of chrysomelids and other pests of SRC can be increased

through silvicultural practices. In particular the provision of tussocky grasses as overwintering habitat for ground beetles and spiders, flowering plants as nectar sources for parasitoid wasps and flies and nesting habitat for birds.

Where other methods fail, and large chrysomelid populations develop over several years, targeted insecticide sprays can be employed in the crop edges during the spring, when chrysomelids are re-colonising plantations from their over-wintering habitats.

By the strategic use of susceptible varieties, and by leaving islands of uncut coppice in cut plantations to trap and concentrate colonising chrysomelids, populations can be manipulated into certain parts of fields if necessary.

13.2 Introduction

Controlling insects using insecticides is the most ecologically damaging practice undertaken on many modern farms and in Britain at least their use is on the increase. In a normal farming system, only the target insect or pest is considered when making a decision to use an insecticide. The abundance of the pest is assessed and when a certain threshold is reached (balancing the cost of the spray itself with the loss to production), this is the only information that is needed when making a decision to spray.

In an Integrated Crop Management (ICM, see Section 1.0) approach, the other impacts of the insecticide are taken into account, in particular the effect on non-target insects, which may be playing a beneficial role in limiting the abundance of the pest in the long term. These secondary costs can lead to the development of alternative management strategies.

The integrated approach to insect pest management (IPM) described here, would be a central component of an ICM strategy in SRC crops. For insects, IPM aims to manage insect pests in such a way that numbers remain below economic threshold levels, rather than attempting periodic eradication.

SRC is particularly suited to IPM because of its high economic threshold to pest damage. This allows low levels of the pests themselves to be maintained which in turn is usually required to support a population of the naturally occurring pest enemies. Another factor is that as a perennial crop on, typically, a three year rotation, it is a relatively stable habitat (compared to an annual crop). This allows time for the natural enemies of pest species to colonise the crop and to become effective.

In sections 7.0 to 12.0 of this report, we describe the main insect pests of SRC in the context of the whole insect community, and then investigate aspects of the pest and crop ecology which we anticipate might enable us to develop an integrated approach to the management of insect pests in SRC crops.

13.3 The main pests and damage

The main current pests of SRC are identified in Section 8.0 as a group of leaf-eating beetles the chrysomelids. They have been widespread and abundant in SRC plantations throughout the period of this study, and were responsible for most of the leaf defoliation observed at a large sample of sites. At some sites, defoliation caused a reduction in crop growth and at several it caused substantial areas of coppice to die-back following repeated attacks over several years.

This work indicates that the potential for large scale defoliation and production losses of SRC crops by chrysomelid beetles and possibly other species is considerable. However, the use of overall insecticide sprays to control pest outbreaks in perennial biomass crops is difficult, is unlikely to be cost effective in most situations and is environmentally undesirable.

Based on the findings in Section 8.0, other likely pests in UK SRC plantations include sawflies, which defoliate the leaf as larvae and were widsepread during the extensive surveys but were abundant at only one site, midge species which affect leaf growth, and stem aphids which form colonies on coppice stems. The effect of damage caused by stem aphids on yields is being investigated in another ETSU/GCT project (B/W2/00577/00/00).

13.3.1 Economic thresholds and cost benefit

We have not yet developed economic thresholds for defoliation by chrysomelids and other insect defoliators, although at the time of writing we have a further field trial underway that is designed to quantify the impact of leaf defoliation on the growth of willow (ETSU/B/M4/00532/03/00). We have however undertaken some work on this (Section 8.0) and there are laboratory based studies which document decreasing yields with increasing defoliation in willows and field studies which indicate that weed problems are exascerbated by defoliation. These are discussed in Section 8.5.3. In this section we use these data in the context of our experience with this pest to suggest the levels of chrysomelid abundance at which willow SRC plantations may benefit from a IPM strategy.

Properly defined, economic thresholds balance the cost of controlling a pest with the value of the consequent increase in yield. As indicated, in an ICM approach the cost in terms of environmental impacts would be particulalry high in SRC. It would also be difficult and expensive to use overall insecticide applications in SRC – spraying recently cut coppice may not have a significant controlling effect on chrysomelids as they are reluctant to colonise cut stools

(Section 12.0). Without further information, we would not recommend the use of overall insecticide sprays to control chrysomelids under any circumstances.

We expect, and hope to show in another ongoing study (ETSU B/W2/00571/00/00), that the use of edge sprays (Section 12.0 and 13.7 below) has a relatively small effect on the insect community in an SRC field. The project also aims to demonstrate the method itself. If successful in its aims, the use of an edge spray to reduce a chrysomelid population that exceeds the abundance levels suggested in section 8.5.3 in willow SRC, and which had caused obvious and severe defoliation for at least one season, may be justified. However we refer the reader to the forthcoming report B/W2/00571/00/REP.

13.4 Natural controls

Section 9.0 details how we have accumulated considerable evidence of parasitism and predation of the main pests during the course of this study. An IPM strategy for SRC would aim first to enhance the activities of these naturally occurring insect pest predators and parasites. This is done primarily by encouraging the habitats that support them, or more likely, by not removing these habitats when they naturally develop in and around the coppice. The natural predators and parasites of chrysomelids and/or other potential pests including sawflies and stem aphids include, birds, tachanid flies, predatory beetles and spiders, parasitic flies and wasps and other larval parasites.

We do not know the impact of these species on pest populations as these density-dependant relationships are extremely difficult to study. It is however reasonable to assume that some of these insects are capable of limiting the abundance of the pest species in certain circumstances. In particular, when the abundance of the pest species is low, a low predation or parasitism rate by a beneficial species may be enough to prevent a steep increase in numbers, even when other conditions might be conducive to this. This density dependant effect is difficult to study precisely because numbers of both the pest and the control species are small.

In Section 9.0 we describe how areas of tussocky grasses within the coppice or in the headlands of SRC fields, provide winter refugia for predatory beetles and spiders and certain perennial shrubs and herbs attract parasitoid wasps and flies. Flowering plants such as Umbellifers *Umbelliferae* (like cow parsley *Anthriscus sylvestris*) are known to enhance the activities of adult parasitoid wasps and flies. These grasses and other flowering plants also contribute to the diversity and habitat value of plantations to other wildlife. Crucially, the provision of these sorts of habitats need not cost the grower and may actually reduce costs by avoiding unnecessary management of ground flora in SRC and possibly by preventing a pest problem.

Even if they were economic, the regular use of overall insecticide applications is more or less excluded from such an IPM approach because they usually damage or destroy the naturally occurring pest predators and parasites. These processes have been well documented in other crop types for example cereals.

13.5 Plantation design

An IPM approach for chrysomelids in SRC would however start at the planning stage. Section 10.0 indicates that the location of a plantation can be used as a tool to avoid chrysomelid infestations. In particular, fields along willow-lined waterways should be avoided. However locating an SRC plantation according to the probability of attack from this pest may not be practical – there may be many more important reasons for using particular fields and the likelihood of chrysomelid problems may not be the most important. Nevertheless, the knowledge that infestations are likely is still useful because the plantation design can incorporate secondary defences. These can easily be accommodated with no or very little compromise in terms of crop production. In particular the careful layout of susceptible and resistant varieties in those parts of the fields that are prone to colonisation in the spring (Section 12.0).

For chrysomelids, cultural control methods designed to reduce over-wintering refugia in the vicinity of SRC plantations (Section 12.0) may reduce the abundance of this pest. It may also be possible to avoid obvious overwintering sites at the planning stage. Adult chrysomelids over-winter under the bark of mature trees within a few hundred metres of the coppice plantation, or in other niches that simulated this habitat, such as fence posts, log piles, stonework, standing dead vegetation stems etc. However in practice, the extent to which such methods would be need to be applied (considering the distances beetles appear to travel to hibernate, and the range of habitats in which they will overwinter) would make them impractical and undesirable from an ecological or landscape perspective. It is however useful to know where chrysomelids are likely to be overwintering as this enables simple montoring of populations, which and facilitates their control, if necessary, as described in Section 13.7 below.

13.6 Varietal selection

The use of resistant cultivars depends on the future development of willow and poplar varieties for SRC (Section 11.0). There has been a substantial amount of work undertaken on the selection of willow and poplar species and varieties, by chrysomelids and other insects, and the reasons that underpin it. This is discussed in detail in Section 11.5. Unfortunately, there are currently few that appear resistant to all the three main chrysomelid species. The two *Phratora* species require very different chemicals from their food plants which they use as part of their defensive strategies, and between them they will infest most willow and poplar varieties. Notable exceptions are varieties that include *S. triandra* in their parantage, such as Q83, but the third chrysomelid (*Galerucella lineola*) will defoliate these. There is however scope to develop high yielding resistant varieties in the future, which could be used in circumstances where plantations were particularly vulnerable to attack. Sufficient information is available in this report and elsewhere for chrysomelid resistance in new varieties to be explored by the SRC breeding programmes in Sweden and the UK.

However, even without these developments, a survey of free-living willows and poplars and chrysomelids in the vicinity of a proposed plantation, to identify if one or other species is much more common in the area, can provide guidance. If for example, *Phratora vitellinae* on poplar is abundant in the vicinity of a proposed plantation, the grower would be advised to plant willows, for example *S. viminalis*, as this beetle does not feed on most willows.

The results of a study at one site indicated that mixing susceptible willow varieties with sub-optimal ones may not reduce the colonisation by beetles of the susceptible varieties (Section 11.5.3). In other crop ecosystems it has been shown that monocultures tend to support larger populations of insect pests and diseases and suffer greater damage than mixed planting. It has already been demonstrated that the rust pathogen spreads less quickly through a susceptible hybrid in a mixed willow SRC plantation than the same hybrid in a monovarietal block (Royle et al 1993). The results of this survey do not indicate a similar effect for chrysomelids.

However the study was not conclusive and it may be the case that chrysomelids will be limited in their movements through larger mixed willow or poplar plantations. The study undertaken here was in a plot of 4 ha and limitations to the movements of these beetles may have gone unobserved because of the small plot size.

The strategic use of highly susceptible varieties, to attract and concentrate colonising chrysomelids and hence to manipulate populations into certain parts of fields has greater potential within an IPM strategy for these pests and is discussed in greater detail below.

13.7 The use of local insecticides

Section12.0 describes the process by which all three main chrysomelid species emerge from over-wintering habitats in the spring and then colonise SRC plantations. As suggested in the Section, this process may facilitate a control method involving a local application of an insecticide which could be used when chrysomelids populations threaten crop productivity.

For the last three years, we have found that at SRC sites in Britain that contain chrysomelids, most beetles do not occupy the crop during the winter. Instead, they disperse to nearby habitats that contain crevices and niches into which the adult beetles secrete themselves. Mature trees, shrubs, hedgerows, dead standing herbage, fence posts, buildings, wood piles etc., have all been found to contain overwintering chrysomelids.

In the spring the beetles emerge from overwintering habitats around the plantation and fly into the first few metres of the nearest standing coppice. The emergence of the adults coincides with initial leaf emergence of their food plants and while it can vary in length from several days to several weeks, it is easy to predict. Once in the crop edge, they start feeding on the newly emerged leaves and remain for several days or even weeks. As more beetles emerge, the density of beetles along the edge increases. Up to 800 beetles per coppice stool have been recorded at this time. At some point the beetles disperse into the rest of the crop and begin ovipositing on relatively undamaged leaves. This secondary dispersal enables the beetles to feed and then breed without spoiling the food availability for the young larvae hatching from the eggs. The trigger for this dispersal is not known but in spring 1995 and 1996 it coincided with periods of warm weather.

This concentrated edge distribution prior to dispersal in the spring facilitates the localised application of an insecticide. The opportunity occurs before the beetles lay any eggs. Edges are the only part of a plantation to which a spray could readily be applied and an application would only affect a small proportion of the cropped area. This would be much cheaper than overall spraying and would greatly reduce negative ecological impacts. There are chemicals available which are known to be effective against chrysomelids in other crops and application equipment which could be used in SRC is regularly used for spraying bush and fruit tree crops.

At the time of writing The GCT was in the process of conducting an experiment to investigate the practicalities and effectiveness of a chrysomelid control method which takes advantage of the concentrated edge distribution of chrysomelids described above (ETSU contract B/W2/00400/00/00). We used a fan-assisted directed canon sprayer and a pyretheroid insecticide in infested willow and poplar plantations. We aim to quantify the effect of the spray on the pest species and the non-target insects in the edge and to intepret this on a whole field scale.

The aim of the method would be to kill the majority of beetles before oviposition commences. Complete control is not necessary in SRC as willows and poplars have a high economic threshold to pest damage and chrysomelids will go through only one or at most two generations in a season. We anticipate the method will cause a minimum impact on the non-target insect population in the coppice field which, as already indicated, can be abundant and diverse in SRC plantations. This is because only a small fraction of large plantations would be sprayed and it would be done at a time (mid spring) when many insects would not yet have emerged.

It would provide a ‘fire-brigade’ measure as part of an Integrated Pest Management strategy for these crops. In the minds of potential growers and investors, risk from pests and diseases can often be a major factor in the decision to plant or not. This is especially true of relatively low value crops or where the grower has little previous experience. Both these factors often apply to SRC. The threat of chrysomelid infestations may therefore prevent growers from planting SRC in the first place.

The experiment outlined would address this threat. It aims to demonstrate the practicality and effectiveness of an emergency control measure for chrysomelid infestations when other pest management strategies fail. It would enable growers to be reassured about chrysomelid damage before they plant.

If the spraying method proves succesful, with acceptable impacts to non-target invertebrates, the method could be incorporated into the design and planning of plantations that are considered to be at risk from chrysomelids. For example, the strategic use of susceptible varieties to create sacrificial areas as traps for colonising beetles that could then be sprayed. Such areas would need to be placed in the vicinity of over-wintering sites. Another interesting finding of the study in Section 12.0 was that chrysomelids will fly over and not colonise just cut areas of SRC, especially if standing coppice exists nearby. This means that the movements and colonisation of chrysomelid populations could be manipulated by cutting certain areas, and concentrating them in uncut strips which can then be sprayed.

13.8 Disease

Currently, the rust *Melampsora* spp. is probably the biggest agronomic threat to SRC crops in Britain. Recent research indicates that the number of different pathotypes, and hence the diversity of cultivars attacked by rust has increased in recent years (Pei et al. 1997) and cultivars previously considered to some extent resistant have now become highly susceptible.

While there are many fungicides that are effective against these rusts, the regular use of sprays is considered impractical and uneconomic in SRC crops. To control rust effectively, several applications would be required each year and the difficulties of accessing uncut SRC precludes the use of commonly available farm equipment. Single applications following cut-back and up to July the same year with a cereal sprayer has been proposed and may remove inoculant that is immediately present. Re-infection from outside the crop would however usually be rapid.

Although we have not studied rust in this study, the management of rust would be an integral part of any ICM strategy for SRC. Currently, the main disease management strategy for rust in willow SRC is the use of mixtures, either intimate or in single-cultivar strips (McCracken & Dawson, 1997). Some research also indicates that another fungus, *Sphaerellopsis filum*, which parasitizes willow and poplar rusts, could be used as a biological control agent. The use of a cheap, partially effective one-off fungicide treatment could form part of a management strategy for rust.

It may be possible to incorporate plantation design measures that reduce the effect of insect pests and rust simultaneously.

13.9 References

Pei M.H., Parker, S.R., Hunter T. & Royle D.J. (1997) Variations in the populations of Melampsora willow rust and the implications for design of short rotation coppice plantations. Aspects of Applied Biology 49: 91-96.

McCracken A.R. & Dawson W.M. (1997) Using mixtures of willow varieties as a means of controlling rust disease. Aspects of Applied Biology 49: 97-104.

14.0 BIRDS IN WINTER

14.1 Summary

Monthly surveys of birds were undertaken at seven short-rotation coppice sites across the south of England in the winter of 1996-7. On each occasion all birds seen or heard within the coppice itself were recorded.

In total, twenty-nine species of bird were found at the seven SRC sites over the period. Although flocks of larks and finches have been recorded in previous years, during the winter 1996-7, very few substantial groups of birds were found.

Blackbird (*Turdus merula*), robin (*Erithacus rubecula*), wren (*Troglodytes troglodytes*), dunnock (*Prunella modularis*), blue tit (*Parus caeruleus*) and chaffinch (*Fringilla coelebs*) all occurred at seven sites with song thrush (*Turdus philomelus*) and long-tailed tit (*Aegithalos caudatus*) present at six.

Long-tailed tit was the most abundant species and several species of conservation concern were also recorded. Bird density decreased significantly with increasing crop area but all sites held larger numbers of birds than typical for other agricultural crops.

Possible reasons for the use by songbirds of these SRC plots are discussed.

14.2 Introduction

SRC involves less intensive farming methods than traditional agriculture and consequently it tends to add to the wildlife value of a farm and increase local biodiversity (Göransson, 1990; Sage & Robertson, 1996; Sage *et al.*, 1994; Sage & Tucker, 1997). Research has also shown that areas of SRC can be integrated into the game management of an area, with particular respect to pheasants (*Phasianus colchicus*) (Sage & Robertson, 1994, and see Section 17.0). During fieldwork visits to SRC in the winters 1994-5 and 1995-6, anecdotal sitings of birds were noted and it was apparent that the crop supported substantial populations of song birds throughout the winter. So that the species using SRC could be documented and investigated, a survey of SRC sites across the south of England was initiated. It was also intended that this survey would contribute to the intensive study of snipe (*Gallinago*

gallinago) by providing information on the distribution of snipe between SRC sites (see Section 15.0)

The aims of the study were therefore;

1. To conduct regular ornithological surveys at SRC sites across the south of England during the winter to identify which birds were using coppice.

2. To identify site characteristics which most suited wintering birds.

The work compliments the more detailed and extensive surveys of breeding birds in SRC crops described in Sage *et al.* 1994 and Sage and robertson 1996.

14.3 Methods

Winter bird surveys were conducted at seven established willow and poplar SRC sites in the south of England in the winter of 1996-7. The seven plantations were; Home Farm, Saint Michael Penkivel, Cornwall (Figure. 14.1, site1), Holdridge Farm, North Molton, Devon (site 2), Knowle Farm, Hunstrete, Somerset (3), Roves Farm, Sevenhampton, Wiltshire (4), Friars Court Farm, Faringdon, Oxfordshire (5), Forestry Authority, Wishanger, Hampshire (6) and Ashmans Farm, Kelvedon, Essex (7) and so roughly at an equal latitude on a line from west to east. Observations were made on a monthly basis from November to March to ascertain the distribution of wild birds between the sites over the course of the winter. Each site was surveyed by walking the rides and headlands as well as through the crop at regular intervals whilst listening and watching for birds. The crop characteristics at each site are given in Table 14.1.

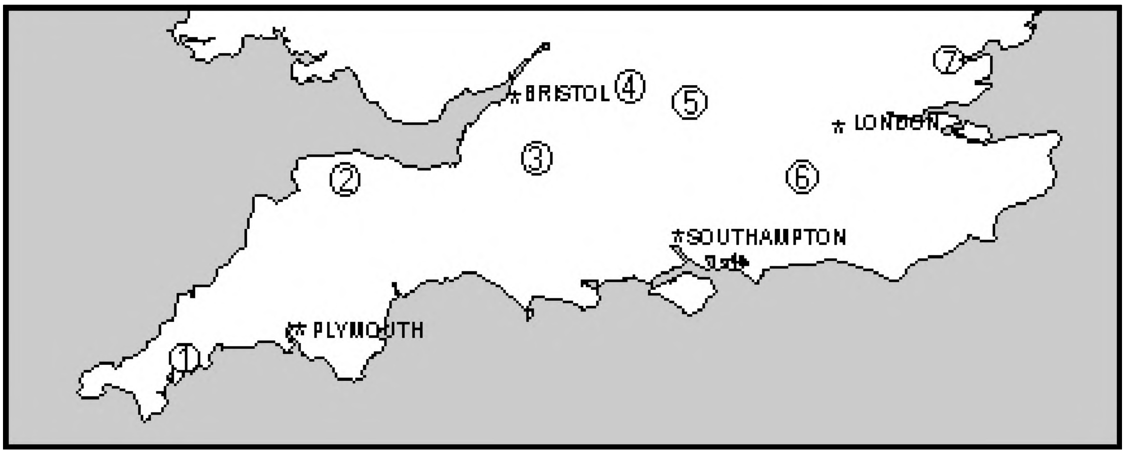

Figure 14.1. Map of the south of England showing the locations of the winter bird survey SRC sites (1-7)

Table 14.1. The crop details of the seven survey sites.

		MAIN SPECIES	AREA PLANTED	AGE CLASS
1	Home Farm, Cornwall	Poplar	10 ha	1-3
2	Holdridge Farm, Devon	Willow	40 ha	0-2
3	Knowle Farm, Somerset	Poplar	10 ha	0-3
4	Roves Farm, Wiltshire	Willow	24 ha	0-2
5	Friars Court, Oxfordshire	Willow	10 ha	1-4
6	Forestry Authority, Hampshire	Will+Pop	1.4 ha	0-3
7	Ashmans Farm, Essex	Will+Pop	10 ha	0-3

14.4 Results

Twenty nine species of bird were recorded wintering in the SRC study plots between November and March although not all occurred at one site. The species records are listed in Appendix 14A. Pheasant (*Phasianus colchicus*) occurred in all plots and red-legged partridge (*Alectoris rufa*) in two but as there were release pens situated in the near vicinity of all sites their numbers are not representative of wild populations. These two species are consequently ignored in the following analyses. Blackbird (*Turdus merula*), robin (*Erithacus rubecula*), wren (*Troglodytes troglodytes*), dunnock (*Prunella modularis*), blue tit (*Parus caeruleus*) and chaffinch (*Fringilla coelebs*) occurred at all seven sites with song thrush (*Turdus philomelus*) and long-tailed tit (*Aegithalos caudatus*) present at six.

Other species were more sporadic in their occurrence. Long-tailed tit was the most abundant species with 119 bird-days[1] recorded. Table 14.2 shows the number of bird-days for each species and the number of sites at which the species was recorded. The number of bird species recorded at a site ranged from nine to nineteen and is illustrated in Figure 14.2 (mean 14.6 ± 3.5).

The mean bird density at each SRC site is presented in Figure 14.3. The mean bird density for all visits to all sites was 3.85 ± 2.42 birds ha^{-1}. Log mean density was found to be inversely proportional to crop area (Figure. 14.4) (R^2=0.7282, f=0.0145). Mean density over all seven sites decreased slightly from 4.0 birds ha^{-1} in December to 3.7 birds ha^{-1} in March but this trend was not significant.

Snipe were the seventh most abundant bird, and were found at two sites during the survey period. Two birds were seen in the Cornish poplar SRC plantation in December and again in February. The January count was conducted in freezing conditions which probably led to this site being

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[1] Each bird seen on a visit constitutes one bird day for that species, so the same flock of six birds recorded on four different visits would result in a count of 24 bird-days.

unsuitable for snipe at that time due to the ground being frozen. At the Devon site, up to 29 snipe were present at any one time during the winter (see section 15.0).

Table 14.2. The frequency of occurrence of the bird species recorded wintering at seven SRC plots in the south of England. Species of conservation concern are indicated with ^{R} for red list species and ^{A} for amber list species (see discussion).

SPECIES		N° OF SITES	N° OF BIRD-DAYS
(Pheasant	*Phasianus colchicus*	7	229)
Long-tailed tit	*Aegithalos caudatus*	6	119
Blackbird^A	*Turdus merula*	7	97
Reed bunting^R	*Emberiza schoeniclus*	3	93
Blue tit	*Parus caeruleus*	7	89
Robin	*Erithacus rubecula*	7	82
Dunnock^A	*Prunella modularis*	7	76
Snipe^A	*Gallinago gallinago*	2	75
Chaffinch	*Fringilla coelebs*	7	70
Song thrush^R	*Turdus philomelos*	6	59
Redwing^A	*Turdus iliacus*	6	54
Wren	*Troglodytes troglodytes*	7	52
Yellowhammer	*Emberiza citrinella*	2	32
Skylark^R	*Alauda arvensis*	3	21
Woodcock^A	*Scolopax rusticola*	5	19
Fieldfare^A	*Turdus pilaris*	2	16
Goldfinch^A	*Carduelis carduelis*	2	14
Kestrel^A	*Falco tinnunculus*	4	12
Meadow pipit	*Anthus pratensis*	2	12
(Red-legged partridge	*Alectoris rufa*	2	11)
Linnet^R	*Acanthis cannabina*	2	9
Goldcrest	*Regulus regulus*	2	8
Great tit	*Parus major*	5	8
Moorhen	*Gallinula chloropus*	2	8
Magpie	*Pica pica*	1	5
Wood pigeon	*Columba palumbus*	1	5
Chiffchaff	*Phylloscopus colybita*	2	3
Marsh tit^A	*Parus palustris*	1	2
Greenfinch	*Carduelis chloris*	1	1

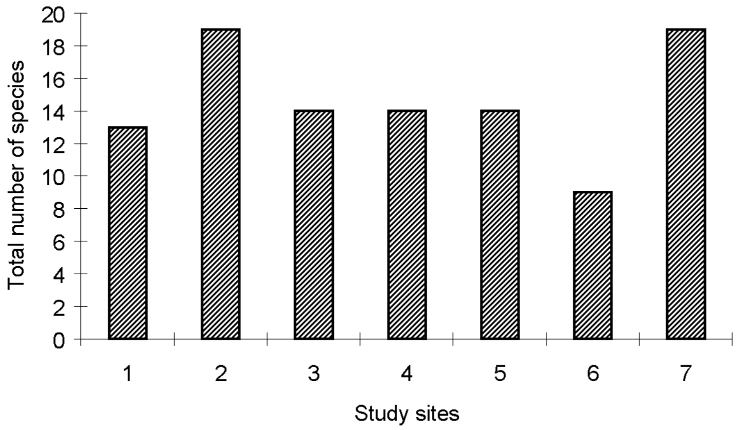

Figure 14.2. Total number of bird species recorded wintering at each of the seven SRC study sites

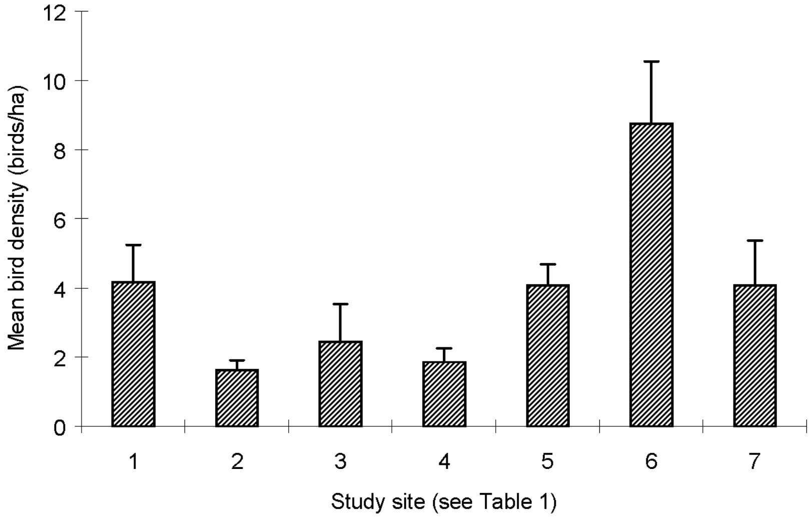

Figure 14.3. Mean density of birds in winter 1997 on seven SRC plots

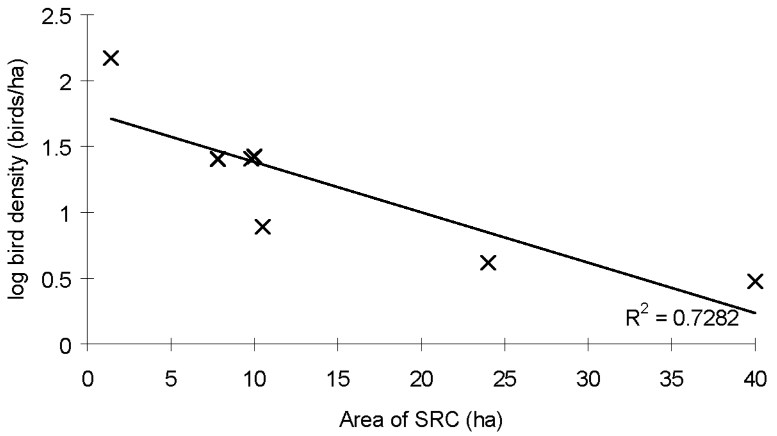

Figure 14.4. Plot of log bird density with fitted regression line (f=0.0145)

14.5 Discussion

The species of bird present at the seven study sites were typical of both hedgerows and open field situations. In this respect the numbers of species present are higher than would be expected for other crops which only hold open field species. Tucker (1992) found the mean bird density in winter on six traditional farm habitats (cereal stubble, bare till, winter cereal, oil-seed rape, permanent pasture and temporary ley) to be 0.55 ± 0.570 birds ha^{-1}. This is considerably less than the mean density for the coppice sites in this study (3.85 ± 2.42 birds ha^{-1}). The perennial nature of SRC means that there is a great deal of variation in the crop at any one time. The crop may be one, two or three years old or newly cut and all or most of these phases of the crop will be present in one plantation. Probably of as much or even more importance than the crop itself is the vegetation growing beneath and around the stools. This variability is not found in traditional crops which tend to be densely planted genetically similar annuals which vary little and from which all natural ground vegetation is excluded.

The vertical dimension of SRC was an important component of the habitat; without it such arboreal species as the tits (*Parus* spp. and *Aegithalos caudatus*) and warblers (*Regulus regulus* and *Phylloscopus collybita*) and skulking species like wren, dunnock and robin would not have occurred away from the hedge. Sage and Robertson (1996) found that structural complexity was strongly correlated with number of bird species and number of individual birds recorded in SRC during the breeding season.

At the same time as providing vertical cover, the openness of the leafless crop coupled with the frequent provision of rides and wide headlands made it suitable for species such as yellowhammer (*Emberiza citrinella*) and finches (*Fringillidae*) which would normally be associated with hedge and field situations. Cut areas provided habitat for skylark (*Alauda arvensis*) and meadow pipit (*Anthus pratensis*). Invertebrates in the leaf litter were probably attracting the small flocks of mixed thrushes (*Turdus* spp.) including the declining song thrush. The good numbers of song birds in itself was attractive to predators such as kestrel (*Falco tinninculus*) although this species was perhaps more likely to be taking voles (*Microtus* spp.). Whilst not recorded in this survey, sparrowhawk (*Accipiter nisus*) and tawny owl (*Strix aluco*) (which was frequently heard at night in the vicinity of the Devon site) might also be expected to be attracted by the feeding opportunities offered by SRC. This represents a large range of species for an agricultural crop and is a factor of the crop's structural diversity.

Several of the species recorded were of conservation concern as identified in a recent publication supported by a number of conservation bodies including the Royal Society for the Protection of Birds, British Trust for Ornithology, Birdlife International and the Game Conservancy Trust (RSPB, 1996). These species are indicated in Table 14.2 as belonging to the amber (medium conservation concern) or red list (high conservation concern). Red list species are defined as; "…those whose population or range is rapidly declining, recently or historically, and those of global conservation concern.". There are 36 red list species in the UK. Amber list species, of which there are 110, are defined as; "…those whose population is in moderate decline, rare breeders, internationally important and localised species and those of unfavourable conservation status in Europe." (RSPB, 1996).

Thus some of the species recorded here may not be particularly rare but their future is uncertain as they are in decline or of localised distribution. For example, species such as skylark, linnet and song thrush (all of high conservation concern) may still be seen frequently in the countryside but all have suffered declines of more than 50% on farmland in the last 25 years. That SRC in this study contained four red list and nine amber list species is important. Red list species are described as "…deserving urgent, effective conservation action" (RSPB, 1996), such is the importance placed on them. SRC may currently support populations locally but if this crop were to become more widely planted a more significant national effect might be produced. This is particularly true for the reed bunting which both winters and breeds in high numbers in many SRC plantations (K. Tucker, pers obs.; Sage & Robertson, 1996).

Bird density was observed to decrease with increasing plantation size. This is to be expected as the smaller a plantation, the more it is influenced by edge effects (the edge to area ratio increases) and birds and other species are frequently more numerous at the habitat interface between two habitats (Weins, 1989). This suggests that the ornithological interest of SRC will decrease in relation to increasing size. However, within one large plantation there will always be interfaces between cut and uncut coppice, between coppice coups of different ages and between blocks of coppice and access rides. Habitat interest will always be maintained and the crop's structural diversity is likely to always make it more attractive than open (two dimensional) fields to many species. Furthermore, as coppices increase in age they are likely to become richer botanically and richer in invertebrates, and so attract even more bird species. It is likely that sympathetically planted SRC plots may encourage many species of birds into them in winter, including several species of conservation concern. SRC may in no small way increase the biodiversity of farmland providing improved prospects for many species currently in decline.

14.6 References

Bates J. 1995. *Alternatives in agriculture - growing crops for industrial, energy and other non-food purposes.* Parliamentary Office of Science and Technology, London.

Göransson G. 1990. Energy foresting in agricultural areas and changes in avifauna. *Fauna Norvegica, Series C, Cinclus, Supplement* 1: 17-20.

Hall D O, Scrase J I. & Rosillo-Calle F. 1997. Biomass energy: The global context now and in the future. *Aspects of Applied Biology 49, Biomass and Energy Crops*, pp 105-111.

RSPB. 1996. *Birds of Conservation Concern.* The Royal Society for the Protection of birds, Sandy.

Sage R.B. & Robertson P.A. 1994. The wildlife and game potential of short rotation coppice in the UK. *Biomass and Bioenergy*, 6: 41-48.

Sage R.B. & Robertson P.A. 1996. Factors affecting songbird communities using new short rotation coppice habitats in spring. *Bird Study*, 43, 201-213.

Sage RB, Robertson PA. & Poulson J G. 1994. Enhancing the conservation value of short rotation biomass coppice - Phase 1 the identification of wildlife conservation potential. *Report of the Energy Technology Support Unit, Department of Trade and Industry.*

Sage RB. & Tucker K. 1997. Invertebrates in the canopy of willow and poplar short rotation coppices. *Aspects of Applied Biology 49, Biomass and Energy Crops*, pp 105-111.

Towers W, Morrice J, Aspinall R, Birnie D. & Dagnall S. 1997. Assessing the potential for short rotation coppice in Scotland. In *Environmental Impact of Biomass for Energy - proceedings of a conference in Noordwijkerhout, The Netherlands 4-5 November 1996.* Pp 165-167. Ed. By G. van der Bijl & E E. Biewinga. Centre for Agriculture and Environment, Utrecht.

Tucker G. M. (1992) Effects of agricultural practices on field use by invertebrate-feeding birds in winter. *Journal of Applied Ecology.* **29**, 779-790.

Weins, J. A. (1989) *The Ecology of Bird Communities.* Cambridge University Press, Cambridge.

15.0 SNIPE IN WINTER

15.1 Summary

Winter surveys of all birds including snipe, were undertaken at seven short-rotation coppice (SRC) sites across the south of England in the winter of 1996-7 (see Section 14.0).

At several of these snipe were recorded, adding to information we had already noted on snipe using SRC plantations during winter. Snipe are declining in the UK but have a economic value to many landowners as a quarry species.

At one of these sites, four snipe (*Gallinago gallinago*) were radio-tracked to determine the extent to which they used the coppice crop. We found that the radio-tagged birds, alnog with other snipe, roosted in cut and uncut SRC plantations throughout the day.

Improved and rushy pastures in the vicinity of the SRC plantations were used at night for feeding. Analysis of soil samples indicated a greater food abundance and softer soil in pastures compared with SRC.

The advantages of roosting in SRC are discussed and it is likely that the soil amongst the coppice stools affords good camouflage, the stools themselves, whether cut or not, provided cover and shelter at the right height, whilst the willow stems in uncut coppice provided an amenable microclimate.

15.2 Introduction

Research has shown that areas of SRC can be integrated into the game management of an area, with particular respect to pheasants (*Phasianus colchicus*) (Sage & Robertson, 1994). During fieldwork visits to SRC in the winters 1994-5 and 1995-6, snipe (*Gallinago gallinago*) were regularly flushed from the crop on a number of occasions. Snipe are a declining species in the UK with specific habitat requirements. They are also quarry species and like the pheasant, may provide another opportunity to integrate SRC management for biomass production and management for game interest.

Snipe are generally regarded as birds of continually wet habitats (Cramp & Simmons, 1983). They are waders belonging to the family *Scolopacidae* which also includes such birds as sandpipers (*Calidris, Limicola* and *Tringa*), curlews (*Numenius*) and godwits (*Limosa*). In the UK snipe breed on upland and lowland bogs, marshy river valleys and rough and semi improved wet pastures on the upland/lowland margins (Cramp & Simmons, 1983). There are currently estimated to be around 30 000 pairs breeding in the British Isles (Gibbons *et al.*, 1993). The number breeding has decreased in recent times because of improved agricultural drainage and the intensification of farming. This has been especially noticeable in the lowlands and the upland/lowland margin (Marchant *et al.*, 1990). In winter snipe are more widely distributed in the British Isles as numbers are augmented by migrants from the continent. Western Britain and Ireland are particularly favoured as here milder conditions tend to prevail due to the more oceanic climate and as a result feeding marshes tend to remain ice free (Lack, 1986).

The occurrence of flocks of snipe in SRC is surprising as these plantations do not resemble typical snipe habitat. SRC tends to be relatively dry with hard ground not suitable for the snipe's usual feeding method which involves probing soft ground for invertebrates (Cramp & Simmons, 1983). It was decided to investigate the use of SRC by snipe to discover when and for what purpose snipe inhabited coppice plantations and thereby identify the potential for encouraging snipe into SRC through appropriate crop management. The aim of the study was therefore to catch and radio track a number of snipe to identify which other habitats the birds used and how important SRC was in respect to these other habitats.

15.3 Methods

15.3.1 Winter bird surveys

Snipe were counted as part of the winter bird survey at seven sites across the south of England and the methods and results are reported in Section 14.0. This survey identified the site holding the most snipe in the winter of 1996-7 to be Holdridge Farm in North Devon (see Section 14.4). This site was therefore chosen for the more intensive investigation of snipe movements and habitat use.

15.3.2 Snipe habitat use

Holdridge Farm (national grid reference SS7328) consisted of approximately 40 ha of SRC willow and about 0.5 ha of SRC poplar on the tops of steep-sided, sheep-grazed hills. Adjoining farms were predominantly sheep-grazed on the hill tops as well as the hill sides. There were areas of semi-natural oak (*Quercus* sp.) woodland on the valley sides whilst the valley bottoms were mostly poorly-drained rushy pasture. The underlying soil was a brown earth with some gleying in the marshy valleys. Altitude ranged from 120m above sea level in the valley bottoms to 230m on the hill-tops.

Mist nets were set to catch birds in the areas of coppice which appeared to be most frequently used by snipe. Each bird caught was ringed and fitted with a radio transmitter and its subsequent position recorded several times during the day and night until such time as no signal was received. This was probably when the birds left the area but could also have been due to radio failure or predation of the bird. The exact location of each bird was recorded on a map of the area. Locations and activities of any other snipe seen in the area were also recorded whenever they were encountered.

At the end of the period of radio-tracking, 25 soil samples were collected from each of the three field-types most frequently used by the; rushy pasture in the valley bottom, willow coppice on the hill top and an improved pasture also on the top of the hill. The soil samples were approximately 15cm x 15cm x 12cm deep (approximately 2.7 litres) and were transferred immediately to plastic bags. The soil was taken to the laboratory and examined by hand, all samples being completed within a week of collection. All invertebrates above 2mm in length were removed, weighed and identified at least to order and where possible to family.

At each of the 25 soil collection points in each of the fields five penetrability measurements, using a standard penetrometer, were taken to provide a measure of the soil softness and five measures of vegetation height were taken.

15.4 Results

Four snipe were caught at the Holdridge Farm site, north Devon between 12/12/96 and 22/1/97 and fitted with radio transmitters. The length of time for which signals were received from each bird ranged from 12 hours to 22 days. The bird which was lost within 12 hours is thought to have fed in the evening before moving on. It was located on pasture after its release at approximately 0900 hours and remained there until, at least, the evening but could not be relocated the following morning. A summary of the amount of time each of the other three birds spent in each habitat type is given in Table 15.1.

It can be seen that the three birds varied individually in the amount of time they spent in each habitat. Despite this, no bird was ever recorded spending the night in SRC. Snipe flew into the crop at dawn, and spent the day there. At dusk all birds left within five to ten minutes of each other. On flying out the radio-tagged birds would often circle over the farm for two or three minutes before flying to their chosen feeding pasture. On other occasions birds appeared to fly straight to the pasture. On a small number of occasions birds circled the area for ten minutes or more before settling. The absence of snipe from the crop through the night was confirmed by lamping which found no snipe in the crop during the hours of darkness.

Table 15.1. Time spent and percentage of time spent in each of the three habitats used by snipe on Holdridge Farm, North Devon, winter 1996-7. The final row shows the means weighted to give proportionally more importance to the birds tracked over a longer time period.

BIRD	SRC	IMPROVED PASTURE	RUSHY PASTURE	ALL HABITATS
A	22h 40m (17.7%)	27h 45m (21.5%)	77h 55m (60.7%)	128h 20m (100%)
B	7h 50m (25.1%)	0	23h 20m (74.9%)	31h 10m (100%)
C	77h 20m (42.7%)	92h 20m (51.0%)	11h 30m (6.3%)	181h 10m (100%)
MEAN FOR ALL 3 BIRDS	36h 0m (31.7%)	40h 0m (35.2%)	37h 40m (33.1%)	
WEIGHTED MEANS	34.0%	40.4%	25.5%	

The period from dusk until dawn was always spent on pasture. It was observed that birds only used areas of improved pasture on misty nights when visibility was reduced. On clear nights, birds always used rushy pasture and misty nights which became clear before dawn induced birds to move back to their daytime roost sites early. Birds (especially bird A) occasionally roosted in rushy pasture but never in improved pasture. Mean grass height in the improved pasture was 5.7±1.4cm and of a uniform nature. Vegetation height in the rushy pasture was variable (5.6±2.5cm), the grass being short but with tall rush (*Juncus sp.*) tussocks and patches. Both pastures exhibited 100% vegetation cover. From observations and radio-tracking data it was clear that the time in the coppice was spent resting.

Excepting the coppice stools the SRC fields were almost totally barren of ground vegetation being mostly bare soil with some leaf litter and some isolated grass patches and tussocks (15.2% cover, vegetation height 0.7±1.7cm). Observations of snipe which had not been radio-tagged suggested considerably higher densities during the day in SRC than in rushy pasture. Every evening whilst tracking radio-tagged snipe leaving the coppice to feed, between seven and nineteen other snipe were seen to fly out. A survey of all SRC plots on the farm revealed 29 snipe roosting within the crop. Rushy pastures occupied by radio-tagged snipe were also rigorously searched for other birds on three occasions but only produced a maximum of 2 snipe. These figures translate to maximum densities of 0.725 snipe ha^{-1} roosting in coppice and 0.166 snipe ha^{-1} roosting in rushy pastures.

The greatest recorded distance commuted by a radio-tracked snipe from SRC to feeding pastures was 0.925km. The proportions of the three habitat types available within 1km radius of the coppice crop (this covering the maximum distance moved) is presented in Table 15.2. There are not sufficient data to conduct a ranges type analysis of habitat utilisation by snipe. It can be seen by comparing with the weighted means in Table 15.1, however, that snipe in this study used SRC considerably more frequently than might be expected if habitat choice were random. SRC and improved pasture, however, were each only used for one activity; daytime roosting and night time activities respectively. Rushy pasture was used by the birds for both activities. By taking the two activities separately and considering the choice of habitat within each activity, we can examine the habitat preferences of the birds in this study. Doing this, it can be seen that 72.2% of all recorded night time activity was spent on improved pasture with only 27.8% being spent on rushy pasture. Similarly, 76.5% of all roosting activity was spent in SRC and only 23.5% in rushy pasture.

Table 15.2. Proportion contributed by each habitat type to the land area within 1km radius of the centre of the SRC fields on Holdridge Farm, North Devon, winter 1996-7.

HABITAT TYPE	PROPORTION OF LAND AREA
SRC	11.5%
Rushy Pasture	18.8%
Improved Pasture	54.2%
Miscellaneous wood & urban	15.5%

Measures of soil penetrability showed no variation between rushy pasture (2.60 ± 0.64kg force cm^{-2}) and improved pasture (2.60 ± 0.40kg force cm^{-2}), but SRC fields were significantly more difficult to probe (3.04 ± 0.57kg force cm^{-2}; p=0.001).

The results of the soil invertebrate analysis are shown in Figures 15.1 to 15.3. Earthworms were the most frequently encountered group and contributed the greatest mass of all the soil invertebrates. Rushy pasture and improved pasture contained a total of 1.27g and 1.11g of invertebrates per litre of soil respectively. The SRC field contained a significantly smaller mass of invertebrates compared with both types of pasture (0.19g l^{-1}, p=0.001). Comparison between the two types of pasture indicated marginally more tipulid larvae in the improved pasture and more earthworms in the rushy pasture but these differences were not significant.

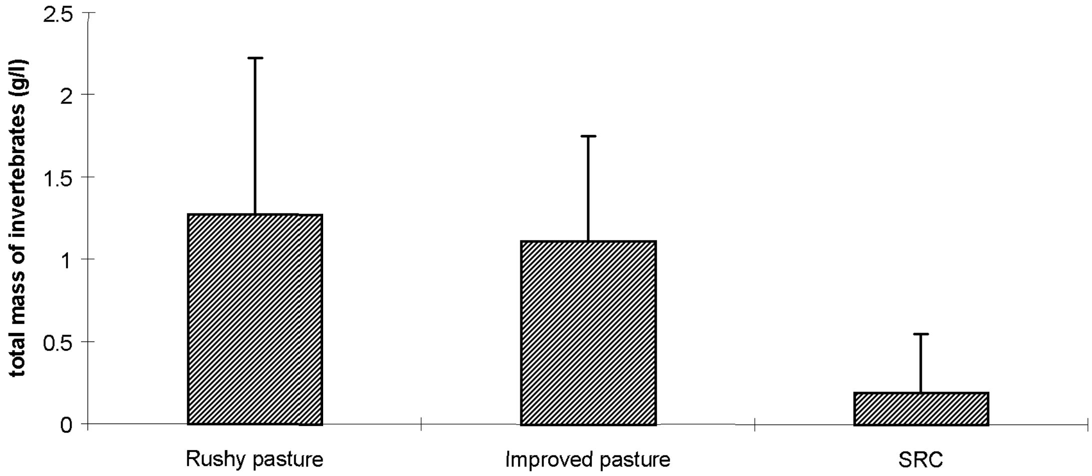

Figure 15.1. Mass of all invertebrates (g l^{-1}) in three field types frequented by radio-tagged snipe

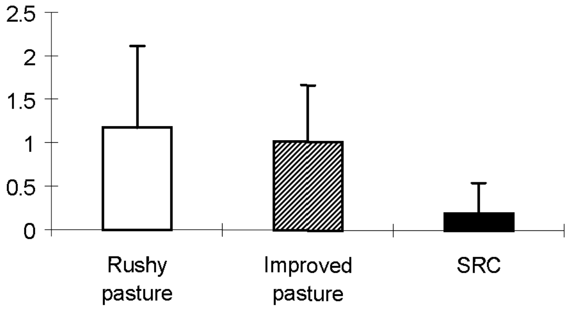

Figure 15.2. Distribution of worms between three field types frequented by radio-tagged snipe.

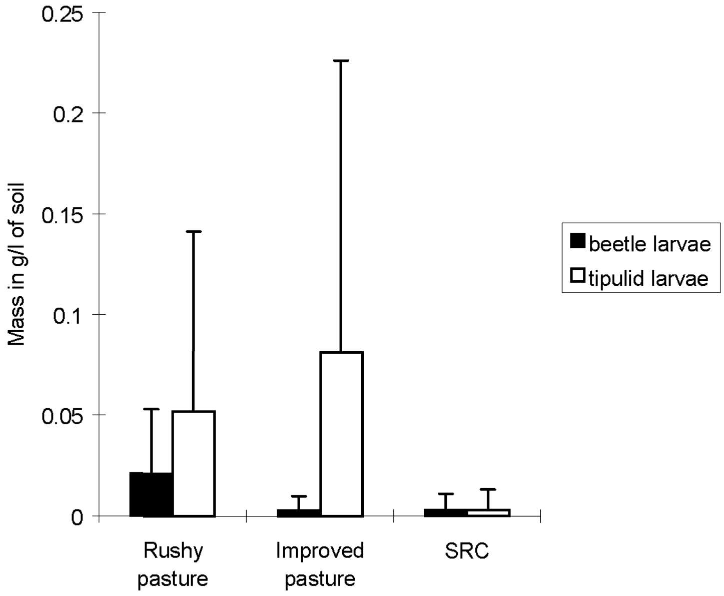

Figure 15.3. Distribution of beetle larvae and tipulid larvae between three field types frequented by radio-tagged snipe.

15.5 Discussion

At the intensive study site, snipe used the crop for roosting and as is usual for roosting birds, feather maintenance activities were also undertaken here (White & Harris, 1966). Most or all of the birds' feeding was probably done at night in areas of pasture. This was supported by the relatively high numbers of soil invertebrates found there in comparison with the SRC fields. Furthermore, Swift, (1978-79) and Tuck, (1972) state the snipe feeding activity is mostly crepuscular (dawn and dusk). There were differences in which type of pasture individual birds preferred but there did appear to be a preference for improved pasture on misty nights. It is likely that snipe preferred improved pasture due to the increased number of tipulids which were available but the exposed nature of the short sward probably prevented this naturally shy species utilising this habitat on clear or moonlit nights when the likelihood of predation was increased. On such moonlit nights the relative safety of dense grass and rushes found in rushy pastures was preferred.

As well as SRC, snipe also roosted in rushy areas but birds in the study area preferred to roost in SRC as supported by radio-tracking data and observations of untagged birds. Why SRC was preferred is unclear but can be speculated upon. A likely explanation is that the brown, uneven terrain of the soil amongst the SRC stools provided good camouflage and the stools themselves, whether cut or uncut provided cover and protection at the right height. The way the stools are planted in rows allows good visibility at ground level, yet the dense canopy structure in uncut SRC prevents detection and access by aerial predators. Rushy pasture is greener, providing less suitable camouflage but more direct concealment. This is, however, countered by the lack of visibility in this rather enclosed habitat. Visibility is likely to be important for detecting any ground-based predators which do approach.

This study indicates that a variety of habitats is important for wintering snipe; birds need habitat in which to roost and in which to feed. These two requirements may be fulfilled by the same habitat, in this study birds both fed and roosted in rushy pasture, but preferred to roost in SRC and fly out at night to feed on soft pasture. Growers wishing to encourage wintering snipe into their plantations need to be aware of this. The four radio-tracked snipe in this study had relatively small home ranges and rarely flew further than was necessary from roosting to feeding site and back again. Although the number of birds tracked is too small to be conclusive, this strongly suggests that a farm with an integrated patchwork of SRC and invertebrate-rich rough and improved pasture would best suit snipe.

Consequently, growers of SRC wishing to encourage wintering snipe to roost in their coppice must also be able to provide adequate feeding pastures (preferably some rather rough and tussocky with rushes and others grazed or mown short) within about 1km radius. This is the pattern of land use on the Somerset Levels where snipe are common in winter and are driven from their whithy bed daytime roosts for shooting purposes. This closely mixed habitat pattern will also benefit other bird species because of the increased incidence of coppice edge that would be created (see Section 14.5). Sympathetically planted SRC plots are likely to support increased numbers of birds in winter (Section 14.0, and Göransson, 1990), and in the west of Britain and Ireland in particular, snipe may be especially encouraged as it is in these areas that suitable feeding pastures and an amenable climate coincide to produce good winter conditions for this species.

15.6 References

Bates, J. (1995) *Alternatives in agriculture - growing crops for industrial, energy and other non-food purposes.* Parliamentary Office of Science and Technology, London.

Cramp, S. and Simmons, K. E. L. (1983) *Handbook of the Birds of Europe the Middle East and North Africa: The Birds of the Western Palearctic.* Volume III, Waders to Gulls. Oxford University Press, Oxford.

Gibbons, D. W., Reid, J. B. and Chapman, R. A. (1993) *The New Atlas of Breeding Birds in Britain and Ireland: 1988-91.* T & A. D. Poyser, London.

Göransson G. 1990. Energy foresting in agricultural areas and changes in avifauna. *Fauna Norvegica, Series C, Cinclus, Supplement* 1: 17-20.

Lack, P. (1986) *The Atlas of Wintering Birds in Britain and Ireland.* T. and A. D. Poyser, London

Marchant, J. H., Hudson, R., Carter, S. P. and Whittington, P. (1990) *Population Trends in British Breeding Birds.* The British trust for Ornithology, Tring.

Sage R.B. & Robertson P.A. 1994. The wildlife and game potential of short rotation coppice in the UK. *Biomass and Bioenergy*, 6: 41-48.

Sage R.B. & Robertson P.A. 1996. Factors affecting songbird communities using new short rotation coppice habitats in spring. *Bird Study*, 43, 201-213.

Sage R.B., Robertson PA. & Poulson J G. 1994. Enhancing the conservation value of short rotation biomass coppice - Phase 1 the identification of wildlife conservation potential. *Report of the Energy Technology Support Unit, Department of Trade and Industry.*

Sage R.B. & Tucker K. 1997. Invertebrates in the canopy of willow and poplar short rotation coppices. *Aspects of Applied Biology 49, Biomass and Energy Crops*, pp 105-111.

Swift J.A. 1978-79. The wintering ecology of common snipe (*Capella g.allinago*) at Sevenoaks. *Verh. Orn. Ges. Bayern,* 23. 203-216.

Tuck L.M. 1972. *The snipes: a study of the genus* Capella. Canadian Wildlife Service Monograph Series N° 5, Ottawa. 429 pages.

White M. & Harris SW. 1966. Winter occurrence, foods and habitat use of snipe in Northwest California. *Journal of Wildlife Management*, 30:1, 23-34.

16.0 THE BREEDING BIRDS OF SRC

16.1 Summary

The birds of an area of farmland incorporating pasture and a mixture of age classes of short rotation coppice in Northern Ireland were surveyed each breeding season during 1994-97 inclusive.

During this time 44 species of bird were recorded in the area and of these, 32 were recorded in the crop on at least one occasion and 22 held a mean of at least one territory per year.

Two of these regularly occurring species, pheasant and reed bunting, always incorporated SRC into their territories whilst three species were never recorded using SRC, blackcap, chiffchaff and goldcrest. The remaining 17 species held territories which sometimes incorporated SRC but did not always do so.

The most frequent species were willow warbler and wren each holding a mean of 18.5 territories per year in the area. Garden warbler, lapwing, meadow pipit, pheasant, reed bunting, sedge warbler and willow warbler all incorporated SRC into their territories more than any other habitat.

Three species of high conservation concern regularly held territory in SRC. These were bullfinch, reed bunting and song thrush.

Selection of different age classes was apparent for some species.

The juxtaposition of habitats is discussed and it is clear that a range of habitats within a small area will increase species diversity. The establishment of a patchwork of SRC of different ages within an otherwise traditional farmland landscape will provide new niches for birds and increase the number and diversity of species able to breed. This alone makes SRC an environmentally desirable crop as some of the species which benefit most are of high conservation concern and are otherwise declining in numbers on UK farms.

16.2 Introduction

Birds attract a great deal of public attention. Their songs, often bright plumage, relative obviousness when compared with other vertebrates and main mode of locomotion (flight) make them endearing to many people who otherwise have little interest in ecological matters. The abundance and diversity of birds in an area therefore has more than ecological relevance. It has relevance with respect to the public perception of the environmental state of a site, often whether or not the site has actual ecological importance. Birds advertise their presence during the breeding season by singing. Consequently, a study of breeding birds is an important and relatively straight forward part of almost any environmental assessment.

Through extensive surveys of nearly 30 sites, Sage *et al.*, (1994) showed that SRC held a relatively large number of bird species and individuals when compared with the agricultural crops it tended to replace. This is largely a result of the increased structural diversity which SRC provides. The physical structure of SRC changes as it grows and how this affects the species of bird which are to be found has also already been shown in by Sage *et al.* (1994). Their study was centred on point counts taken at SRC sites of singing birds in the early morning. This did not indicate whether birds maintained territories in SRC for sustained periods or used SRC in isolation from other habitats or not. In order to gain more insight into the use SRC by birds and the relationship of this to their use of other habitats, a four-year intensive study of a typical area of willow SRC within a traditional farming landscape was initiated. This section reports the results of that study and aims to identify the species which may particularly benefit from increased planting of SRC.

16.3 Methods

The study site, Castle Archdale, was located in Northern Ireland at the Grassland Experimental Farm, Lisnarick near Enniskillin, County Fermanagh. The planting was initiated to provide a large-scale plantation suitable for testing harvesting techniques. The soil type at the site was a silty clay-loam with generally impeded drainage. The farm was predominantly dairy and consisted mostly of grass leys for grazing and silage. The plantations themselves replaced permanent pasture. Some areas of plantings did not establish well due to rust attack and bad drainage. These areas were allowed to die back and formed areas of rough grassland with tall herbs and occasional willow shrubs. Much of the adjacent land use was mature conifer forestry on the Castle Archdale estate. The layout of the SRC blocks in relation to the other land uses can be seen in the maps, Figures 16.1 to 16.4. The site was chosen for its good mix of SRC age classes placed within a traditional agricultural landscape. The willow varieties used were Bowles hybrid, dasyclados, SQ683, Q83, Germany, mullatin, reifenweide, calodendron, stipularis and delamere. Planting was at 20 000 stools per hectare with some intimate mix and single variety plots.

A standard and established method of surveying breeding birds in agricultural and forest landscapes was used in this study. It was a territory mapping method involving repeated visits. This method is identical to that used in the Common Bird Census (CBC) developed and used by the British Trust for Ornithology (BTO) (Bibby, Burgess and Hill, 1992; Enemar, 1959; Kendleigh, 1944; William, 1936; Williamson, 1964). A mapping technique is particularly suitable for making associations between birds and habitats as the mapping actually records the positions of birds in space relative to different types of land use and landscape features.

The method involved selecting and walking a path through the chosen area so that no point was further than 50m from the path. The path was walked slowly so that each bird could be identified. The position of each individual was marked on a map of the site. Also recorded were the specific activities of the birds - calling, singing, carrying food and so on. Each survey was conducted in the morning shortly after dawn when birds were most active and easily observed. The survey was repeated eight times during the breeding season at regular intervals from mid-April to early July during the four years 1994 to 1997. This protracted period of observation ensured that all species were discovered as some, mostly resident species, were most active early in the year and others, summer migrants, were most active later into the summer.

At the end of the field season the maps of the different visits were combined to produce single maps for each species containing all registrations throughout the season. The different visits were indicated for each registration by using a different letter, A to H, for each visit. In this way, one map was produced per species showing clusters of registrations through time. These clusters were then interpreted in terms of bird territories. Recurring registrations in the same area over several visits were viewed as a cluster of registrations representing a territory. Where many territories appeared to be clustered together, records of two or more individuals of the same species singing at the same time were used to identify separate clusters and so separate territories. The exact notation used on maps and the methods used to identify territories are described well in Bibby, Burgess and Hill (1992). As there is some subjectivity involved, the interpretation of the species maps was conducted by one person analysing all species for all four years (1994-7) together to ensure that the method was the same enabling comparisons to be made.

16.4 Results

A total of 44 species was recorded during the four years. The species and their occurrence in each year are presented in table 16.1. Many of the species did not hold territories and were merely recorded on one or two occasions as migrants of passage (i.e. did not form clusters of registrations). These species included curlew (*Numenius arquata*), grey wagtail (*Motacilla*

FIGURE 16.1, 16.2, 16.3 AND 16.4 NOT AVAILABLE ELECTRONICALLY

Table 16.1 Number of territories for each bird species recorded at Castle Archdale 1994-97 (P indicates birds recorded as present but not holding territory). The species in **bold** held a mean of at least one territory per year. ^{A} and ^{R} indicate amber and red list species of conservation concern (RSPB, 1996)

	Number of Territories					
Species	**1994**	**1995**	**1996**	**1997**	**Total**	**Mean±se**
Blackbird^{A}	**6**	**6**	**4**	**4**	**20**	**5.00±0.58**
Blackcap	**2**	**1**	**1**	**P**	**4**	**1.00±0.40**
Blue tit	**3**	**2**	**4**	**3**	**12**	**3.50±0.41**
Bullfinch^{R}	**2**	**1**	**1**	**2**	**6**	**1.50±0.29**
Buzzard	0	0	0	P	0	0
Chaffinch	**9**	**6**	**9**	**11**	**35**	**8.75±1.03**
Chiffchaff	**1**	**1**	**1**	**2**	**5**	**1.25±0.25**
Coal tit	**2**	**2**	**3**	**4**	**11**	**2.75±0.48**
Cuckoo	0	0	1	0	1	0.25±0.25
Curlew^{A}	P	0	0	0	0	0
Dunnock^{A}	**6**	**4**	**4**	**6**	**20**	**5.00±0.58**
Garden warbler	**1**	**3**	**4**	**1**	**9**	**2.25±0.75**
Golcrest	**6**	**3**	**2**	**1**	**12**	**3.00±1.08**
Goldfinch^{A}	P	P	0	0	0	0
Grasshopper	0	0	0	1	1	0.25±0.25
Great tit	**2**	**3**	**2**	**4**	**11**	**2.75±0.48**
Greenfinch	0	0	0	1	1	0.25±0.25
Grey wagtail	0	P	0	0	0	0
House sparrow	0	0	0	P	0	0
Jay	0	P	0	0	0	0
Kestrel^{A}	0	0	0	P	0	0
Lapwing^{A}	**1**	**2**	**2**	**1**	**6**	**1.50±0.29**
Long-tailed tit	1	P	0	P	1	0.25±0.25
Mallard	0	P	1	1	2	0.50±0.29
Meadow pipit	**4**	**4**	**2**	**2**	**12**	**3.00±0.58**
Mistle thrush	**1**	**1**	**1**	**1**	**4**	**1.00±0.00**
Pheasant	**2**	**1**	**1**	**1**	**5**	**1.25±0.25**
Pied wagtail	1	0	0	P	1	0.25±0.25
Raven	0	P	0	0	0	0
Redpoll	P	1	P	P	1	0.25±0.25
Reed bunting^{R}	**2**	**2**	**2**	**P**	**6**	**1.50±0.50**
Robin	**16**	**7**	**9**	**11**	**43**	**10.75±1.93**
Sedge warbler	**1**	**5**	**12**	**7**	**25**	**6.25±2.29**
Siskin	0	0	P	P	0	0
Skylark^{R}	1	0	P	P	1	0.25±0.25
Snipe^{A}	P	P	0	P	0	0
Song thrush^{R}	**6**	**2**	**1**	**6**	**15**	**3.75±1.31**
Sparrowhawk	0	0	P	0	0	0
Spotted flycatcher^{R}	0	P	0	1	1	0.25±0.25
Treecreeper	**1**	**1**	**2**	**1**	**5**	**1.25±0.25**
Wheatear	0	P	0	0	0	0
Willow warbler	**17**	**18**	**22**	**17**	**74**	**18.50±1.19**
Woodcock^{A}	0	0	0	1	1	0.25±0.25
Wren	**22**	**19**	**17**	**15**	**73**	**18.25±1.49**

cinerea), snipe (*Gallinago gallinago*) and wheatear (*Oenanthe oenanthe*). Other species occurred uncommonly because they were more strictly associated with surrounding habitats, especially human settlements and mature conifer forestry, or were species which occupied large home ranges and over-flew the area only infrequently. Species in these two groups are many and include buzzard (*Buteo buteo*), cuckoo (*Cuculus canorus*), house sparrow (*Passer domesticus*), jay (*Garrulus glandarius*), kestrel (*Falco tinnunculus*), raven (*Corvus corax*), redpoll (*Acanthis flammea*), siskin (*Carduelis spinus*), sparrowhawk (*Accipiter nisus*) and treecreeper (*Certhia familiaris*). Yet other species were simply rare in the area, like bullfinch (*Pyrrhula pyrrhula*), goldfinch (*Carduelis carduelis*), spotted flycatcher (*Muscicapa striata*) and grasshopper warbler (*Locustella naevia*).

Of the 44 species, 12 species (27.3%) were never recorded in SRC and, conversely, 32 species (72.7%) were, at some time, recorded in SRC. For eight species (18.2%), all clusters incorporated SRC (although other habitats were used by the individuals in each cluster) (Table 16.2). These figures are of limited relevance, however, as species which occurred only once or twice contribute disproportionately to the overall picture of habitat use. It is better to consider only those species which regularly held territory.

Of the 44 species recorded, 22 held a mean of at least one territory per year in the survey area (i.e. tended to breed every year - see species in **bold** Table 16.1). Analysis of the habitat use of these 22 regular breeding species is presented in table 16.2 and Figures 16.5a-d. The data is presented in terms of the proportion of registration clusters (territories) which contain registrations in each of the habitat types. Maps of the actual positions of each cluster of registrations (territory) are also presented for the seven species which achieved a mean of five or more territories per year in Figures 16.6 to 16.12.

The available habitats in the survey area are broken down into rough grassland with scattered tall herb and shrubs, improved grass leys and edge habitats. Edge habitats includes the boundary features between units of land (hedges, fences and ditches) as well as the shrubby edges of the surrounding woodland. Of these 22 species, pheasant (*Phasianus colchicus*) and reed bunting (*Emberiza schoeniclus*) (9.1% of regular breeding species) always incorporated SRC within their territories. Blackcap (*Sylvia atricapilla*), chiffchaff (*Phylloscopus collybita*) and goldcrest (*Regulus regulus*) (13.6%) were never recorded in SRC despite being regularly recorded in the survey area. The majority of species (77.3%) held territories which sometimes incorporated SRC but did not always do so (Table 16.2, Figures 16.5a-d).

The species with the highest number of territories were willow warbler (*Phylloscopus trochilus*) and wren (*Troglodytes troglodytes*), each occupying a mean of 18.5 territories per year. The four most common species at the Castle Archdale study site (willow warbler, wren, robin (*Erithacus rubecula*) and chaffinch (*Fringilla coelebs*)) used SRC to a large extent but also used other habitats within the area. Of these species, only willow warbler selected

Table 16.2 Proportion of the territories of each species for which registrations were recorded in each of the four habitats; rough grass, improved grass ley, edge habitats and SRC. The species in **bold** held a mean of at least one territory per year. ^{A} and ^{R} indicate amber and red list species of conservation concern (RSPB, 1996)

	Proportion of territories with registration in each of four habitat types (mean±standard error)			
	rough	**grass**	**edge**	**src**
Blackbird^{A}	**0.21 ±0.02**	**0.23 ±0.10**	**0.96 ±0.04**	**0.85 ±0.05**
Blackcap	**0.25 ±0.13**	**0**	**0.75 ±0.24**	**0**
Blue tit	**0.17 ±0.10**	**0**	**0.83 ±0.10**	**0.42 ±0.05**
Bullfinch^{R}	**0.25 ±0.25**	**0**	**1.00**	**0.88 ±0.13**
Buzzard	0	0	0	1.00
Chaffinch	**0.17 ±0.02**	**0.07 ±0.04**	**0.98 ±0.02**	**0.45 ±0.05**
Chiffchaff	**0**	**0**	**1.00**	**0**
Coal tit	**0**	**0**	**1.00**	**0.06 ±0.06**
Cuckoo	0	0	1.00	1.00
Curlew^{A}	0	0	0	0
Dunnock^{A}	**0.04 ±0.04**	**0**	**0.88 ±0.07**	**0.81 ±0.07**
Garden warbler	**0.06 ±0.06**	**0**	**0.69 ±0.24**	**0.94 ±0.06**
Goldcrest	**0.04 ±0.04**	**0**	**1.00**	**0**
Goldfinch^{A}	0	0	0	0
Grasshopper warbler^{A}	1.00	0	0	1.00
Great tit	**0.08 ±0.08**	**0.13 ±0.13**	**0.88 ±0.13**	**0.46 ±0.04**
Greenfinch	0	0	1.00	1.00
Grey wagtail	0	0	0	0
House sparrow	0	0	0	1.00
Jay	0	0	0	0
Kestrel^{A}	0	0	0	0
Lapwing^{A}	**0**	**0.38 ±0.24**	**0**	**0.88 ±0.13**
Long-tailed tit	0	0	1.00	0
Mallard	0	0.50 ±0.25	0.50 ±0.25	0.67 ±0.33
Meadow pipit	**0.25 ±0.25**	**0.50 ±0.29**	**0.19 ±0.19**	**0.69 ±0.24**
Mistle thrush	**0.50 ±0.29**	**0.75 ±0.25**	**0.75 ±0.25**	**0.50 ±0.29**
Pheasant	**0.50 ±0.29**	**0**	**0.75 ±0.25**	**1.00**
Pied wagtail	0	1.00	0	1.00
Raven	0	0	0	0
Redpoll	0	0	1.00 ±0	0.75 ±0.25
Reed bunting^{R}	**0.33 ±0.14**	**0.17 ±0.13**	**0.17 ±0.13**	**1.00**
Robin	**0.14 ±0.05**	**0.02 ±0.02**	**0.84 ±0.07**	**0.44 ±0.09**
Sedge warbler	**0.20 ±0.09**	**0**	**0.04 ±0.04**	**0.95 ±0.05**
Siskin	0	0	0	0.50 ±0.50
Skylark^{R}	0	0	0	1.00
Snipe^{A}	0	0	0	0.33 ±0.33
Song thrush^{R}	**0.21 ±0.10**	**0.29 ±0.24**	**0.92 ±0.05**	**0.83 ±0.12**
Sparrowhawk	0	0	0	0
Spotted flycatcher^{R}	0	0	1.00	1.00
Treecreeper	**0**	**0**	**1.00**	**0.25 ±0.25**
Wheatear	0	0	0	0
Willow warbler	**0.16 ±0.06**	**0**	**0.65 ±0.18**	**0.68 ±0.04**
Woodcock^{A}	1.00	0	0	1.00
Wren	**0.19 ±0.02**	**0**	**0.79 ±0.04**	**0.39 ±0.05**

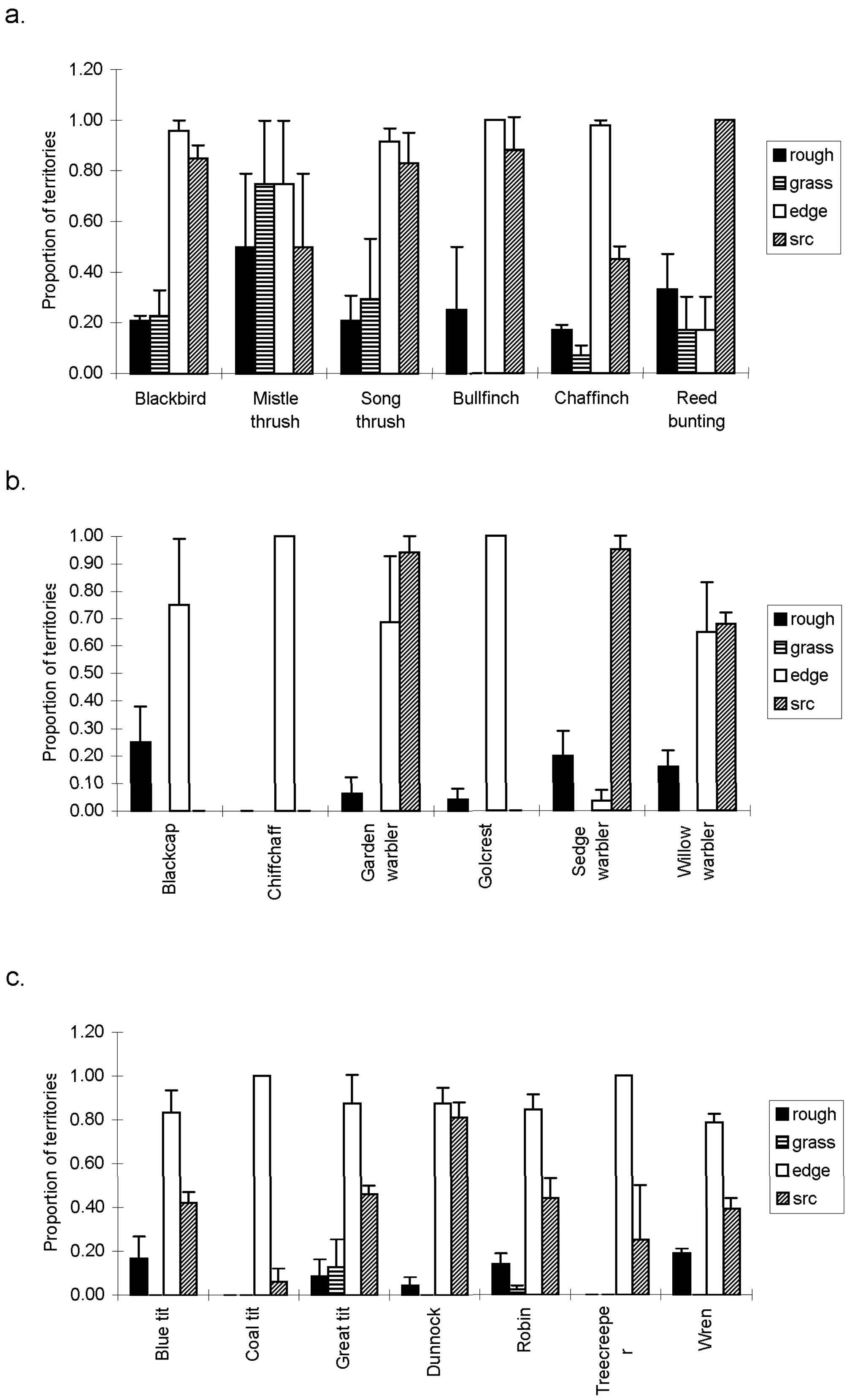

Figure 16.5a-c See over for caption

d.

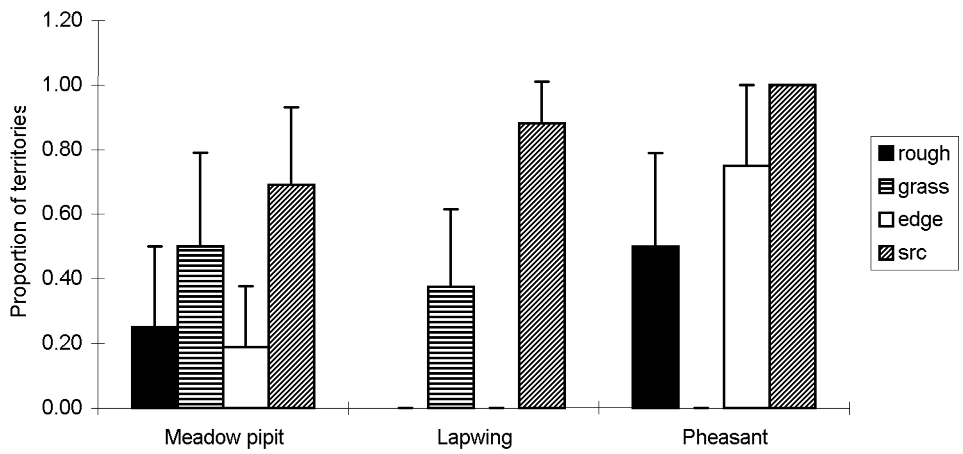

Figure 16.5d The proportion of territories of each species incorporating each of the four main habitat types at Castle Archdale. 'Rough'=rough grassland with tall herbs and occasional shrubs, 'grass'=intensively managed grass leys, 'edge'=linear boundary habitats such as fences and hedges and the shrubby edges of the adjacent woodland

SRC in proportionally more territories than it selected edge habitats although this difference was very slight and not significant. The other three species were significantly more frequently recorded from edge habitats than SRC (chaffinch, t=6.971 p<0.01; robin, t=5.196 p<0.02; wren, t=6.245 p<0.01). Regularly occurring species which appeared to preferentially select SRC over other habitats included pheasant, garden warbler (*Sylvia borin*), sedge warbler (*Acrocephalus schoenobaenus*), and reed bunting. Of these, only the latter two showed a statistically significant preference (sedge warbler, t=7.384 p<0.01; reed bunting, t=5.196 p<0.02). Lapwing (*Vanellus vanellus*) and meadow pipit (*Anthus pratensis*), traditionally open field species, also showed a preference for SRC but numbers involved were too low to demonstrate a significant difference.

Other species strongly linked with SRC were blackbird (*Turdus merula*) (85% of territories), bullfinch (88%), dunnock (*Prunella modularis*) (81%) and song thrush (*Turdus philomelos*) (83%). The selection of different SRC age-classes by the species which incorporated SRC into the majority of registration clusters is presented in Figures 16.13a-c. In these charts, the number of territories using each age-class is adjusted to allow for differences in the area of each age-class available over the four years of the study. A two way analysis of variance yielded no significant differences in the use of different age classes by those species which utilised more than one age class. Lapwing used only year 0 SRC (i.e. just cut) whilst garden warbler never used year 0 coppice.

FIGURES 16.6a-d, 16.7a-d, 16.8 a-d, 16.9a-d, 16.9a-d, 16.10a-d, 16.11a-d, 16.12a-d NOT AVAILABLE ELECTRONICALLY

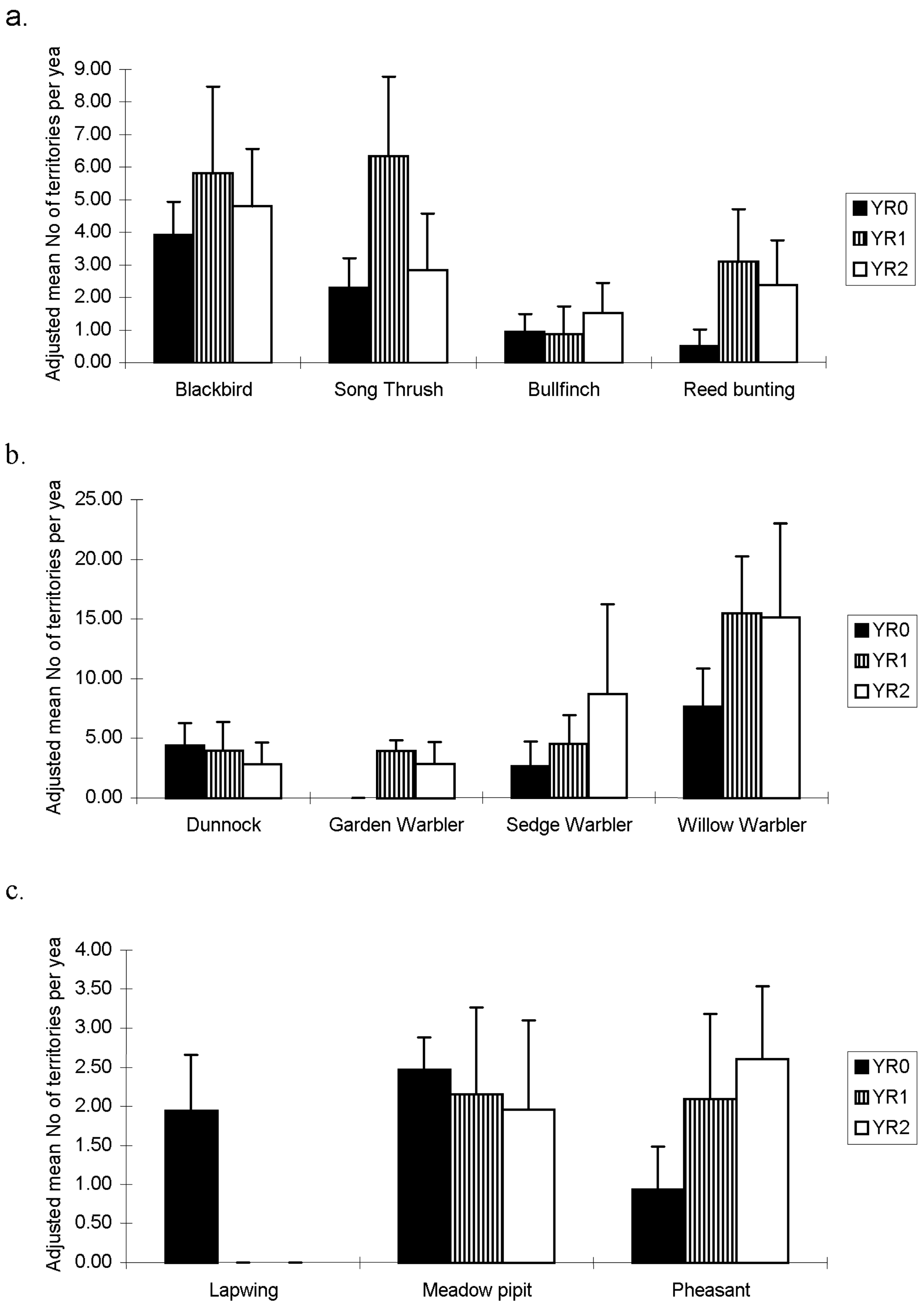

Figure 16.13a-c Mean annual use of SRC age classes by the 11 regular breeding species that incorporated SRC into more than half of their territories. The figures were adjusted to account for the different amounts of each age class available to the birds

16.5 Discussion

Sage and Robertson (1996) in their national songbird survey recorded 41 bird species in SRC in spring and summer. Of these, 18 were recorded from at least 10% of sites. The 44 species recorded by this study, of which 22 regularly held territory, compares very favourably as although this is a more detailed survey, it does not have the geographical range of the Sage and Robertson study. The total species lists for the two studies are in many ways quite different (see Appendices A and B) but these differences are mostly due to the rarely occurring species and these are often non-songbirds at Castle Archdale which the methods of Sage and Robertson were not designed to monitor. There is good agreement between the studies if we consider only the most frequent species. Of the 22 regular breeders at Castle Archdale (those species highlighted in bold in table 16.2) three were not recorded by Sage and Robertson at all. These species (coal tit, goldcrest and treecreeper) were all associated most strongly with edge habitats (see Figures 16.5b & c) and their presence in the Castle Archdale study area is due probably to the presence of these edge habitats. Fifteen of the remaining 19 regular breeders at Castle Archdale were recorded at 10% or more of the sites surveyed by Sage and Robertson.

For the common species then, it is probably safe to assume that Castle Archdale is representative of SRC sites throughout the British Isles. The commonest species at the Castle Archdale study site (willow warbler, wren, robin, chaffinch) are also amongst the most common British breeding species (Gibbons, Reid & Chapman, 1993; Stone *et al.*, 1997). They occupy a broad range of habitats wherever there is some cover for feeding and nesting (Gibbons, Reid & Chapman, 1993; Simms, 1971 & 1985). Consequently these species used SRC to a large extent but also used other habitats within the area (see figs 16.5a-c, 16.7, 16.9, 16.11 and 16.12). Of these four species, only willow warbler (the commonest breeding bird in SRC, see Environmental Resources Management, 1995; Göransson, 1994; Sharples, 1997) preferred SRC over edge habitats and this difference was marginal and not significant.

The species which did prefer SRC were almost all scrub specialist. Notably, two common species (blackcap and chiffchaff) which like to sing from high tree canopies (Clement, 1995; Cramp & Simmons, 1992; Simms, 1985,) and which were present in surrounding habitats were never recorded in the SRC plots;. SRC obviously does not provide the conditions suitable for these, and presumably other, truly arboreal species. The birds of SRC were the common birds of hedgerow and scrub (Fuller, 1982; Simms, 1971). This does not mean, however, that they are of no conservation value. Several of the species are red list (high conservation concern) or amber list (medium conservation concern) species as recognised by the Royal Society for the Protection of Birds, British Trust for Ornithology, Birdlife International and the Game Conservancy Trust (RSPB, 1996) and as already discussed for wintering birds (section 14.5). None of the five red list species which occurred at Castle

Archdale (see table 16.1) are rare as UK birds but they are all suffering severe national population declines (Gibbons *et al.*, 1993; Marchant *et al.*, 1991; O'Connor & Shrubb, 1986b;RSPB, 1996).

Of the three red list species which held at least one territory per year at Castle Archdale, song thrush and bullfinch were recorded most in edge and SRC habitats while reed bunting much preferred SRC over the next frequented habitat, rough grassland (Figure 16.5a). The reed bunting was found to be one of the most abundant breeders at Friars Court Farm, Oxfordshire by Sharples (see section 9), was recorded by Göransson (1994) in Swedish SRC, by Environmental Resources Management at two of the five farm sites (1995) and occurred at 27% of SRC sites surveyed by Sage and Robertson (1994 & 1996). Furthermore, reed bunting was the third most common wild bird recorded from SRC sites during the winter bird survey being recorded from almost half of the sites (see section 14). Clearly, if SRC were more widely grown it could become an important habitat for this species which has declined because of the intensification of British agriculture (Gibbons *et al.* 1993; O'Connor & Shrubb, 1986a & b).

Song thrush and bullfinch have also decreased nationally as a result of agricultural intensification (Gibbons *et al.* 1993; O'Connor & Shrubb, 1986a & b). These two species were discovered at all of the five farms sites (Environmental Resources Management, 1995) and Sage and Robertson (1996) recorded them at 17% and 3% respectively of their survey sites. The unobtrusive habits of bullfinch probably results in the low figure obtained by Sage and Robertson. From these results it can be seen that both species regularly use SRC where it is available and may also be expected to benefit from more widespread planting.

Of the amber list species (less threatened, but still not of favourable conservation status) three bred regularly at Castle Archdale, all incorporating SRC into most territories. Two of these, blackbird and dunnock, are generalist species which occur in a range of habitat types including gardens (Fuller, 1982). They are suffering population declines which are not yet of grave concern (Gibbons *et al.*, 1993; Marchant *et al.*, 1991; RSPB, 1996). The third species, lapwing, is showing a more severe and sustained decline and may yet be added to the red list (Gibbons *et al.*, 1993; Marchant *et al.*, 1991). This species, together with meadow pipit, constitute something of a surprise regarding their associations with SRC. As birds of open habitats they are unexpected, but they fit into a wider picture, which has become apparent during the course of this entire project.

Similar open field species recorded in year 0 SRC during fieldwork for other sections of this report include oystercatcher (*Haemantopus ostralegus*) (an amber list species, successful nesting in East Anglian poplar), yellow wagtail (*Motacilla flava*) (probable nesting at several willow and poplar sites in southern England and recorded as holding territory by Environmental Resources Management, (1995)), skylark (*Alauda arvensis*) (red list, probable nesting at several willow and poplar sites in southern England) and quail (*Coturnix coturnix*) (a red list species, three singing birds in willow and poplar, Devon with other birds reported from Yorkshire). Additionally there have been many records of lapwing on year 0 coppice throughout the British Isles (*pers. obs.*; Sage and Robertson, 1996; Sage *et al.* 1994; Environmental Resources Management, 1995). This suggests that far from excluding birds of open field as might be expected, cut coppice can simulate rough open grassland and provide feeding or nesting habitat for these species. Due to the intensity of modern grassland and arable management this is likely to result in an increase in suitable habitat even where SRC is replacing grassland. In respect of lapwing, it prefers to nest on bare ground adjacent to grasslands where the chicks may feed (Galbraith, 1998; Shrubb, 1990; Shrubb and Lack, 1991). Bare ground is exposed when SRC is cut and at Castle Archdale, as at many other sites, these plots were adjacent to grass leys. Without SRC at this site it is unlikely that lapwing would occur as regularly as the bare ground they need would not be present on this otherwise pasture orientated farm.

It can be seen from Figures 16.5 to 16.12a-d and that the intensively managed grass leys at Castle Archdale were the least favoured habitat present at the site. It was used most by meadow pipit , lapwing and thrushes with no species favouring it. The study of soil invertebrates on a north Devon farm (Section 15) shows that this habitat can hold important numbers of worms and so it is likely that these fields are used for feeding. It is unlikely that any species is able to nest regularly in this exposed and disturbed habitat. It is likely therefore that, as is shown above for the lapwing, grass leys are important habitats only when they are adjacent to suitable nesting areas (hedges or SRC).

This highlights the importance of edge habitats for birds. The interiors of large blocks of uniform habitat are important for specialised but very small numbers of bird species (Weins, 1989). The majority of birds in an agricultural landscape are associated with the edges of habitat features and the interfaces present between two or more adjoining habitats (Arnold, 1983; Weins, 1989). These interfaces are frequent where different land uses are mixed within a landscape. Solid blocks of SRC may provide breeding sites for a relatively few species. When situated in a patchwork of farm woodland, hedgerows and pasture the number of habitat interfaces is high and significantly more species benefit. The distribution maps (Figures 16.6 to 16.12a-d) illustrate how most territories are situated around the edges of blocks of habitat where use can be made of two or more distinct areas. SRC can increase the number of birds on a farm not by providing new, complete territories but by allowing hedgerow territories to be expanded into fields so that more territories may be spaced along the same boundary.

Sage and Robertson (1996) demonstrated a difference in the number of individual birds and species composition of the bird communities using different SRC age classes. Figures 13a-c illustrates that some age class selection was probably occurring at Castle Archdale but that the numbers involved were too small to show this statistically. The patterns of age class use shown by sedge warbler, willow warbler and reed bunting in particularly are typical of the patterns that Sage and Robertson identified. The picture is more confused with the other species and numbers are generally too small to make meaningful conclusions except that lapwing will only use year 0 SRC and that garden warbler will not use this age class.

The benefits which a diverse avifauna bring for growers of SRC may not be immediately apparent. However, Sharples (1997, see section 9) demonstrated that birds nesting in SRC have the potential to consume large numbers of pest species (32% of identifiable items in faecal matter originated from defoliating insects). The two most important consumers of defoliators in the very small sample studied were garden and willow warblers, two species strongly associated with SRC at Castle Archdale. A healthy and varied songbird population may well be an important agent in controlling outbreaks of pests and they certainly do no harm.

Care must be excercised when siting new coppice plantations, they should not replace ecologically valuable habitats such as unimproved wet grassland, for example. However, the increase in bird numbers and diversity which occurs as a result of converting agriculturally intensive (and consequently, ecologically poor) pasture or arable land to energy coppice is certainly to be welcomed at a time when farmland song birds are declining all over the Britain and Ireland. There is grave concern in many quarters regarding this decline and the positive effect that SRC has can only help the image of energy crops in general and SRC in particular. If planted sympathetically so that it links and provides extensions to areas of woodland and hedgerows (the important edge habitats identified above) it can support good numbers of birds which would not otherwise be present.

16.6 References

Arnold, G.W. (1983) The influence of ditch and hedgerow structure, length of hedgerows, and area of woodland and garden on bird numbers on farmland. *Journal of Applied Ecology*, 20: 731-750.

Bibby, C.J., Burgess, N.D. and Hill, D.A. (1992) *Bird Census Techniques*. Academic Press, London.

Cramp, S. and Simmons, K.E.L. (Ed.) (1992) *Handbook of the birds of Europe, the Middle East and North Africa: The birds of the Western Palearctic. Volume 6, Warblers*. Oxford University Press, Oxford.

Enemar, A. (1959) On the determination of the size and composition of a passerine bird population during the breeding season. *Vår Fågelvärld Supplement* 2: 1-114.

Environmental Resources Management (1995) Ecological Assessment of Energy Coppice: Results of Third Year Monitoring Studies, Annexes. *Interim Report to ETSU*. Department of Trade and Industry.

Fuller, R.J. (1982) *Bird Habitats in Britain.* Poyser, London.

Galbraith, H. (1988) The breeding ecology of lapwings *V. vanellus* on Scottish agricultural land. *Journal of Applied Ecology*, 25: 487-504.

Gibbons, D.W., Reid, J.B. and Chapman, R.A. (1993) *The New Atlas of Breeding Birds in Britain and Ireland: 1988-91*. T & A. D. Poyser, London.

Göransson, G (1994) Bird fauna of cultivated energy shrub forests at different heights. *Biomass and Bioenergy*, 6: 49-52.

Kendleigh, S.C. (1944) Measurement of bird populations. *Ecological Monographs* 14: 67-106.

Marchant, J.H., Hudson, R., Carter, S.P. and Whittington, P. (1990) *Population Trends in British Breeding Birds.* The British trust for Ornithology, Tring.

O'Connor, R.J. and Shrubb, M. (1986a) *Farming and Birds.* Cambridge University Press, Cambridge.

O'Connor, R.J. and Shrubb, M. (1986b) Recent changes in bird populations in relation to farming practices in England and Wales. *Journal of the Royal Agricultural Society (England).* 147; 132-141.

RSPB. (1996) *Birds of Conservation Concern*. The Royal Society for the Protection of birds, Sandy.

Sage R.B. & Robertson P.A. (1994) The wildlife and game potential of short rotation coppice in the UK. *Biomass and Bioenergy*, 6: 41-48.

Sage R.B. & Robertson P.A. (1996). Factors affecting songbird communities using new short rotation coppice habitats in spring. *Bird Study*, 43, 201-213.

Sage RB, Robertson PA. & Poulson J G. (1994) Enhancing the conservation value of short rotation biomass coppice - Phase 1 the identification of wildlife conservation potential. *Report of the Energy Technology Support Unit, Department of Trade and Industry.*

Sharples, A. (1997) *A preliminary investigation into the diets of five songbird species frequenting short rotation coppice in the UK: with specific interest in bird predation on defoliating insect pests.* Report submitted for the M.Sc. in Pest Management (Applied Entomology), University College of London and for the Diploma of Imperial College.

Shrubb, M. (1990) Effects of agricultural change on nesting lapwings *Vanellus vanellus* in England and Wales. *Bird Study*, 37: 115-127.

Shrubb, M. and Lack, P.C. (1991) The numbers and distribution of Lapwings *V. vanellus* nesting in England and Wales in 1987. *Bird Study*, 38: 20-37.

Simms, E. (1971) *Woodland Birds*. Collins, London.

Simms, E. (1985) *British Warblers*. Collins, London.

Stone, B.H., Sears, J., Cranswick, P.A., Gregory, R.D., Gibbons, D.W., Refisch, M.M., Aebischer, N.J. and Reid, J.B. (1997) Population estimates of birds in Britain and in the United Kingdom. *British Birds*, 90: 1-22.

Weins, J. A. (1989) *The Ecology of Bird Communities.* Cambridge University Press, Cambridge.

William, A.B. (1936) The composition and dynamics of a beech-maple climax community. *Ecological Monographs* 6: 317-408.

Williamson, K. (1964) Bird census work in woodland. *Bird Study* 11: 1-22.

Appendix A

List of bird species recorded by Sage, Robertson and Poulson (1996) in willow and poplar SRC in Spring 1993.

Species	**% of sites**
Blackbird	69
Willow warbler	52
Chaffinch	48
Wren	38
Robin	34
Pheasant	34
Great tit	34
Starling*	27
Reed bunting	27
Sedge warbler	27
Garden warbler	27
Goldfinch	21
Blue tit	21
Long-tailed tit	17
Wood pigeon*	17
Chiffchaff	17
Song thrush	17
Dunnock	14
Magpie*	14
Swift*	10
Whitethroat*	10
Yellowhammer*	10
Meadow pipit	10
Swallow*	7
Spotted flycatcher	7
Skylark	7
Grey partridge*	7
Blackcap	7
House sparrow	7
Red-legged partridge*	7
Greenfinch	7
Redpoll	3
Pied wagtail	3
Corn bunting*	3
Bullfinch	3
Lapwing	3
Jay	3
Nightingale*	3
Moorhen*	3
Rook*	3
Mistle thrush	3

* Indicates species not recorded in the present study.

Appendix B

Species recorded in the present study but not by Sage, Robertson and Poulson (1994)

Buzzard
Curlew
Grasshopper warbler
Grey wagtail
Kestrel
Mallard
Raven
Siskin
Snipe
Sparrowhawk
Treecreeper
Wheatear
Woodcock

17.0 GAMEBIRD USE OF SRC

17.1 Summary

Gamebirds provide a considerable incentive to plant and manage new woodlands. Previous work under the ETSU/GCT contract B/W5/00277/00/REP indicated that SRC may provide attractive habitat for some gamebird species and could increase the value of the crop.

We investigated the use of SRC species and clones by both pheasants and red-legged partridges at one site, where the planting of distinct blocks seperated by rides, and the presence of both gamebirds in the area, facilitated a statistically rigorous study.

A method using sand quadrats to record gamebird footprints and hence relative use was developed by a student at London University under supervision by The GCT. Each morning during the spring 1995, the movement of these gamebirds into and out of the SRC blocks at the study site was recorded by monitoring footprints in the sand quadrats.

Pheasant footprints were recorded more frequently in the quadrats alongside the willow coppice blocks than the poplar. Certain varieites were more commonly used by the birds but the differences were not significant.

Conversely, partridge footprints occurred more frequently in the quadrats alongside the poplar coppice. These results are consistent with previous observations during extensive surveys of partridges using poplar SRC plots and pheasants using willow.

17.2 Introduction

The pheasant is the most widespread and extensively managed gamebird in the UK. It represents a considerable incentive for landowners to plant and manage small woodlands. Pheasants are often found in or near woodland, particularly in winter and spring. They tend to prefer small or irregularly shaped woods with a high edge-to-area ratio (Robertson 1994). Pheasants make use of various woodland and scrub habitat types during the year and there is evidence that pheasants do use SRC plantations (Sage *et al.*, 1994, Sage and Robertson, 1994, Goransson, 1987).

A predictive model was developed in ETSU B/W5/00277/00/REP (Sage et al. 1994) using measures of woodland vertical structure from which an index of pheasant attractiveness can be calculated on the basis of cover provision. The model suggested that willow SRC was more attractive to pheasants than poplar, and provided suitable winter cover for pheasants comparable with more traditional coppice types within two years of planting. The index of pheasant attractiveness was higher in multi-stemmed coppice hybrids with denser stool spacings and abundant ground vegetation. Sage *et al*. (1994) went on to investigate the effect of these and other variables on pheasant presence and absence at a large sample of sites. Although a considerable amount of useful information on the abundance and distribution of pheasants in SRC was accumulated, no significant trends were identified in the use of different SRC species or age due to site effects. This section describes a study that uses a different approach, by considering selection of willow and poplar varieties by pheasants and red legged partridge,at one site in southern England over several weeks (Baxter *et. al.,* 1995).

17.3 Study site and Methods

17.3.1 Study site

This study used a four hectare trial of short rotation willow and poplar coppice at Westfield Farm, Buckhamshire, established by the Water Research Centre at Medmenham to assess the effect of organic fertilisers on the yield of SRC. The main area of the trial consisted of 40 blocks of different willow and poplar varieties in 10 rows, randomly located. The site was planted in early March 1992, and coppiced in late January /early February 1993. The blocks were separated by broad grassy rides or edge roads (ranging in width from 5 to 10 metres). The tree varieties include: *Salix dasyclados*, *Salix viminalis* 'Bowles Hybrid', *Salix viminalis* x *triandra* 'Q 83', *Populus trichocarpa* x *deltoides* 'Beaupre', *Populus trichocarpa* 'Trichobel' and *Populus trichocarpa* x *deltoides* 'Boelare'.

The site was surrounded by arable land with a tributary of the River Thames running along the south-west edge. Along this edge the external features such as the ride width, composition and distance from the site fence and tributary were uniform. Within the trials, the only features which varied along this edge were the different tree species of SRC, their varieties, their planting layout and their spacings within the blocks. The presence of pheasants in the area and the layout of the SRC plantings were ideal for this study.

17.3.2 Gamebird use assessment method

Sand quadrats were placed in a transect close to the south-west edge of the trials area along the 10 blocks that faced this edge. The transect ran the length of the trial and was located 0.5m from the coppice stools, forming a band 0.5m wide. This was considered appropriate for detecting game bird activity closely related to the particular coppice block, and to limit the effect of the differing tree spacings for each hybrid. The transect was interrupted at each internal ride and for one metre at each corner of the coppice blocks so as to eliminate any edge effects.

A quadrat size of 0.5m x 0.5m was found to be adequate for registering tracks. Two different materials were investigated for recording pheasant and partridge footprints, plastering sand and horticultural (silver) sand. These are compared elsewhere (Baxter *et al.* 1995). Both materials recorded gamebird footprints with sufficient accuracy for identification and the materials were easy to obtain and use in the field. The sand was laid 2 - 3 cm deep on cotton or plastic sheets.

Brown et al. (1987) enabled identification of pheasant prints in this study. Information on the identification of partridge footprints was available in Bang (1974). Once the prints had been recorded, each quadrat was carefully prepared for the next sampling period by removing any marks or colourations and smoothing the sand's surface with a wooden offcut.

Between three and six quadrat were laid adjacent to each block - a total of 48 quadrats that were functioning by the start of the actual sampling period from March 20 to April 3, 1994. The majority were positioned on site for between one and two weeks prior to March 20 to allow wildlife to become accustomed to their presence.

The presence and absence of pheasant and partridge prints were recorded each day between 10.00 and 12.00 for the 11 day sampling period (20 March - 3 April inclusive). If the footprints in any quadrats were not clear enough to identify with accuracy, for instance due to rain washing, this was noted.

Daily means of the proportion of quadrats containing footprints along each SRC block were calculated over the 11 day sample period. These data were then arcsine transformed ($\arcsin\sqrt{x}$) to normalise the distribution and were analysed for each relevant grouping of SRC blocks - SRC hybrid, species (willow or poplar) or spacing. A t-test was used to identify any differences between the groups. All data analysis were carried out using Systat (Wilkinson, 1990)

17.4 Results

The proportion of quadrats with pheasant footprints varied significantly along the transect between the seven different blocks of SRC hybrids (t-test, $F_{6,70}=3.350$; $P<0.01$) (Figure 17.1). The proportion of quadrats with partridge footprints did not vary between the different blocks of SRC hybrids ($F_{6,70}=1.769$; $P>0.1$). the Figure suggests that the pheasant tended to select the willow hybrids and the partidge the poplar.

To investigate this further, the data for all willow hybrids and the poplar hybrids were grouped together and tested for significance. This test confirmed that the proportion of quadrats with pheasant footprints was significantly greater in the willow areas when compared with poplar, ($F_{1,31}=8.621$; $p<0.01$). The proportion of quadrats with partridge footprints was now found to be significantly greater in the poplar area when compared with willow ($F_{1,31}=5.131$; $p<0.05$).

FIGURE 17.1 NOT AVAILABLE ELECTRONICALLY

17.5 Discussion

The method to assess the presence of gamebirds based on footprint information developed in this study, offers an accurate and inexpensive method of assessing how gamebirds use different habitats, especially within small areas. For the Medmenham SRC site, the results indicate that pheasants use willow more than poplar SRC and that partridges use poplar more than willow. Pheasants are traditionally associated with shrubby woodland edges (Robertson 1992) whilst partridges are associated more with open fields. Willow SRC typically has many more stems per stool in comparison with the poplar SRC and hence provides more cover for pheasants. The more open structure of poplar SRC appears to provide a suitable habitat for partridge.

The study suggests selection by pheasants for specific willow hybrids (or poplar by partridge), as predicted by the study of structure (Sage & Robertson 1994, sage et al. 1994) but the results were not significant. It does however seem likely that shrubbier varieites are more attractive to the birds. The red-legged partirdge however appears to prefer the more open conditions found in poplar SRC and this is consistant with the known habitat preferences by this bird.

Willow SRC can be grown as a rapidly established attractive habitat for pheasants, and it is that shrubbier varieites will be more attractive to the birds. With careful design, the supplementary income generated by shooting could significantly improve the overall value of SRC. The layout for holding, driving and flushing birds is particularly important and site specific advice from The GC advisory service is recommended. In general however, maximising the length of the edge and planting a dense belt of a multi-stemmed willow hybrid, combined with establishing and/or managing the edge ground flora, could enhance the attractiveness to pheasants as winter cover (Sage et al. 1994)

17.6 References

Bang P. and Dahlstrom P. (1974). *Collins guide to animal tracks and signs.* Collins, London.

Baxter D.A., Sage, R.B. Hall, D.O. (1995) A methodolgy for assessing gamebird use of short rotation coppice. *Biomass & Bioenergy* 10, 301, 306

Brown R., Ferguson, J., Lawrence, M. and lees D. (1987) *Tracks and signs of the birds of Britain and Europe.* Christopher Helm, London.

Goransson G. (1987). Energy Foresting in Agricultural Areas and Changes in the Avifauna. *Fauna Norv. Ser. C, Cinclus, Supplement 1,* 17-20.

Robertson P.A. (1992) *Woodland Management for the Pheasant.* Forestry Commission Bulletin 106, HMSO, London 4.

Sage R.B. and Robertson P.A. (1994). Wildlife and Game Potential of Short Rotation Coppice in the U.K. *Biomass and Bioenergy,* 6, 41-48.

Sage R.B., Robertson P.A., & Poulson J.G. (1994) *Enhancing the conservation value of Short Rotation Biomass Coppice*; Phase 1: the identification of wildlife conservation potential. ETSU/DTI Report B/W5/00277/REP.HMSO, London.

Wilkinson, L. (1990) *SYSTAT, The System for Statistics.* Systat Inc. Evanstan, Illinois, USA.

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18.0 MAMMALS AND OTHER VERTEBRATES OF SRC

18.1 Summary

No formal survey of mammals, reptiles and amphibians was conducted in SRC during the course of this study.

Anecdotal observations recorded a minimum of ten species of mammal, three of amphibians and one reptile species during fieldwork in SRC 1994-97 inclusive.

A full survey would probably increase the number of mammals recorded but not the numbers of the other non-avian vertebrate groups.

Species that were particularly noticeable in SRC were roe deer, rabbits and brown hare. All three of these species caused local damage to SRC stools through browsing young shoots.

18.2 Introduction

Often nocturnal and secretive and generally without songs or calls to indicate their presence, mammals, reptiles and amphibians are considerably less obvious than birds in the British countryside. Despite this they are still to be found in every habitat throughout the country, including SRC. More than 35 species of terrestrial mammal, introduced and native but not including bats, occur in mainland Britain as well as six reptiles and seven or so amphibians.

A formal investigation of the use made by non-avian vertebrates of SRC was not within the remit of this project. During fieldwork for other sections of this report, however, several mammals and a small number of herpitiles (reptiles and amphibians) were often noticed in and around the crop. This section therefore provides data on the presence and absence of certain species but does not investigate the extent of or reasons for their occurrences.

18.3 Mammals

Table 18.1 List of mammal species recorded from willow and poplar SRC 1994-1997

Species		Willow. Poplar or both
Badger	*Meles meles*	Poplar
Brown Hare	*Lepus capensis*	Both
Common Shrew	*Sorex araneus*	Both
Field/bank vole	*Microtus agrestis/ Clethrionomys glareolus*	Both
Northern mole	*Talpa europaea*	Both
Red fox	*Vulpes vulpes*	Willow
Rabbit	*Oryctolagus cuniculus*	Both
Roe deer	*Capreolus capreolus*	Both
Stoat	*Mustela erminea*	Willow
Wood/field mouse	Apodemus sylvaticus/ flavicollis	Both

Table 18.1 lists the species of mammals recorded from SRC during 1994 to 1997 inclusive. All species were seen except for badger and mole. For the former species an active set was discovered at the edge of a plantation and for the latter, mole-hills were frequently seen. It is likely that several other species use SRC, especially species like hedgehog which are ubiquitous but was not recorded during fieldwork for this project.

Species that were particularly obvious included rabbit which were seen at many sites and roe deer which were often seen although they were even more noticeable due to their browsing activities. Both rabbits and deer caused damage by browsing. This was recorded from both willow and poplar where the young shoots of year 0 stools would be eaten. This damage tended to be very localised and of little consequence except on occasions where only one or two rows of a particularly palatable variety were planted amongst less palatable varieties. These were then so severely and frequently browsed that they sometimes died or at best failed to regained the vigour of unbrowsed adjacent varieties.

Brown hares were also very noticeable with small numbers recorded at most low lying sites in south east England and a few others away from this area. These also left evidence of browsing but this often only amounted to occasional nipped shoots scattered over a wide area - not the localised intense damage caused by the two species already mentioned. Rabbits appeared to be mostly, but not solely, associated with year 0 growth and the edges of plantations whereas roe deer and hares were frequently observed deep within willow and poplar supporting two or three year old growth.

All other species in Table 18.1 were infrequently observed and appeared to cause no, or little damage to the stools. Some growers did suggest that voles may cause damage by eating bark and young shoots. This is possible, but evidence is scant. Bodnor (1995) found that the abundance of small mammals such as wood mouse was affected mainly by the management intensity, and that weedy SRC will contain a greater abundance and diversity of small mammals than weed free plots.

18.4 Reptiles and Amphibians

Amphibians are strongly tied to, usually still, water for egg-laying and although they occur in a variety of damp habitats their distribution is limited by this need for ponds and lakes. A number of common frogs (*Rana temporaria*) and common toads (*Bufo bufo*) were recorded in damp grass in the headland and rides of some of the wetter SRC sites. Common newts (*Triturus cristatus*) were also recorded at the edge of one SRC willow plot. SRC is unlikely to provide good habitat for these species although occasional individuals will continue to appear in selected sites.

Reptiles need areas for basking in the sun. Consequently, they are unlikely to be recorded in the shady conditions created by SRC. Despite this, a grass snake was recorded beneath the canopy of year 2 willow at a site in the south of England.

18.5 Conclusions

The limited observations made indicate that SRC can provide a suitable habitat for a range of species. Roe deer, rabbits and brown hare were noted in particular and were capable of causing local and repeated damage to the crop through browsing the young shoots. Small mammals are associated with weedy SRC plots. Reptiles and amphibians are unlikely to ever use SRC more than occasionally as it does not normally meet their habitat requirements.

18.6 References

Bodnor S. (1995) Small Mammlas in short rotation energy coppice. Unpubl. Report. University of Central England.

19.0 CHANGES IN GROUND FLORA WITH TIME

19.1 Summary

Surveys of the vegetation growing in 21 SRC plantations incorporating 36 individually surveyed plots were conducted in spring 1996. These data were compared with the results of a similar survey at the same sites undertaken in spring 1993. This comparison allowed changes over time in the flora community of a wide range of SRC plantations to be investigated.

Within each plot, five 10 x 1m quadrats were randomly positioned between the rows of coppice stools and the abundances of all the species occurring in the quadrats were recorded.

151 plant species were identified in total during the two surveys. The mean number of species per plot was 13.46 ± 5.66 in 1993 and 13.83 ± 6.57 in 1996 and hence did not differe over the period. The most frequently occurring species was common nettle (*Urtica dioica*) which was recorded in 81% of SRC plots in both years. Eighteen other species were recorded in at least 25% of the plots.

The mean abundances from the five quadrats for each plot constituted one vegetation sample. These samples were classified according to their constituent species using two different schemes. The resultant classifications were used to describe the vegetation and analyse changes over the four years.

The National Vegetation Classification (NVC) was the first scheme used. Samples were classified into NVC types using the program *TABLEFIT*. Three broad types of vegetation were observed, these were tall herb, short ruderal and woodland vegetation communities.

The vegetation samples were also classified using plant ecological strategies (after Grime, 1988) into ruderals, competitors, stress-tolerators and strategies intermediate between these. The vegetation samples were then ordinated using detrended correspondence analysis (*DECORANA*). This enabled the relationships between groups within each of the classification systems and between the two classifications themselves to be more easily visualised.

The results indicate that tall herb communities (consisting of competitive strategists) were associated with SRC plantations in their early years. After this time most ground floras developed into either woodland (stress-tolerant stategists) or sparse ruderal (ruderal strategists) ground floras dependant on the previous land use, the proximity of woodland and crop management.

These factors are related to geographic position - western sites tending to be ex-pasture in more wooded landscapes, eastern sites tended to be ex-arable and often isolated from woods. Consequently, western plantations tend in time to develop a woodland-type ground flora and eastern sites a ruderal weed-type ground flora.

These results have implications for weed management strategies in SRC crops and indicate the types of woodland ground flora communities that could develop in time or which could be introduced.

19.2 Introduction

As with any agricultural crop, weeds are an important consideration. Currently herbicide is regularly applied before planting and after the initial cut-back at the end of the first year's growth. This is regarded as good practice and ensures that the crop gets off to a good start (Clay, 1996; Clay & Dixon, 1996). Herbicide application after subsequent cut-back is less straight forward and little quantitative information was previously available to assess its importance and its effect on the crop. However Section 21.0 of this report describes an important trial that provides information on economic thresholds for herbicide use in estrablished coppice for the first time.

There is great potential for the ground flora to be beneficial to the crop, the grower or both as it often plays a part in supporting natural agents of pest-control (see Sections 13.0 & 20.0), protecting the soil (Section 20.0), providing food and cover for game birds (Sections 17.0 & 20.0) as well as supplementing amenity, conservation and landscape benefits (Section 20.0). There is conversely the potential for ground flora to harm or retard SRC by being too vigorous and competing for resources with the crop (see Section 21.0). If too dense, it may even hamper harvesting machinery.

When discussing naturally occurring assemblages of plant species it is necessary to classify them into groups of similar vegetation types so that they may be compared and so that temporal or spatial changes are easily monitored. Without such a classification system it is difficult to describe vegetation without considering each vegetation sample individually as no two ground-floras are exactly alike (Kent and Coker, 1992). We all classify vegetation using terms like woodland, grassland, marsh or heath. For vegetation classification to be really useful there needs to be more detail than this to reflect the species composition and dominance. There are many means of classifying vegetation samples (two are used within this section together with a method of arranging the vegetation samples in space (ordinating) so that their relationships may be seen (see Section 19.3.2)). These techniques enable the ground flora of SRC plantations to be described in standard terms and so facilitate comparison between sites and between years.

This section examines the types of weed flora that developed in existing SRC plantations over time using surveys of SRC weed flora conducted in 1993 and reported in Sage *et al.* (1994) and repeated in 1996 in over 30 plots throughout the British Isles. The three year gap between surveys allows vegetation progression to be investigated.

The aims of this study were:

1. To identify the plant species which occurred in existing SRC plantations
2. To classify these species into vegetation types (or communities) to facilitate description and comparison
3. To understand the environmental and management factors which dictated the distributions of the different weed communities between the sites
4. To follow the succession of weed communities with time from one vegetation type to another

The objective was to produce recommendations for the management of the weed flora of SRC to the benefit of the crop and wildlife.

19.3 Methods

19.3.1 Collection of the vegetation data

Vegetation surveys were conducted at 29 SRC plantations throughout England, Scotland, Northern Ireland and the Republic of Ireland between 28th April and 4th June 1993 (Sage *et al.*, 1994). The survey was repeated at 21 of these sites between 2nd May and 28th June 1996 (several sites had been grubbed up in the intervening period) incorporating 36 different plots. The survey technique followed standard methods (Southwood, 1978) and used five randomly positioned 10 x 1m linear quadrats in each plot. The quadrats were relatively large so that a large area of ground was surveyed in areas where ground vegetation was sparse and so would have fallen largely outside of smaller quadrats. It was thought that this scenario was likely given the shady conditions below the coppice canopy and the poor weed flora likely to be present due to most SRC sites being ex-arable land which had been regularly sprayed with herbicide. Similarly, more than one quadrat position was essential to gain a balanced picture of the ground flora when surveying an area as large as a coppice plot. Five quadrats were chosen to incorporate the majority of variation likely in one SRC plot but not take a prohibitively long time to survey. The quadrats were linear so that they were easily incorporated between the rows of coppice stools. All plant species occurring within the quadrat were identified with the exception of mosses. Although these are sometimes important in classifying vegetation types, their identification is complex and was considered too time consuming when so many sites needed to be surveyed. For this reason, and because the rather disturbed ground to be investigated was unlikely to possess a well developed moss flora, they were ignored.

Once all the species within the quadrat had been identified, their abundances were estimated and each species given an abundance score. The scoring system was as shown in Table 19.1. The DAFOR system is frequently used and is named after the initial letters of the five abundance classes. We added a sixth class (V) to account for Very rare species which occurred as single small specimens within the quadrat.

Table 19.1. The DAFOR system used to estimate abundance of each species within the survey quadrats

% cover of the species within the quadrat	DAFOR score	DAFOR code
0-1	Very rare	V
1-5	Rare	R
5-10	Occasional	O
10-25	Frequent	F
25-50	Abundant	A
50-100	Dominant	D

The data from the five quadrats within each plot were combined to give a mean abundance for each species for each plot. This data could then be classified into vegetation types so that similarities and differences between sites and years could be investigated and explained. These classifications are complicated and are described below. It is not important to understand how the classification is derived, merely to be able to use the vegetation classes which are the result.

19.3.2 Analysis of the vegetation data

All the data were computerised and analysed using TABLEFIT (Hill, 1996) and DECORANA (Hill, 1994 & Kent and Coker, 1992). The primary ecological strategy of each plant species which occurred in SRC was also identified; species were described in terms of ruderals, competitors or stress tolerators (after Grime, 1988).

Analysis using TABLEFIT and The National Vegetation Classification

TABLEFIT is a computer program produced by the Institute of Terrestrial Ecology (Hill, 1996). It is used by botanists to classify vegetation samples (a list of species for each site with their relative abundances) into pre-named and fully described vegetation types. The classification system it uses is called the National Vegetation Classification (NVC) and was developed at the University of Lancaster (Rodwell 1991a, 1991b, 1992, 1995). The NVC attempts to identify, name and describe all the vegetation assemblages in the UK. In reality it is not always possible to positively identify a vegetation sample as vegetation communities are dynamic entities constantly changing in species composition and relative abundances. Consequently, a plant community may often be between two (or more) NVC vegetation types. TABLEFIT enables the user to analyse a vegetation sample and identify the one or more NVC types it most closely resembles. All vegetation samples from the 1993 and 1996 surveys were analysed using TABLEFIT and the most likely NVC type(s) were identified. These NVC types are described in detail in Rodwell (1991a, 1991b, 1992, 1995) and are a nationally recognised way of describing and analysing vegetation. They allow vegetation samples to be compared with any other throughout the UK. (Another use of the NVC can be found in Section 20.0 where it was used to predict the plant species thought most likely to succeed on introduction into SRC.)

Analysis using DECORANA

Another program commonly used for vegetation analysis is DECORANA which is also produced by the Institute of Terrestrial Ecology. It is not a classification system but can be used in conjunction with the NVC. DECORANA organises data for the purposes of description, discussion and understanding. It is a form of multivariate statistical analysis called detrended correspondence analysis (from which the program name is derived) (Gauch, 1982; Kent and Coker, 1992). This ordinates vegetation samples according to the species which they contain so that the samples may be plotted on axes and represented spatially. In this way vegetation samples which are similar in terms of their species composition will be placed close together in the plotted space and those which are dissimilar will be plotted further apart. If the NVC-types of the plotted vegetation samples are known, their relationship to one another can be viewed easily. In this way, DECORANA and the NVC compliment each other. In the context of this investigation DECORANA enables the relationships between the weed communities of different SRC plots to be viewed pictorially. As a result, the way the vegetation types grade from one type to another can be seen and interpreted in the context of environmental or management factors. This provides an opportunity for understanding the way in which SRC sites may be managed to encourage a particular weed community - perhaps that which competes least with the crop, or that which is of greatest wildlife value. All vegetation samples from the 1993 and 1996 surveys were analysed and plotted using DECORANA. Without this program and the NVC any analysis would be difficult and would involve directly comparing and cross-referencing lists of species for all 36 plots included in the survey.

Analysis using primary ecological strategies

Another classification system uses the primary ecological strategy of individual plants. These are recurrent types of specialisation associated with particular habitat conditions or niches. A recognition of these primary strategies provides a key to understanding the structure and dynamics of communities and ecosystems (Grime, 1988). The C-S-R model developed by Grime (1977, 1979, 1987, 1988) describes plant strategies in terms of the two major external forces which determine them; stress and disturbance. Stress is the restriction of one or more of the resources essential for plant growth (this could be light, water or soil nutrients etc.). Disturbance is associated with the partial or total destruction of vegetative biomass (through, for example, grazing, mowing, burning or ploughing). Within the four permutations of high and low stress and high and low disturbance, there is one which does not permit the growth of plants. This is high stress and high disturbance. The other three permutations result in the three primary ecological strategies of competitor (C), stress-tolerator (S) and ruderal (R) (Table 19.2). These three strategies are the extremes of plant ecology and between them fall the majority of plant species which are intermediate in character.

Table 19.2. The three primary ecological strategies in plants and the environmental conditions which determine them (From Grime, 1977.)

	Low disturbance	**High disturbance**
Low stress	Competitor	Ruderal
High stress	Stress-tolerator	(No viable strategy)

The plant species which fall within each of the three strategies exhibit certain stereotyped characteristics or traits which allow them to survive and reproduce under the specific levels of disturbance and stress which define that strategy. These traits are summarised in Table 19.3. A recognition of these strategies and traits helps us understand the exact mechanisms which determine vegetation communities. From this understanding it is possible to influence existing species composition through appropriate management to produce the conditions which support a more desirable vegetation community.

All the species within each vegetation sample were classified using the terms ruderal, competitor and stress-tolerator (or intermediate terms like stress-tolerant competitive ruderal) as described for each species in Grime (1988). An over all life strategy was assigned to each vegetation sample according to which species were dominant and which life strategies were most prevalent.

Table 19.3 Stereotyped ecological traits displayed by competitive, ruderal and stress-tolerant plants.

	Competitor	**Stress-tolerator**	**Ruderal**
Relative growth rate	High	Low	High
Proportion of annual production given to seeds	Small	Small	Large
Longevity	Relatively short (Biennials/ short-lived perennials)	Long to very long (perennials)	Very short (annuals)
Life form	Herbs, shrubs, trees	Bryophytes, herbs, shrubs, trees	Herbs, bryophytes
Nutrient storage	Nutrients rapidly incorporated into growth. Some storage for rapid spring growth	In leaves, stems and roots	In seeds only
Flowering	Frequent	Intermittent	Very frequent
Common regenerative strategies	Vegetative & seeds	Mostly Vegetative	Seeds only

19.4 Results

19.4.1 General trends and statistics from the species data

One hundred and fifty one plant species were recorded growing in SRC during the 1993 and 1996 surveys (Table 19.4, Appendix 19A)). The species most frequently recorded from SRC during this survey was the common nettle (*Urtica dioica*) which was recorded from 81% of plots in both years. 18 other species were recorded in at least 25% of the plots surveyed in one or both years (Table 19.4, Appendix 19A)). The mean number of species per plot was 13.46 ± 5.66 in 1993 and 13.83 ± 6.57 in 1996. In 1993 this ranged from 3 species at Castle Rising in Norfolk to 24 species at Florence Court and

Castlearchdale in northern Ireland. In 1996 the range was from 4 species at Craibstone near Aberdeen to 31 species at Wick.

19.4.2 Results of analysis using TABLEFIT

The NVC types most likely to represent each vegetation sample are given in Table 19.5 (Appendix 19B). The NVC each vegetation type is represented by a code of letters and numbers and by a name representing the typical dominant species (Rodwell 1991a, 1991b, 1992, 1995). The one or two letters in the code represent the major vegetation type being considered and the subsequent numbers identify exactly which community; e.g. W6d is one of the woodland and scrub vegetation types (W) and the community (6) is *Alnus glutinosus-Urtica dioica* (alder-common nettle community). Further to this is the sub-community (d) which in this case is the *Sambucus nigra* (elder) sub community. The sub-community is not given in Table 19.5 as this level of detail is not reliable for the present data.

The vegetation type code letters which appear in Table 19.5 (Appendix 19B) are as follows; M - MIRES (bog, wet heath, marsh, spring), MG - MESOTROPHIC GRASSLANDS (permanent pastures, meadows etc.), W - WOODLANDS AND SCRUB, OV - OTHER VEGETATION (weed communities and other vegetation types of open habitats). There are other vegetation types which do not occur in the current dataset. TABLEFIT gives a goodness of fit coefficient as part of its output and these are also presented in Table 19.5. A goodness of fit of 60 or more indicates a good match between the data and the species composition of the proposed NVC-type (Hill, 1996). Those below this figure indicate that the sample does not match well and this is likely to be due to the vegetation being poorly established or intermediate between vegetation types. Where the latter is likely, the two or more NVC-types involved are presented in the table.

Three major groups of NVC type are apparent from Table 19.5 (Appendix 19B). These are the weed communities (OV 7, 8, 9, 10, 13, 19, 22) the tall herb communities (OV 24, 25, 27) and the woodland/scrub communities (W 6, 7, 21, 23, 24). A few other communities occur (e.g. MG 9 and 10) but these are very much in the minority and can generally be considered with the tall herb communities. The division of sites into these three main categories is shown in Table 19.6. Figure 19.1 shows the changes in the proportions of these three major vegetation types between 1993 and 1996.

Table 19.6. The classification of each vegetation sample into one of the three broad NVC types (Section 19.4.2) and after Grime *et al.* (1988) in terms of life strategies. C= competitor, R= ruderal, S= stress tolerator, S-C= stress-tolerant competitor, C-R= competitive ruderal, C-S-R= stress-tolerant competitive ruderal

SITE	1993 VEGETATION TYPE	1993 PLANT ECOLOGICAL STRATEGY	1996 VEGETATION TYPE	1996 PLANT ECOLOGICAL STRATEGY
Aberdeen	Tall herb	C-R	Ruderal	C-R
Brahan	Ruderal	C-R	Ruderal	C-R
Broadlaw	Ruderal	C-R	Tall herb	C-R/C-S-R
Buckfast	Woodland	C-S-R	Tall herb	C/C-R
Castle Archdale 1	Woodland	C-S-R	Woodland	C-S-R
Castle Archdale 2	Tall herb	C-S-R	Tall herb	C-R
Castle Archdale 3	Tall herb	C-S-R	Tall herb	C-S-R
Castle Rising 1	Ruderal	R	Ruderal	R
Castle Rising 2	Ruderal	R	Ruderal	R
Dunstal 1	Tall herb	C-R	Ruderal	C-R
Dunstal 2	Ruderal	C-S-R	Tall herb	C-S-R
Dunstal 3	Tall herb	C-R/C-S-R	Woodland	C-S-R
Dunstal 4	Woodland	C-S-R	Woodland	C-S-R
Florence Court	Tall herb	C-R/C-S-R	Tall herb	C-R
Guisachan	Tall herb	C-S-R	Tall herb	C-S-R
Haydon Bridge	Ruderal	R	Ruderal	R
Johnstone Castle 1	Tall herb	C-S-R	Woodland	S-C
Johnstone Castle 2	Tall herb	S-C	Woodland	S-C
Kinsealy	Tall herb	C-R	Woodland	C-R
Loughall 1	Tall herb	C-R	Woodland	C-S/C-S-R
Loughall 2	Ruderal	C-R	Woodland	C-S-R
Mepal 1	Tall herb	C-R	Tall herb	C-R
Mepal 2	Ruderal	R	Tall herb	R
Parbold	Ruderal	C-R	Tall herb	C-R
Peacock	Ruderal	C-R	Ruderal	R
Pond 1	Tall herb	C-S-R	Ruderal	R
Pond 2	Ruderal	C-R	Woodland	C-S-R
Silsoe Clover Hill	Tall herb	C-R	Woodland	C-S-R
Silsoe Pavilion	Tall herb	S-C	Ruderal	R
Stoneleigh 1	Tall herb	C/C-S-R	Woodland	S-C
Stoneleigh 2	Tall herb	C-R	Woodland	S-C
Swanbourne 1	Ruderal	C-R	Woodland	C-S-R
Swanbourne 2	Ruderal	C-R	Woodland	C-S-R
Wick (near railway)	Tall herb	C-S-R	Tall herb	C-S-R
Wick (near road)	Tall herb	C-R	Tall herb	C-S-R
Wishanger	Ruderal	C-R	Ruderal	C-R

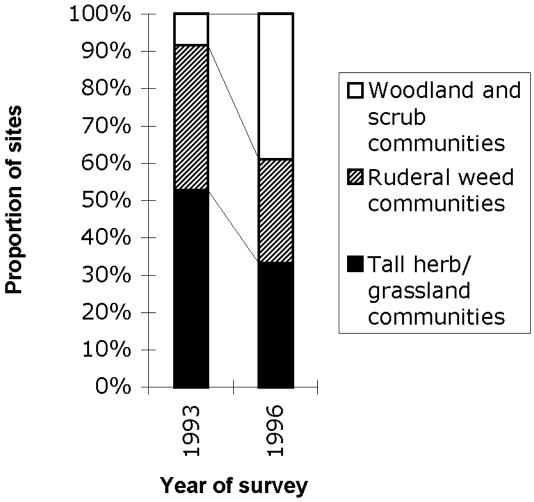

Figure 19.1. Proportion of SRC plots displaying the three main vegetation types in 1993 and 1996.

The vegetation samples were divided into those growing adjacent to woodland and those isolated from it and these two categories were in turn separated into those which had received relatively intensive herbicide treatment and those which had not after the initial establishment period. The proportion of sites in each category displaying each of the three major types of weed flora are illustrated in Figure 19.2. A woodland weed flora developed on over 60% of sites which were both adjacent to woodland and not treated with herbicide after the initial establishment period yet there were no woodland weed floras at sites which were regularly sprayed and which were isolated from woodland. Short ruderal weed communities developed best at sites which were away from woodlands and at sites which were sprayed with herbicide. They did least well at sites adjacent to areas of woodland which were not sprayed.

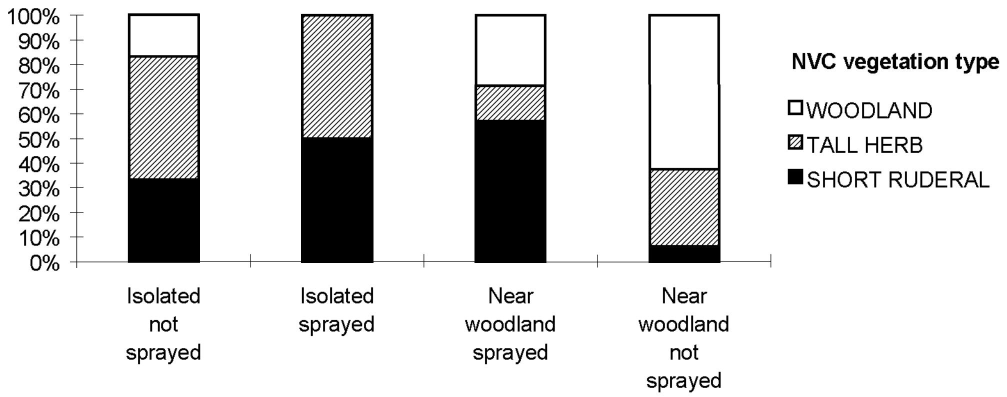

Figure 19.2. The proportion of vegetation samples displaying each of three major vegetation types under different circumstances of woodland proximity and frequency of herbicide application.

Figure 19.3 presents the distribution of the three major NVC types in relation to eastern ex-arable sites and western ex-pasture sites in accordance with Sage et al. (1994). They found a difference in SRC weed flora dependent on the previous land use which tended to be related to geographic position i.e. western sites were ex-pasture and eastern were ex-arable.

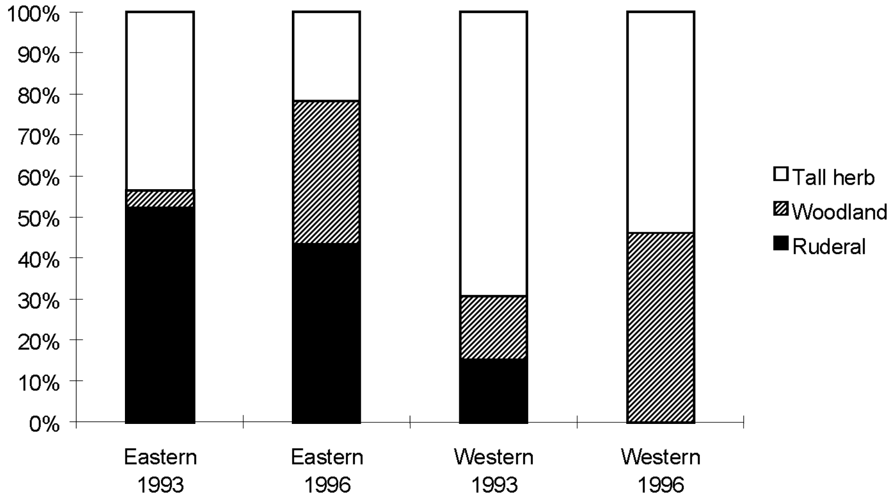

Figure 19.3 The division of "Eastern" and "Western" sites (from Sage *et al.*, 1994) into the three major NVC types

19.4.3 Results of analysis using DECORANA

The ordination (spatial representation) of the vegetation samples is presented in Figures 19.4 to 19.10. All the vegetation samples for both the survey years were analysed together in one ordination and this is shown in Figure 19.4. Subsequent ordination plots (Figures 19.5 to 19.9) show this one plot of vegetation samples broken down into sub-sets (according to survey year or NVC type) and displayed separately to aid understanding. So, although plotted separately, these plots represent the same axes. Figure 19.5 represents the ordinated positions of all the sites in 1993. Figure 19.6 shows the ordinated positions of the same sites in 1996. The distribution of the three main vegetation types identified by TABLEFIT (tall herb communities, woodland communities and small weed communities - see Table 19.6 and Section 19.4.2) are shown in Figures 19.7 to 19.9.

Figure 19.10 is a plot of all the plant species. Each species has co-ordinates (called scores) calculated by DECORANA for positioning in the ordination. It is these species scores which determine the position of each vegetation sample as its position is the mean of the scores of its constituent species. Indicated on Figure 19.10 are the positions of competitors, ruderals and stress-tolerators as identified using analysis of plant ecological strategies (see Section 19.4.4). As few of the species were stress-tolerators, stress-tolerant competitors have also been plotted to illustrate better the stress-tolerant dimension of the plot.

19.4.4 Results of analysis using plant ecological strategies

Grime's classification identifies every species in terms of its established ecological strategy (Grime, 1988) and this classification is presented in Table 19.4. Using this system, each vegetation sample was given an overall ecological strategy derived from the strategies of its dominant plant species. This data is presented in Table 19.6 and illustrated in figures 19.11 and 19.12 in relation to sample year and NVC type.

FIGURES 19.4, 19.5, 19.6, 19.7, 19.8, 19.9 AND 19.10 NOT AVAILABLE ELECTRONICALLY

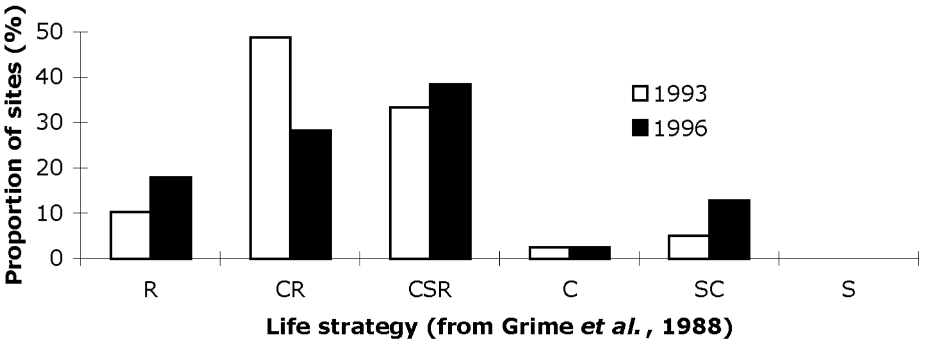

Figure 19.11. Proportion of each life strategy class (*sensu* Grime, 1988) in 1993 and 1996

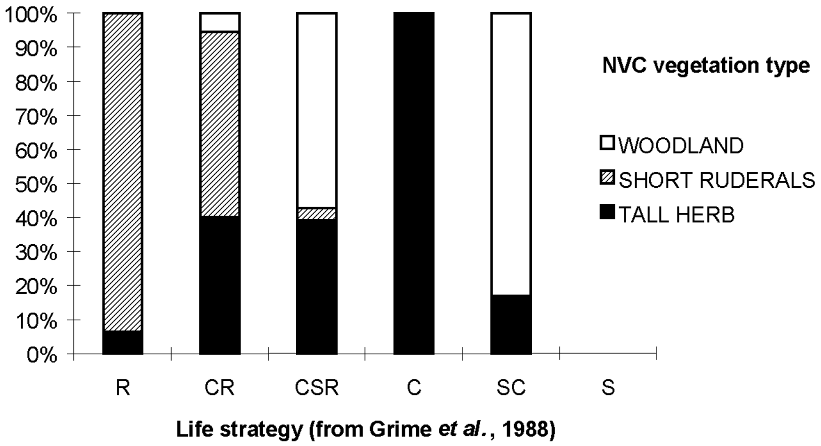

Figure 19.12. Proportion of each life strategy class (*sensu* Grime, 1988) in each of the three major NVC types for both survey years combined.

19.5 Discussion

The total number of species recorded during the two surveys was high; 151 species compared with an estimated 200-300 on all British lowland farms combined (Hill *et al.*, 1995; Potts, 1991). The list (Table 19.4) does not include hedge or headland surveys - only species recorded under the crop towards the field centre. There was individual site variation, however, and the mean number of species per plot was only around 13.5 during both surveys. This is a low figure if considering semi-natural habitats (Hill, *et al.*, 1995) but is high for an agricultural crop (NCC, 1989; Potts, 1991). Despite the mean number of species being almost constant between the two surveys, major changes occurred within the floral composition over the three years with individual species increasing and decreasing.

The species with the greatest change in distribution was rosebay willowherb (*Chamaenerion angustifolium*) which occurred at over 58% of sites in 1993 but only 5.6% in 1996 (Table 19.4). This reflects the maturing of the sites and the perennial nature of the crop which results in undisturbed soils. Rosebay willowherb is a perennial which specialises in colonising bare, disturbed ground (hence its occurrence in younger SRC plantations) (Mabey, 1996; Stace, 1997). It grows quickly and once established can persist vegetatively. It cannot withstand stress and quickly fails in over-shady or dry conditions (Grime, 1988). It is likely that the closing SRC canopy prevents this species from persisting. Common nettle was the most frequent species in both years. This species thrives in phosphate-rich habitats (Mabey, 1996) (for example, its occurrence in lacustrine reed beds is an indicator of eutrophication of the lake's water (Rodwell, 1995)). In SRC it particularly reflects the fact that the crop is often planted on ex-arable land with a legacy of high soil phosphate status.

Grasses also show interesting changes with most perennial species, including meadow grasses (*Poa spp.*), the bents (*Agrostis spp.*) and soft-grasses (*Holcus spp.*), increasing, but arable weed species like couch (*Elymus repens*) and black grass (*Alopecurus myosuroides*) decreasing. Perennial rye-grass (*Lolium perenne*) undertook quite a substantial decline between 1993 and 1996 falling from 25% occurrence to 2.8%. This species is the favoured grass of intensively managed grazing or silage production and in this respect its early high occurrence probably reflected previous or adjacent land use. This grass needs moderate to high soil fertility, frequent grazing or mowing and no shading if it is to persist in a sward (Halley, 1982). All three of these factors change for the worse with respect to rye-grass under coppice management and explain the decrease seen here.

Although it is interesting to consider the changes in frequency of individual species it is not easy to detect the subtle shifts in vegetation which occur using this method. These changes are a product of the different species interacting in response to environmental factors to form communities (e.g. Kent & Coker, 1992; Kershaw & Looney, 1985). If these changes are to be described and the factors affecting change identified, we must first identify the plant communities (Goldsmith & Harrison, 1976; Kershaw & Looney, 1985). None of the classification systems employed by this study is perfect as plant communities are dynamic entities which are continually shifting with regard to the abundances of the constituent species and the presence and absence of different species (Kent and Coker, 1992). Samples may often be difficult to classify because they are intermediate between vegetation types or because human interference makes them atypical (Hill, 1996). By combining the three types of analysis used above it is possible to gain a greater understanding of the weed communities, their development and their ecology than by using one system in isolation (Gauch, 1982).

The National Vegetation Classification is a recognised standard by which vegetation types may be described and compared within the UK (e.g. RSPB *et al.*, 1997; Rushton *et al.*, 1995). Technically, its use in this study was appropriate for UK sites but not Irish ones. However, the Irish flora does not differ from the United Kingdom's so significantly that the NVC would not work for Irish vegetation samples. Figure 19.1 summarises the changes which occurred in NVC type between the two surveys. Initially, over half of the sites displayed characteristics of tall herb communities, specifically OV23, OV24, OV25 and OV27 as well as the mesotrophic grasslands and mire communities MG9, MG10 and M28. It is likely that the nutrient demanding species associated with these vegetation types establish and grow quickly on arable land which still has a high soil nutrient status as a result of previous land use. The plants involved are mostly biennials and perennials such as common nettle, thistles (*Cirsium* species) and willowherbs (*Chamaenerion angustifolium* and *Epilobium* species) which have a chance to succeed in the early years of crop establishment before canopy closure shades them out and soil nutrient status drops. Sites in 1993 that did not support tall herb communities tended to support communities of ruderal weeds such as OV9, OV10, OV13 and OV22. The species involved were mostly annuals like annual meadow grass (*Poa annua*), chickweed (*Stellaria media*), groundsel (*Senecio vulgaris*) and shepherd's purse (*Capsella bursa-pastoris*). Only 8% of sites supported NVC woodland communities.

By 1996, almost 40% of the same sites were identified as NVC woodland communities with a decrease in both tall herb and ruderal weed communities but especially the former (Figure 19.1). The most frequent woodland type was W24 with W6, W7 and W23 also represented. Associated plant species were bramble (*Rubus fruticosus*), Yorkshire fog grass (*Holcus lanatus*), creeping buttercup (*Ranunculus repens*), rough meadow grass (*Poa trivialis*), creeping bent (*Agrostis stolonifera*) and broad-leaved dock (*Rumex obtusifolius*). All of these species are perennials, some rather long-lived and disliking disturbance (Mabey, 1996; Rose, 1981; Stace, 1997).

The DECORANA ordination plots (figures 19.4 to 19.9) illustrate how the weed flora at the sites has diversified with time. This can be seen in the plot for 1996 (Figure 19.6) as a wider spread of the dots compared to that in the 1993 plot (Figure 19.5) which shows a more central core of sites. Remember that these two plots represent different sub-sets of the same ordination and so the axes are the same. Similar samples are plotted close together so we can see that the sites in 1993 were more similar to each other than the same sites in 1996 which have moved apart - the plant communities have diversified. Considering the plots of the individual vegetation types, the ruderal weeds and the woodland communities are almost completely separated from one another (indicating they are dissimilar with regard to species composition) with the tall herb communities providing the link between the two (sharing species with both communities). Given the changes observed in NVC type and the ordination plots in Figures 19.4 to 19.9, it is reasonable to suggest that the sites in this investigation showed a tendency to support tall herb communities early in the lifetime of the crop but that this then tended to develop into either a woodland type flora or that of a ruderal weed community. This is shown by the dense central cluster of data-points representing the (early) sites in 1993 (Figure 19.5) which coincides with the ordinated position of the NVC tall herb communities (Figure 19.7). By 1996 (Figure 19.6), the vegetation has diversified in the wider scatter which coincides more with the woodland and ruderal community positions (Figures 19.8 and 19.9).

Figures 19.10 shows the positions of the extreme plant ecological strategies in the ordination space. This shows that species identified as ruderals by Grime (1988) fall in the same area of the plot as the plant communities identified as short ruderals by the NVC. Similarly, stress-tolerators coincide with NVC woodlands and competitors with NVC tall herb communities. Figures 19.11 and 19.12 also illustrate how different life strategies are important in the different vegetation types. Figure 19.11 indicates that in 1993 when the plots were still young, competitive ruderals (C-R) and stress-tolerant competitive ruderals (C-S-R) were the dominant plant strategies. In 1996 the importance of stress-tolerators was greater with increased C-S-R and stress-tolerant competitors (S-C) and decreased C-R. There was also an increase in ruderals (R).

Comparison of life strategy and NVC type for each sample (Figures 19.10 and 19.12) bears out the observations made using the NVC and DECORANA above. The majority of tall herb communities are predominantly C-R and C-S-R strategists, short ruderal communities are indeed R and C-R strategists and woodland communities tend to be stress-tolerators almost all being predominantly C-S-R or S-C strategists. By comparing this with figure 19.11 it can be seen that the early weed communities are tall herb communities (C-R and C-S-R) later shifting to ruderal (R and C-R) or woodland (C-S-R and S-C) communities.

There may be two reasons for this divergence; the different management techniques occurring at different sites and the composition of the local seed bank influenced by the surrounding habitats (Hill *et al.*, 1995; Wilson & Aebischer, 1995). In a well developed crop in which the canopy has closed a different sort of weed flora must develop from that existing before canopy closure occurs. As we have seen, tall herb communities are mostly competitive strategists and once shaded out will not succeed and will be replaced (Grime, 1988). Given a suitable supply of seed from surrounding areas a shade-tolerant woodland flora may develop.

In the absence of such a seed bank short lived ruderals (annuals which produce large numbers of easily dispersed seed - see Table 19.3) may grow as opportunistic weeds wherever a suitable amount of light reaches the ground. If, however, the management of the SRC has involved repeated applications of herbicide, long-lived woodland perennials will not succeed. Frequently disturbed sites which may be subjected to herbicide treatment or even mechanical weeding will not easily support the long-lived perennial species associated with woodland vegetation types. Short-lived ruderal species can, however, survive in such conditions by utilising the gaps between disturbances to grow quickly and set seed (Grime, 1988). Without these disturbances it is more likely that a relatively stable, long-lived woodland weed flora would develop (Grime, 1988). Figure 19.2 indicates that these two factors may work together to influence the weed flora, a woodland vegetation type being most likely at sites adjacent to woodland which are not regularly sprayed with herbicide.

Sage *et al.* (1994) conducted a simple analysis of the 1993 data in isolation and found that the two most important factors governing the species composition of SRC weed floras were previous land use (pasture or arable which was related to geographic position) and plantation age. This study certainly shows that the weed flora changes with time but also suggests that previous land use is still influential three years later. Figure 19.3 shows the position in 1993 with eastern sites displaying a predominantly ruderal weed community and western sites with a predominantly tall herb community. By 1996 the situation has changed with woodland communities increasing in both the east and west at the expense of the other two communities but still ruderal communities are present at almost half of the eastern sites whilst there are no ruderal sites in the west.

This result is tied to the observations made in the previous paragraph. The western sites tend to have been less heavily treated with herbicides under previous land use and are more frequently situated near to small woodlands or large hedge banks with a woodland flora. (This is due to the topography, geology and land use history of western regions of the British Isles (see e.g. Stamp, 1961; Tansley, 1968.) Consequently the seed bank is available for a woodland type flora to develop, which tends to happen with time. In the east where adjacent woodland is less frequent there is a general movement of the vegetation toward a woodland type flora but this is much slower and the vegetation often tends to “stick” around a ruderal weed flora in the absence of a suitable seedbank.

Some of the weed communities under particular SRC stands vary from the norm and are worthy of individual consideration. These include the plot at Craibstone, Aberdeen. Here the early weed flora was a relic of the previous habitat, being a flag iris-meadowsweet wet grassland (NVC type M28). Most SRC plots are planted on relatively intensively managed agricultural land with a legacy of an arable or grassland weed flora. Despite this different starting point, intensive management of the crop with frequent spraying still produced a sparse ruderal weed flora here by 1996 (less than 5% cover). The site at Buckfast, Devon showed the opposite of many sites moving from a woodland type flora (W24) to a tall herb community (OV25). The starting point is likely to have been achieved by the plot being immediately adjacent to an area of rather lush woodland overlooking the site. Seed supply from this wood is likely to have been high. Early herbicide treatment may have had a limited effect but with continued use a tall herb community developed and it might be anticipated that this will move even further towards a ruderal community given continued herbicide treatment. Sites such as Guisachan, Highland (MG9) and Florence Court, Co. Fermanagh (MG10) were planted in wet areas and their vegetation has not changed. At both sites, canopy closure has been patchy and it is likely that this has allowed the semi-natural wet grassland vegetation to persist relatively unchanged. It is highly likely that the wetness of the site impeded herbicide application and reduced its effectiveness. This then allowed the mesotrophic grassland flora to persist thus hampering the growth of the crop and preventing canopy closure and so ensuring the continued existence of the grassland flora.

This study firstly indicates the importance of weed control at crop establishment (Clay, 1996; Clay and Dixon, 1996). All the sites in this study received weed control at establishment and yet competitive tall herbs were still frequent early in the first rotation. Had the crop not been established well these weeds may have seriously damaged the crop. The sites where tall herb communities continue may well be those where a competitive weed flora overcame the young crop and prevented canopy closure.

If the crop successfully gets through this early stage to canopy closure a low growing annual weed community is likely to develop unless the crop is growing adjacent to established woodland. If this is the case a perennial woodland weed flora may develop (the most likely scenario in western districts). This will be a better flora in terms of its wildlife benefits (see Section 20.0) but may contain species which may be considered undesirable such as bramble. The nature of this vegetation type means however, that areas of bare ground are frequent and the density of the ground vegetation is not high. The mean cover of bramble in the woodland weed floras surveyed was 13%.

If bramble or other potentially troublesome weeds were to become too extensive or dominant at particular sites, herbicide application may occasionally become necessary after cut back. This would not be undertaken as a matter of course and should be a result of regular observation of the state of the weed flora during routine inspection of the crop. An alternative is to introduce a woodland ground flora after establishment of the crop as discussed in Section 20.0. The work described in this Section indicates that these crops provide suitable conditions for these sorts of communities even if they do not naturally occur commonly. By doing this the problem of a poor available seedbank (particularly prevalent in eastern areas) is circumvented and a more suitable woodland ground flora will develop than if this were left to chance. This would lead to the development of a stable ground flora which, as indicated in Section 20.0, could be of benefit to the crop, the grower and wildlife (see Sage *et al.*, 1994 and Appendix 1, Tucker *et al.*, 1997).

19.6 References

Clay D V. 1996. Weed management in short rotation coppice: current status and future requirements. *Report of the Energy Technology Support Unit, Department of Trade and Industry.* 24pp.

Clay D V., Dixon F L. 1996. Report on experiments on weed management in coppice - 1994-1995. *Report of the Energy Technology Support Unit, Department of Trade and Industry.* 89pp.

Gauch H G. 1982. *Multivariate Analysis in Community Ecology*. Cambridge University Press, Cambridge.

Goldsmith, F.B. & Harrison, C.M. Description and analysis of vegetation. In *Methods in Plant Ecology.* Ed. by S.B. Chapman. Blackwell Scientific Publications, Oxford.

Grime J P., Hodgson J G. & Hunt R. 1988. *Comparative plant ecology: A functional approach to common British species*. Unwin Hyman, London. 742pp.

Halley, R. J. (ed.) (1982) *The Agricultural Notebook*, 17th edition. Butterworths, London.

Hill D A., Andrews J., Sotherton N.W. & Hawkens J. (1995) Farmland (chapter 9) in *Managing Habitats for Conservation.* Ed. by W.J. Sutherland & D.A. Hill. Cambridge University Press, Cambridge.

Hill M O. 1994. *DECORANA and TWINSPAN, for ordination and classification of multivariate species data: a new edition, together with supporting programs, in FORTRAN 77.* Institute of Terrestrial Ecology, Huntingdon.

Hill M O. 1996. *TABLEFIT version 1.0, for identification of vegetation types.* Institute of Terrestrial Ecology, Huntingdon.

Kent M. & Coker P. 1992. *Vegetation Description and Analysis: A Practical Approach.* John Wiley & Sons, Chichester.

Kershaw, K.A. & Looney, J.H.H. (1985) *Quantitative and Dynamic Plant Ecology.* 3rd Edition. Edward Arnold, London.

Mabey, R. (1996) *Flora Britannica*. Sinclair-Stevenson, London.

NCC (1989) *The Conservation of Cornfield Flowers*. NCC, Peterborough.

Potts, G.R. (1991) The environmental and ecological importance of cereal fields. In *The Ecology of Temperate Cereal Fields; Proceedings of the 32nd Symposium of the British Ecological Society with the Association of Applied Biologists.* Pp 3-21. Blackwell Scientific Publications, Oxford.

Rodwell J S. 1991a. *British Plant Communities. Volume 1: Woodlands and Scrub.* Cambridge University Press, Cambridge.

Rodwell J S. 1991b. *British Plant Communities. Volume 2: Mires and Heaths.* Cambridge University Press, Cambridge.

Rodwell J S. 1992. *British Plant Communities. Volume 3: Grasslands and Montane Communities.* Cambridge University Press, Cambridge.

Rodwell J S. 1995. *British Plant Communities. Volume 4: Aquatic Communities, Swamps and Tall-herb Fens.* Cambridge University Press, Cambridge.

Royal Society for the Protection of Birds, English Nature and The Institute of Terrestrial Ecology. (1997) *The Wet Grassland Guide: managing floodplain and coastal wet grasslands for wildlife*. RSPB. Sandy.

Sage R.B., Robertson P.A. and Poulson J.G. (1994) Enhancing the conservation value of short rotation biomass coppice - Phase 1 The identification of wildlife conservation potential. *ETSU B/W5/00277/REP*, Harwell Laboratories, Oxford, pp. 44.

Stace, C. (1997) *New Flora of the British Isles*. 2nd Edition. Cambridge University Press, Cambridge.

Stamp, D.L. (1961) *Britain's Structure and Scenery*. Collins, London.

Tansley, A.g. (1968) *Britain's Green Mantle.* 2nd Edition. George Allen & Unwin Ltd, London.

Wilson, P.J. and Aebischer, N.J. (1995) The distribution of dicotyledonous arable weeds in relation to distance from field edge. *Journal of Applied Ecology.* **32**, 295-310.

Appendix 19A Table 19.4 Complete list of plant species recorded in SRC during surveys conducted in 1993 and 1996 with percent occurrence in 36 plots. Also shown is ecological strategy (after Grime, 1988)

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SPECIES		**Ecological strategy**	**% of plots 1993**	**% of plots 1996**
Acer pseudoplatanus	Sycamore	C	5.6	0.0
Aegopodium podagraria	Ground-elder	C-S-R	5.6	0.0
Agrostis stolonifera	Creeping bent	C-R	5.6	16.7
Agrostis tenuis	Common bent	C-S-R	5.6	16.7
Ajuga reptans	Bugle	C-S-R	5.6	2.8
Alopecurus geniculatus	Marsh foxtail	C-R	2.8	2.8
Alopecurus myosuroides	Black grass	C-R	8.3	2.8
Alopecurus pratensis	Meadow foxtail	C-S-R	8.3	2.8
Anagallis arvensis	Scarlet pimpernel	R	2.8	0.0
Angelica sylvestris	Wild angelica	C	11.1	16.7
Anthoxanthum odoratum	Sweet vernal-grass	S-R	2.8	2.8
Anthriscus sylvestris	Cow parsley	C-R	2.8	0.0
Arctium lappa	Great burdock	C-R	0.0	5.6
Arrhenatherum elatius	Oat-grass	C	0.0	2.8
Artemisia vulgaris	Mugwort	C	2.8	0.0
Avena fatua	Wild oat	.	0.0	2.8
Ballota nigra	Black horehound	.	0.0	2.8
Barbarea vulgaris	Wintercress	R	2.8	0.0
Bromus sterilis	Sterile brome	R	2.8	11.1
Calystegia sepium	Hedge bindweed	C	5.6	13.9
Capsella bursa-pastoris	Shepherd's purse	R	13.9	11.1
Cardamine flexuosa	Wavy bittercress	R	8.3	25.0
Cardamine hirsuta	Hairy bittercress	S-R	0.0	2.8
Cardamine pratense	Lady's smock	C-S-R	2.8	5.6
Carex nigra	Common sedge	S-C	8.3	0.0
Carex sylvatica	Wood sedge	S	0.0	2.8
Cerastium fontanum	Common mouse-ear	R	2.8	5.6
Chamaenerion angustifolium	Rosebay willowherb	C	58.3	5.6
Chenopodium album	Fat hen	R	22.2	27.8
Chenopodium murale	Nettle-leaved goosefoot	.	2.8	0.0
Chrysanthemum parthenium	Feverfew	.	0.0	2.8
Cichorium intybus	Chicory	.	2.8	0.0
Circaea lutetiana	Enchanter's nightshade	C-R	2.8	0.0
Cirsium arvense	Creeping thistle	C	52.8	58.3
Cirsium palustre	Marsh thistle	C-S-R	5.6	8.3
Cirsium vulgare	Spear thistle	C-R	36.1	27.8
Clematis vitalba	Traveller's joy	.	0.0	2.8
Conium maculatum	Hemlock	C-R	13.9	11.1
Convolvulus arvensis	Field bindweed	C-R	8.3	0.0
Crataegus monogyna	Hawthorn	S-C	13.9	22.2
Crepis cappilaris	Smooth hawk's-beard	R	5.6	2.8

Dactylis glomerata	Cocksfoot	C	5.6	8.3
Deschampsia caespitosa	Tufted hair-grass	C-S-R	0.0	11.1
Digitalis purpurea	Foxglove	C-R	0.0	2.8
Dryopteris felix-mas	Male fern	S-C	0.0	2.8
Elymus repens	Couch	C	16.7	16.7
Epilobium hirsutum	Great willowherb	C	0.0	2.8
Epilobium montanum	Broad-leaved willowherb	C-S-R	52.8	44.4
Epilobium parviflorum	Hoary willowherb	R	0.0	11.1
Epilobium palustre	Marsh willowherb	S	0.0	8.3
Equisetum arvense	Field horsetail	C-R	2.8	2.8
Equisetum sylvaticum	Wood horsetail	.	2.8	0.0
Filipendula ulmaria	Meadowsweet	C	5.6	5.6
Fraxinus excelsior	Ash	C	2.8	2.8
Fumaria officinalis	Common fumitory	R	5.6	2.8
Galium aparine	Cleavers	C-R	58.3	47.2
Galium mollugo	Hedge bedstraw	.	0.0	2.8
Galium palustre	Common marsh-bedstraw	C-S-R	5.6	2.8
Galium verum	Lady's bedstraw	C-S-R	2.8	0.0
Geranium molle	Dovesfoot cranesbill	R	0.0	8.3
Geum urbanum	Wood avens	S	2.8	2.8
Glechoma hederacea	Ground-ivy	C-S-R	2.8	5.6
Glyceria fluitans	Floating sweet-grass	C-R	0.0	2.8
Hedera helix	Ivy	S-C	5.6	13.9
Heracleum sphondylium	Hogweed	C-R	2.8	2.8
Holcus lanatus	Yorkshire fog	C-S-R	22.2	33.3
Holcus mollis	Creeping soft-grass	C	5.6	11.1
Hordeum murinum	Wall barley		2.8	2.8
Hypericum humifusum	Trailing St. John's-wort	S	2.8	0.0
Hypericum tetrapterum	Square-stalked St. John's-wort	C-S-R	13.9	2.8
Ilex aquifolium	Holly	S-C	0.0	2.8
Juncus articulatus	Jointed rush	C-S-R	0.0	2.8
Juncus effusus	Soft rush	C	16.7	30.6
Lamium album	White dead-nettle	C-R	11.1	11.1
Lamium purpureum	Red dead-nettle	R	2.8	8.3
Lapsana communis	Nipplewort	R	8.3	8.3
Lathyrus pratensis	Meadow vetchling	C-S-R	13.9	0.0
Lolium perennne	Perennial rye-grass	C-R	25.0	2.8
Lonicera periclymenum	Honeysuckle	S-C	0.0	2.8
Lychnis flos-cuculi	Ragged robin	C-S-R	2.8	2.8
Lysimachia nemorum	Yellow pimpernel	S	2.8	0.0
Lysimachia nummularia	Creeping jenny	C-S-R	0.0	2.8
Matricaria matricaria	Pineapple weed	R	8.3	0.0
Mentha aquatica	Water mint	C	0.0	5.6
Myosotis arvensis	Field forget-me-not	R	11.1	16.7
Myosotis caespitosa	Tufted forget-me-not		0.0	2.8
Myosotis scorpoides	Water forget-me-not	C-R	5.6	0.0
Myosotis sylvatica	Wood forget-me-not		0.0	2.8
Papaver rhoeas	Field poppy	R	2.8	0.0

Phleum bertolonii	Smaller catstail		2.8	5.6
Phleum pratense	Timothy	C-S-R	0.0	5.6
Picris echinoides	Bristly oxtongue		0.0	2.8
Plantago lanceolata	Ribwort plantain	C-S-R	2.8	0.0
Plantago major	Great plantain	R	2.8	2.8
Poa annua	Annual meadow-grass	R	27.8	36.1
Poa pratense	Smooth meadow-grass	C-S-R	0.0	11.1
Poa trivialis	Rough meadow-grass	C-R	30.6	44.4
Polygonum amphibium	Amphibious bistort	C-R	0.0	5.6
Polygonum aviculare	Knotgrass	R	0.0	11.1
Polygonum convolvulus	Black-bindweed		0.0	13.9
Polygonum persicaria	Redshank	R	19.4	11.1
Potentilla anserina	Silverweed	C-R	5.6	5.6
Potentilla reptens	Creeping cinquefoil	C-R	2.8	5.6
Pteridium aquilinum	Bracken	C	2.8	0.0
Quercus seedling	Oak seedling	S-C	11.1	0.0
Ranunculus acris	Meadow buttercup	C-S-R	13.9	5.6
Ranunculus flammula	Lesser spearwort	C-R	2.8	5.6
Ranunculus repens	Creeping buttercup	C-R	55.6	58.3
Raphanus raphanistrum	Wild radish	R	0.0	2.8
Rosa arvensis	Field rose	S-C	5.6	0.0
Rosa canina agg.	Dog rose	S-C	0.0	2.8
Rubus fruticosus	Bramble	S-C	33.3	44.4
Rumex acetosa	Common sorrel	C-S-R	13.9	8.3
Rumex conglomeratus	Clustered dock	C-R	5.6	0.0
Rumex crispus	Curled dock	R	27.8	25.0
Rumex obtusifolius	Broad-leaved dock	C-R	52.8	38.9
Sambucus nigra	Elder	C	11.1	25.0
Sanicula europaea	Sanicle	S	2.8	0.0
Saxifraga granulata	Meadow saxifrage		0.0	2.8
Scrophularia nodosa	Common figwort	C-R	0.0	2.8
Senecio aquaticus	Marsh ragwort	R	2.8	0.0
Senecio jacobaea	Common ragwort	R	19.4	8.3
Senecio vulgaris	Groundsel	R	22.2	36.1
Sinapsis arvensis	Charlock	R	8.3	0.0
Sisymbrium officinale	Hedge mustard	R	8.3	2.8
Solanum dulcamara	Woody nightshade	C	0.0	8.3
Solanum nigrum	Black nightshade		2.8	0.0
Sonchus arvensis	Perennial sowthistle	C-R	11.1	11.1
Sonchus asper	Prickly sowthistle	R	27.8	16.7
Sonchus oleraceus	Smooth sowthistle	R	16.7	11.1
Stachys palustris	Marsh woundwort	C-R	8.3	0.0
Stellaria alsine	Bog stitchwort	C-S-R	2.8	0.0
Stellaria media	Common chickweed	R	8.3	19.4
Symphytum officinale	Comfrey	C	5.6	5.6
Tamus communis	Black bryony	C	0.0	2.8
Taraxacum officinale agg	Dandelion	R	27.8	36.1
Trifolium pratense	Red clover	C-S-R	2.8	0.0
Trifolium repens	White clover	C-R	11.1	5.6
Triplospermum inodorum	Scentless mayweed	R	0.0	16.7

Ulex europaea	Gorse	S-C	5.6	2.8
Urtica dioica	Common nettle	C	80.6	80.6
Urtica urens	Annual nettle	R	2.8	8.3
Valeriana officinalis	Common valerian	C-S-R	2.8	0.0
Veronica agrestis	Green field-speedwell	R	0.0	2.8
Veronica beccabunga	Brooklime	C-R	0.0	2.8
Veronica persica	Common field-speedwell	R	0.0	5.6
Veronica polita	Grey field-speedwell	R	0.0	2.8
Veronica serpyllifolia	Thyme-leaved speedwell	R	13.9	5.6
Vicia sativa	Common vetch	R	2.8	5.6
Vicia sepium	Bush vetch	C	0.0	5.6
Viola arvensis	Field pansy	R	2.8	8.3

20.0 INTRODUCING WILD FLOWERS INTO SRC

20.1 Summary

A stable, low-competition ground flora in SRC plantations could provide benefits to wildlife, amenity, landscape and crop protection and hence contribute to an integrated crop management strategy for SRC.

In Section 19, we found that SRC plantations could provide suitable conditions for a slow growing perennial woodland ground flora but that this was unlikely to occur unless a suitable colonisation source existed nearby. In this section we consider an introduced flora.

The environmental conditions which existed below the coppice canopy were investigated. Introduced species needed to be shade tolerant. A list of shade tolerant and slow growing species that provided other benefits such as food for beneficial insects was developed. From this list, 18 species were selected for a replicated introduction trial in two willow plantations at Roves Farm in Wiltshire.

> The establishment and spread of the introduced species was monitored for three growing seasons, i.e. over one rotation. All other species occurring as weeds were also monitored to assess the effectiveness of the introductions to suppress weeds.

Six species achieved a cover of more than 5% within the introduction plots in the first season and eight species spread outside of the one metre square introduction plots by the third year and in total 59% of the introduced species increased from year 1 to year 2.

The weed flora of the introduction plots decreased in cover and the amount of bare ground increased due to shading

over the period. Almost all introduced species flowered and potentially set seed within the first two years. It is argued that as the introduced flora increased it occupied areas of bare ground and so will prevent weed species from germinating there in subsequent years. This will eventually lead to a decrease in the incidence of weeds overall.

20.2 Introduction

SRC tends to be planted and grown on improved land and consequently the weed flora below the coppice canopy is often impoverished and consists mainly of arable weeds such as cleavers (*Galium aparine*), redshank (*Polygonum persicaria*), thistles (*Cirsium* spp.), couch grass (*Elytrigia repens*) and willowherbs (*Epilobium* spp.) (see Section 19.0, Sage, 1995 and Sage, Robertson & Poulson, 1994). It is important to control these weeds at establishment of the crop to maximise growth and to prevent losses and consequently the planting bed is well prepared and treated with herbicide before and after planting with residual and contact herbicides (Clay, 1996. Clay & Dixon. 1996). Once the stools have established, however, it may be desirable to encourage a stable ground flora to develop under the crop for a number of reasons. These reasons are discussed in detail in Tucker, Sage & Buckley (1997, *Introducing other plants into short rotation coppice willow*). In summary a stable ground flora may provide:

- protective ground cover
- a nectar source for insects
- bird nesting cover
- a food source for butterfly larvae
- a food source for game and song birds
- amenity and landscape value

Combined, these factors may also enhance the public perception of SRC and energy forestry so benefiting the industry as a whole.

Plants suitable for growth in the conditions beneath the canopy of SRC may take many years to colonise the crop by natural dispersal from surrounding areas (Wilson & Aebischer, 1995; Kerr, Harmer & Moss, 1996). The species concerned are woodland and hedgerow plants which thrive in shaded conditions (Grime, Hodgson & Hunt, 1988 and Kershaw & Looney, 1985). These species tend to be slow growing and compete little with the crop. If there are no woodlands or suitable hedgerows adjacent to an area of SRC, colonisation may take a very long time indeed (see Section 19.0, Kerr, Harmer & Moss, 1996, Sage, 1995). Consequently, if shade tolerant plant species are desired in SRC crops, they should be introduced.

This section discusses our attempts to introduce plants into an SRC plantation and the success of these introductions. The experimental design and results from the first year of the work are described in Tucker, Sage & Buckley

(1997). This and subsequent years' work is described here in more detail. The aims of this study were:

- to identify a range of plant species which, by means of their growth habit and habitat preference may suit introduction into SRC
- to identify which of these have the most potential to provide the benefits listed above
- to introduce these species into SRC willow plantations and to monitor their survival and propogation

The objective of this work is to devise an inexpensive "wildflower" seed mix suitable for introducing beneath an SRC crop which would produce conservation, landscape and amenity benefits as well as direct benefits to the crop.

20.3 Methods

20.3.1 Site selection and site characteristics

The trials sites for this study needed to contain large plots of willow coppice due to be cut during the winter 1994/1995. We also required soil conditions that were representative of the relatively heavy, poorly drained and slightly acidic soils that are typically planted with willow SRC crops in Lowland Britain. The plantings at Roves Farm, North Wiltshire owned by Rupert Burr were ideal. Two willow plantings, about 2 km apart, were used (Figures 20.1, 20.2 & 20.3). The first field, 'Stepstones' (8 ha), was a level, low lying piece of ground. The second field, Clay Furlong (4.5ha), had a slight slope from west to east, the eastern end of the field being the low point. Both fileds contained clay or clay loam soils with a high moisture retention capacity.

Both fields were strip planted with around ten - twelve willow hybrids each (Figures 20.2 & 20.3) in winter 1993/1994 and were cut-back in early 1995. Clay Furlong also contains an area planted with poplars. The fields have undergone similar management regimes, being sprayed in the year of establishment with 4 litres of Simazine and 5 litres of Pendamethalin (Stomp) per hectare. A soil analysis of both fields was undertaken and summer weed surveys and autumn weed seed counts were conducted on both fields. The soil sampling and analysis and weed seed counts were undertaken by a student at London University, Wye College in 1995.

20.3.2 Measuring crop shadiness

Survey work undertaken during summer 1994 provided information on the leafing periods and expected shadiness of SRC crops, to assess the suitability of certain shade tolerant plants to the crop.

Measures of shadiness within SRC crops were recorded at all sites where invertebrate sampling was undertaken. The percentage of active radiation (PAR) filtering through the crop canopy was measured using a hand held-light meter within the crop, linked to a tripod-held meter stationed, not shaded, outside of the crop. The difference between light levels at the two meters was calculated and expressed as a percentage. The method is described in detail in Section 5.0 and allows comparison with other work on the tolerance of plants to shade.

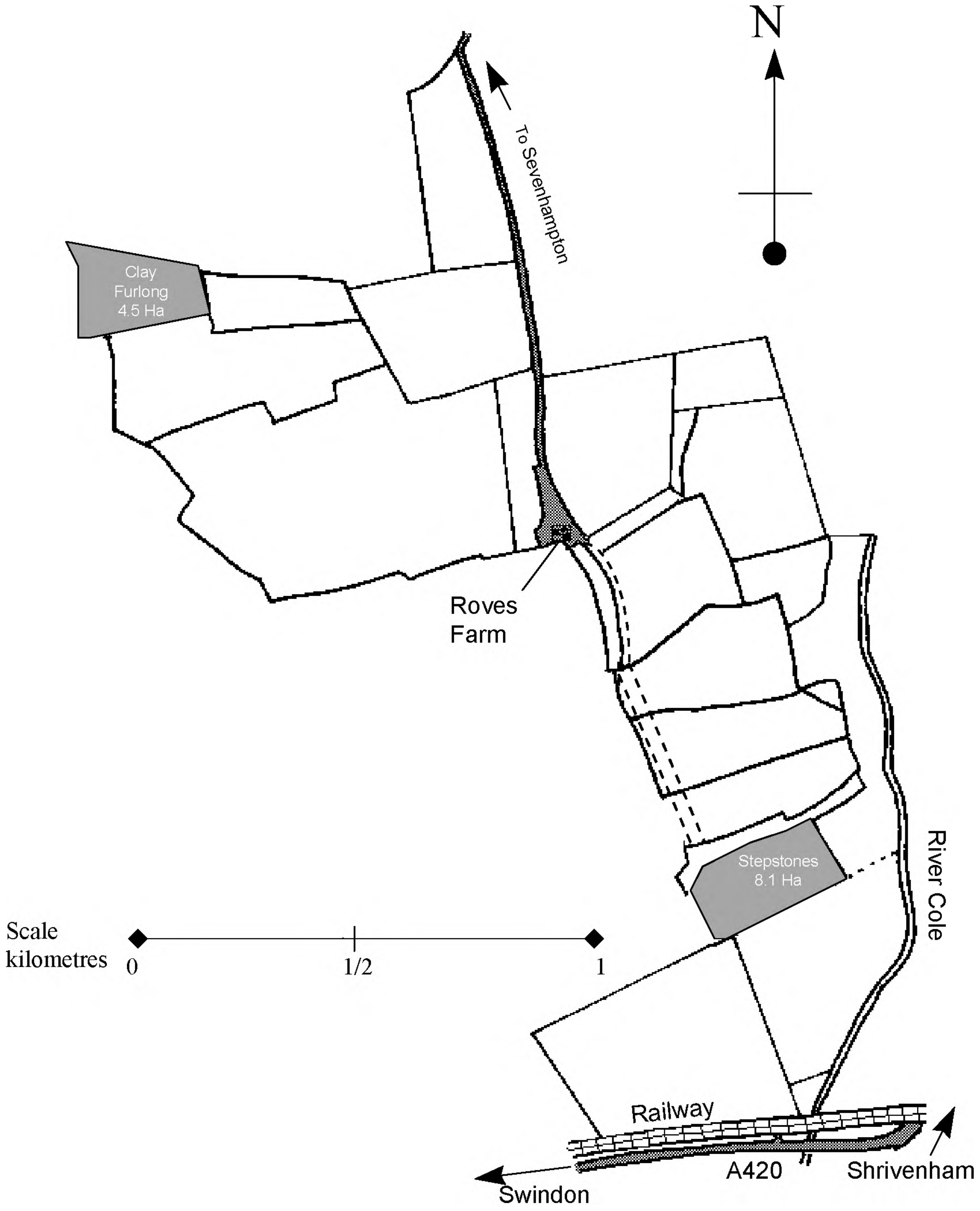

Figure 20.1 Field plan of Roves Farm, Sevenhampton, Wiltshire showing the two fields which contained the flora introduction trials.

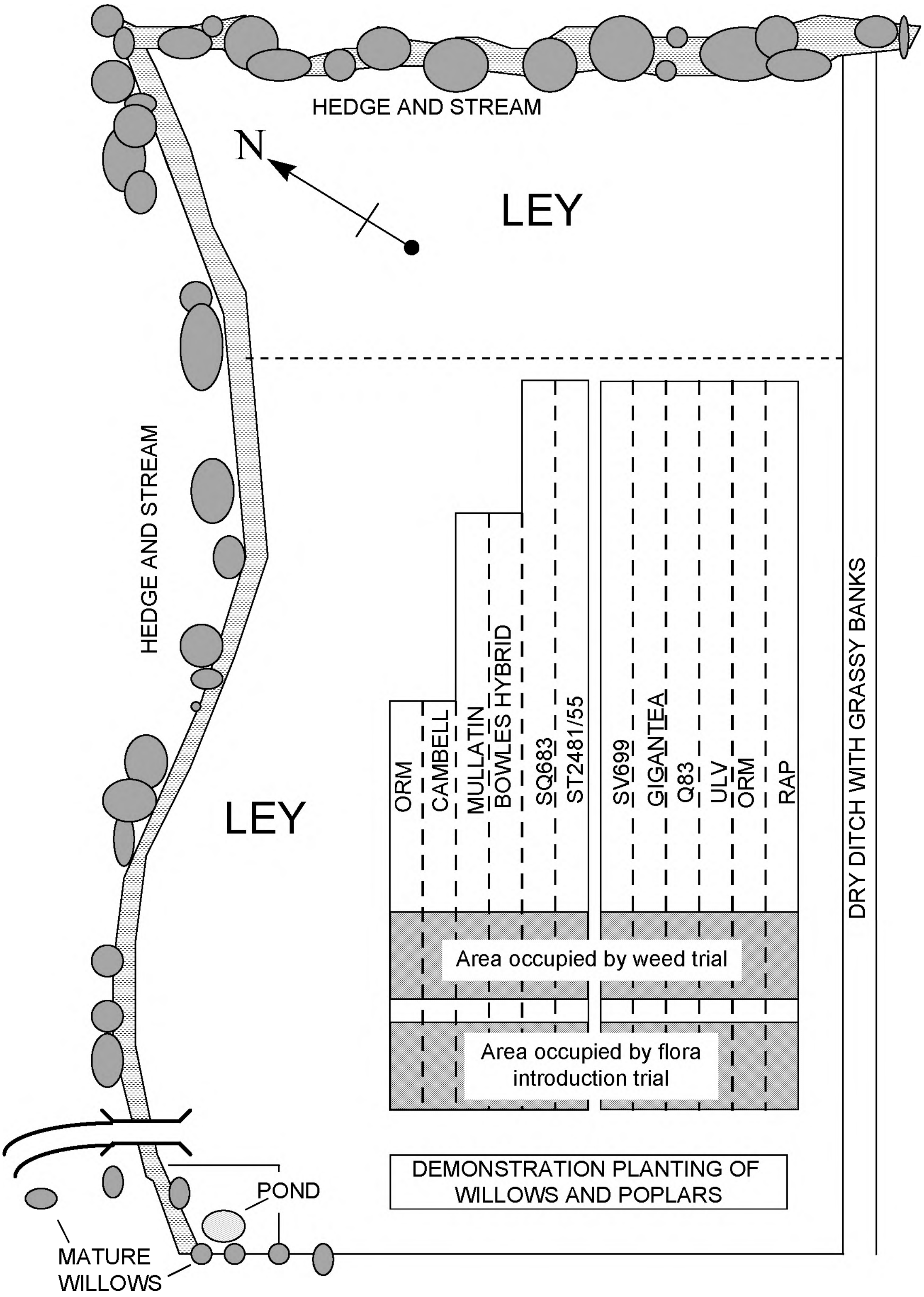

Figure 20.2 General layout of Stepstones field showing positions of the flora introduction trial and the weed effect trial (Section 21).

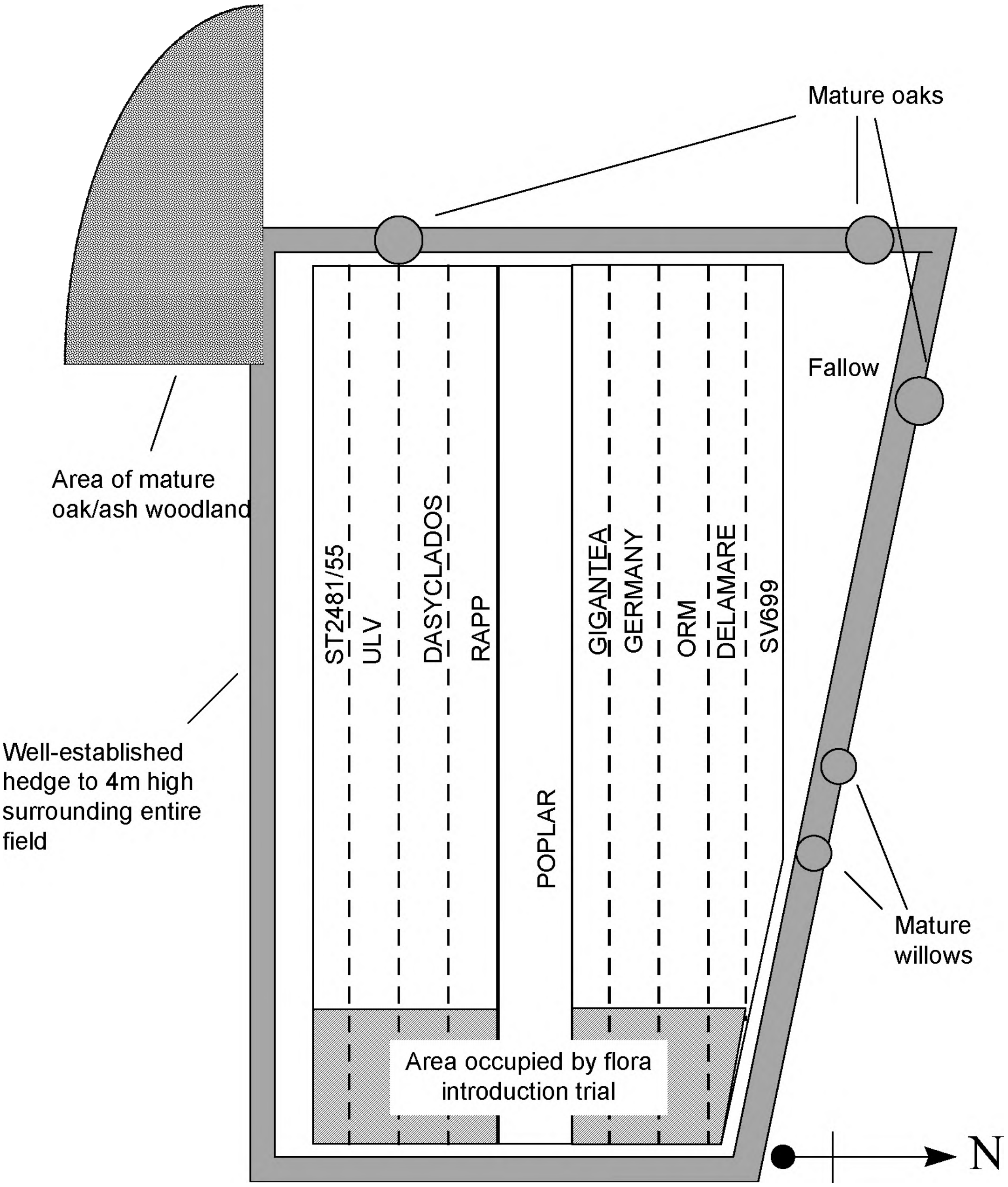

Figure 20.3 General layout of Clay Furlong field showing the position of the flora introduction trial

20.3.3 Plant species selection

A basic list of shade tolerant native plants was compiled from standard floras of the British Isles. This list was used as the basis for selecting species suitable for introduction. The selection of species was supervised by Dr Peter Buckley of London University, Wye College. It was divided into three categories; *within crop* for the true woodland species suited to very shady conditions, *crop edge* for woodland ride and glade species suited to less shady conditions and *headlands and rides* for those species adapted to the kind of conditions exhibited by open scrub and so suitable for the more open areas formed by the rides around the crop edge. The list was further narrowed to those known to occur in NVC woodland W8 (*Fraxinus excelsior-Acer campestre-Mercurialis perennis* woodland) (see Section 19.0 and Rodwell 1991a&b, 1992 & 1995 for an explanation of the NVC). This vegetation type was used as it best represents the woodland type which would occur naturally at the chosen site given its geology, topography and climate. The species in the final list each provided wildlife and amenity benefits in one or more ways as described below:

a) Ground vegetation can encourage predatory invertebrates into the crop and thereby help to control pest species
b) Ground cover can be important for nesting birds either directly by providing nest sites or as a food source. Species involved include gamebirds (particularly pheasants) which can provide additional farm income for those growers with a shooting interest (Sage *et.al.* 1994). Other species may help control pests, as even seed-eating birds need to feed their young with protein-rich invertebrate food (Section 9.0).
c) Plants producing nectar can be important for many insects including butterflies and parasitic hymenoptera. The latter are important control agents of many pest species and may thus be beneficial if encouraged into the crop (Section 9.0)
d) Many woodland grasses produce seeds which are eaten by birds, including pheasants
e) Certain plant species are food-plants for the larvae of woodland butterflies which are becoming increasingly threatened
f) A good covering of ground vegetation may consolidate the soil and so help prevent smearing and compaction during harvesting operations. This might also reduce the number of germination sites for more vigorously growing weed species

Ultimately the final list was modified to those species of NVC W8 woodland (Section 20.0) which displayed one or more of the wildlife and amenity benefits above and which were easily obtainable from wildflower seed merchants. Price was not considered critical as the high cost of many wild flower species represents the low demand that there is for them. Should a demand be created, costs are likely to lessen.

20.3.4 Plot design and preparation

The willow SRC in the two trial plot areas was cut by hand during early February 1995 and the trial squares marked out with white pegs. The trial layout was designed to assess the ability of each plant species to germinate and establish in the crop, both in the presence and absence of weeds, and then to colonise new ground, again both in the presence and absence of existing weeds.

Each of the seventeen species was planted or seeded into ten separate quadrats except for *Primula vulgaris* which was both seeded and planted as seedlings separately. There were, therefore, effectively eighteen species being introduced (see Section 20.3.3). The two fields at Roves Farm therefore contained a total of 180 within crop trial quadrats covering an area approaching 1ha (Figures 20.2 & 20.3). Each quadrat consisted of an 8m x 1m linear quadrat divided into 1m squares, two of which were seeded/plug planted (Figure 20.4). The quadrats were placed in the inter-row spacings. Two squares, one weeded and one unweeded, were seeded/plugged in each quadrat. Either side of each seeded/plugged square, another square, again either weeded or unweeded was left to quantify colonisation. Each block of three squares was separated by a ‘blank’ square. In adjacent rows of the crop the quadrat starting points were staggered by 2m to ensure that a minimum distance of 3m was maintained between each seeded plot.

20.3.5 Sowing and planting

It was intended to sow the seed and plant the plug plant seedlings in the autumn of 1994. Unfortunately heavy rain throughout the whole of that autumn and winter delayed the operation until March 1995. Prior to this time there was much standing water in the plots and seeds in particular would not have been successful. The summer subsequent to the introduction of the plants and seed was the driest for many years with drought conditions over much of the UK until the autumn. Consequently, germination and establishment was poor and so seed and plug plants were re-introduced in the autumn of 1995 into one plot in each of the paired plots. The decision to only sow one plot was based on the excessive costs of repeating this exercise. Consequent to this, studying the effect of weeds on establishing introductions was abandoned as there was no longer a paired plot design in operation.

Seeds were sown on both occasions by broadcast (using a 1m^2 box to prevent sowing beyond the square). The quantity of seed used for each species was calculated by Dr Peter Buckley to give a similar potential covering of 250 young seedlings per m^2, taking into account the average germination potential and conversion to seedlings for the particular species. Sowing rates are shown in Table 20.1. For the plug plants, five plugs were planted into each square in the pattern of a five on a dice with one central

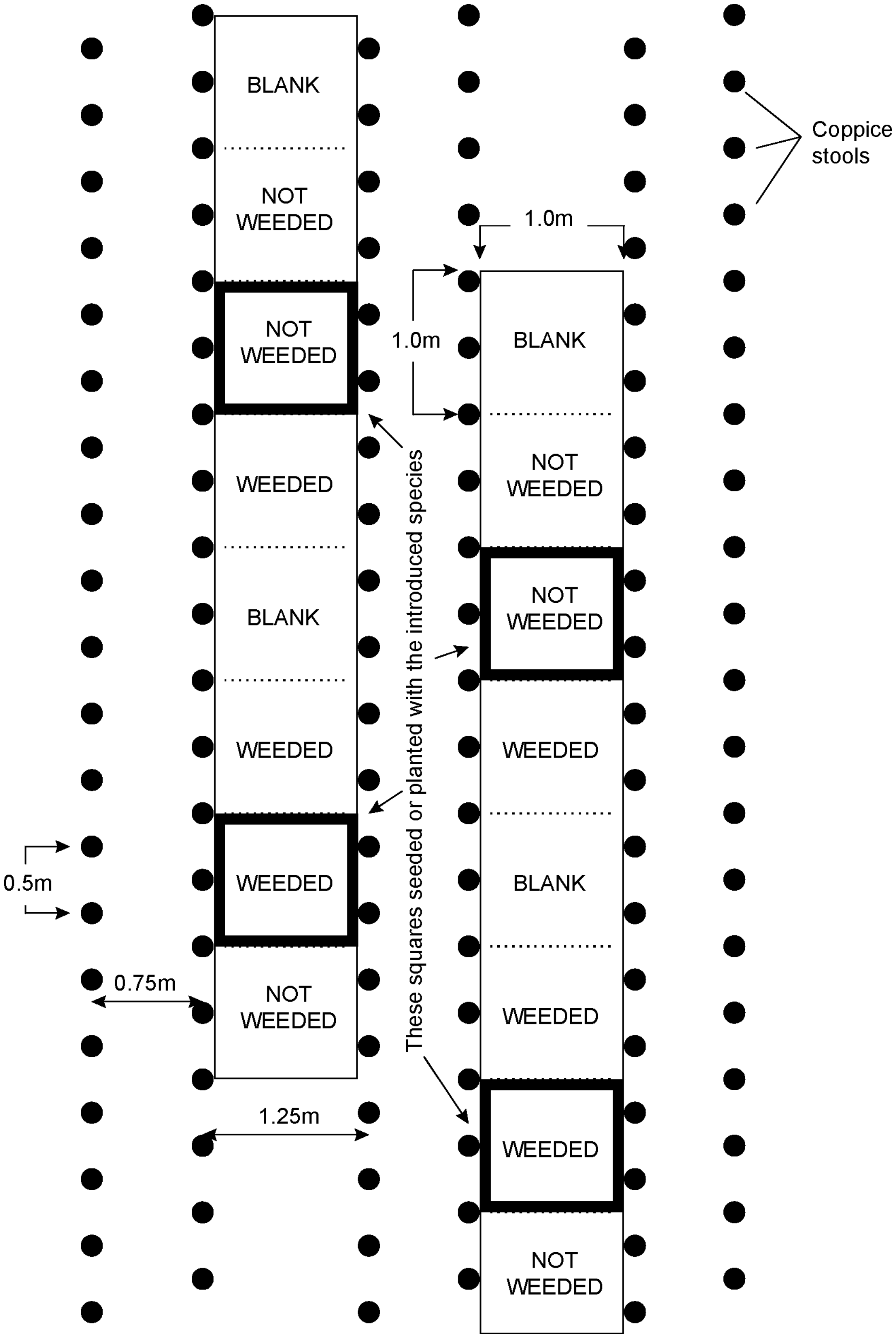

Figure 20.4 The layout of the introduction trial plots showing the regime of weed control in and around the $1m^2$ introduction area.

plug. No ground preparation (other than weeding in the weeded squares at the first sowing/planting) was undertaken before or after sowing/planting.

20.3.6 Monitoring

Monitoring, to record the establishment and spread of the introduced species, was started in spring 1996 and continued each spring until 1998. Monitoring involved estimating the percent cover of each introduced species and counting the number of plants surviving (for plug plants) or seedlings germinated and surviving (seeded plots) unless the number of seedlings was so great as to make this impractical, in which case only percent cover was recorded. The percent cover of bare ground and all other plant species present within the plot was also recorded as was any anecdotal evidence of flowering and seed set by the introduced species.

In the 1996 survey, comparisons were made between the plots which were sown/planted in spring 1995 only and those which were sown/planted in both spring and autumn 1995. In 1997 and 1998, the survey covered only those plots which were both spring and autumn sown/planted.

Changes over the three year study period in the abundance of ground cover for the introduced species, the ground cover of weed species, and the proportion of bare ground in the plots was investigated using repeated measures analysis of variance (Systat, Wilkinson, 1990). The analysis considered all species together but identified whether trends were different between species.

20.4 Results

20.4.1 Site characteristics

The soil analysis undertaken At Wye College, London University, indicated an average pH of 5.9 (range 5.1-6.2) in Stepstones and 5.9 (5.7-6.3) in Clay Furlong. The soil in both fields was a silty clay although in Clay Furlong it tended towards a silty clay loam in places. Both fields, but particularly Stepstones, contained some weeds, especially Redshank (*Polygonum persicaria*), Cleavers (*Galium aparine*), Creeping thistle (*Cirsium arvense*), Black-grass (*Alopecurus myosuroides*) and Couch (*Elytrigia repens*). Analysis of the weed flora composition in both fields after one year under SRC revealed the major vegetation type to be National Vegetation Classification (NVC) OV33 (*Persicaria* muddy weed community). After a further year under coppice the vegetation had shifted in Clay Furlong to NVC OV25 (*Urtica dioica-Cirsium arvense* tall herb community) and in Stepstones to OV25 with a strong influence of OV22 (*Poa annua-Taraxicum officinale* weedy grass community) (see Table 20.2.). More permanent areas such as headlands and pasture not under an arable regime adjacent to the plots tended to be NVC MG6 (*Lolium perenne-Cynosurous cristatus* mesotrophic grassland).

Were woodland to develop at the site, vegetation precursors, geology, climate and geographical position suggest a woodland NVC predominantly of W8 (*Fraxinus excelsior-Acer campestre-Mercurialis perennis* woodland), with some elements of W10 (*Quercus robur-Pteridium aquilinum-Rubus fruticosus* woodland), W2 (*Salix cinerea-Betula pubescens-Phragmites australis* scrub) and W14 (*Fagus sylvatica-Rubus fruticosus* woodland).

20.4.2 Crop shadiness

The mean PAR of different SRC plots (varieties and age classes) at the large sample of survey sites are shown in Section 5.0, Figure 5.1 and in the Stepstones field on a by-variety basis in Figure 5.2. The mean PAR for the Stepstones field, with year two willow coppice was 6.8 %.

20.4.3 Species selection

The initial list of shade tolerant plants is presented in Appendix 20A. This list formed the basis for choosing the exact composition of the final list for introduction. The final list of species was selected according to NVC type, suitability in terms of amenity and wildlife value and availability from seed merchants is presented in Table 20.1. Below is a description of each species outlining its phenology and notable features.

Ajuga reptans Bugle
Flowers May to June. Height 10-30cm.
A low growing, creeping perennial woodland herb. Highly shade-tolerant and producing flowers favoured by bees and butterflies.

Alliaria petiolata Hedge Garlic.
Flowers April to July. Height 20-120cm.
Leafy biennial ground cover most important as the larval food plant of the orange tip butterfly(*Anthocharis cardamines*).

Brachypodium sylvaticum Wood False-brome.
A shade-tolerant perennial grass which can easily survive periods of higher light intensity. Tall with a tufted growth form. Produces ample seed.

Circaea lutetiana Enchanter's Nightshade.
Flowers June to August. Height 20-70cm.
Perennial woodland herb with creeping rootstock but flowers insignificant.

Carex sylvatica Wood Sedge.
A tufted, wintergreen perennial producing numerous seed in the form of small nuts. Sedges (*Carex* spp.) hold over-wintering populations of an organism which attacks the willow rust, *Melampsora* and so may be important in the control of that disease.

Geranium robertianum Herb Robert.
Flowers April to September (at least). Height 10-40cm.

An annual herb often over-wintering and flowering in mild conditions throughout the year and so a potential nectar source at times when others are in short supply.

Geum urbanum Wood Avens.
Flowers May to August. Height 20-60cm.
A perennial herb with some nectar value.

Glechoma hederacea Ground Ivy.
Flowers March to May. Height 10-20cm.
A creeping perennial providing good ground cover and a good source of nectar early in the year for bees and butterflies.

Hyacynthoides non-scripta Bluebell.
Flowers April to June. Height 20-50cm.
Perennial bulb with amenity interest and some nectar value.

Lamiastrum galeobdolon Yellow Archangel.
Flowers May to June. Height 20-60cm.
A perennial with long creeping runners providing nectar for bees in May.

Mercurialis perennis Dog's Mercury.
Flowers February to April (but insignificant). Height 15-40cm.
Perennial herb with creeping rhizomes - typically forming large areas of continuous cover in old woodlands. Good nesting cover.

Milium effusum Wood millet.
A tall but loosely-tufted perennial grass. It used to be planted below trees so that pheasants may feed on its seed.

Poa nemoralis Wood Meadow-grass.
A rather delicate perennial, very loosely tufted adapted to growing in the shadiest areas.

Poa trivialis Rough Meadow-grass.
Stoloniferous less adapted to shade than *P. nemoralis* where it produces few seed. May form a mosaic with that species according to local light conditions.

Primula vulgaris Primrose.
Flowers March to June. Height 10-20cm.
An early flowering perennial woodland herb with some nectar value but most valuable as an amenity and landscape species as it is familiar to most people.

Ranunculus ficaria Lesser Celandine.
Flowers March to May. Height 10-20cm.
A low-growing perennial herb of the buttercup family flowering from late winter until early summer. Some nectar provision and a good ground cover - often in slightly wetter areas. Colourful and hence of amenity value.

Viola odorata Sweet violet.

Flowers March to May. Height 5-20cm.
A well known perennial with blue flowers of amenity and nectar value but even more important as a butterfly food plant. The larvae of several species of woodland fritillary butterflies (*Boloria* and *Argynnis* spp.) depend on violets.

20.4.4 Monitoring

The establishment of the introduced species as measured in the first year's monitoring is presented in the bar-charts in Figure 20.5. *Milium effusum* did not germinate at all but all other species survived to some extent. Of these, ten species* (60%) showed an increased percent cover in the autumn and spring sown/planted plots than in the spring only plots and seven species (40%) showed the opposite. *Poa nemoralis* did not survive at all in the spring-sown only plot.

Other plant species present in the plots as weeds are presented in Table 20.2. *Epilobium montanum*, *Cirsium arvense*, *Elytrigia repens* and *Poa annua* constitute the majority of the cover with most other species present at less than 1% cover.

Percent cover data for all three survey years (1996-8) are presented in Figure 20.6 and summarised for all the introduced species in Figure 20.7. These show that the response of the different introduced species varied but that, in general, the area of bare ground increased to the detriment of the weed species present which decreased with time. Five introduced species (29%) showed a mean decrease in the percent cover from 1996 to 1998, 10 introduced species (59%) showed a mean increase and two (12%) fluctuated or remained the same. Table 20.3 gives the incidence of flowering and the maximum spread of each species outside of the study plots.

Using repeated measures analysis of variance, it was possible to investigate whether the changes over the three year study period in the abundance of ground cover for the introduced species, the ground cover of weed species, and the proportion of bare ground in the plots (shown in Figure 20.7) was statistcally significant. The analysis considered all species together but identified whether trends were different between species.

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* When discussing the introduced species, the seeded and plugged plots of *Primula vulgaris* shall be regarded as if they were different species to allow comparison between the introduction methods.

Table 20.1. List of plant species selected for introduction, their sowing and planting rates and the criteria for their selection.

Sowing/planting rate; P= plug plants, S= seed
Criteria for selection; NS= nectar source, GC= ground cover, BF= butterfly food plant, NC= nesting cover for birds, S= food for seed eating birds and mammals, AL= amenity and landscape value. Letters in bold indicate the most important criteria in each case

	Sowing/planting rate	Criteria for selection
Species		
Ajuga reptans	P(5/m$^{2)}$	**NS**, **GC**
Alliaria petiolata	S(1.5g/m^2)	NS, GC, **BF**
Brachypodium sylvaticum	P(5/m^2)	**GC, NC**, S
Circaea lutetiana	P(5/m^2)	NS, **GC**
Carex sylvatica	P(5/m^2)	**GC, NC**, S
Geranium robertianum	S(1.9g/m^2)	**NS**, **GC**
Geum urbanum	S(0.5g/m^2)	NS, GC
Glechoma hederacea	P(5/m^2)	**NS**, **GC**
Hyacynthoides non-scripta	P(5/m^2)	NS, GC, **AL**
Lamiastrum galeobdolon	P(5/m^2)	NS, **GC**
Mercurialis perennis	P(4/m^2)	**GC, NC**, NS
Milium effusum	S(0.9g/m^2)	GC, NC, **S**
Poa nemoralis	S(0.5g/m^2)	GC, NC, **S**
Poa trivialis	S(0.5g/m^2)	**GC, NC**, S
Primula vulgaris (plugs)	P(5/m^2)	NS, GC, **AL**
Primula vulgaris (seed)	S(0.7g/m^2)	NS, GC, **AL**
Ranunculus ficaria	P(5/m^2)	NS, **GC, AL**
Viola odorata	P(5/m^2)	NS, GC, **BF, AL**

For the ground cover of introduced species, there was a significant trend towards increased cover over the three year period ($F_{2,354}$=3.642, P<0.05). There was no significant difference in this trend between species ($F_{1,177}$=0.615, P>0.1). For the percentage ground cover of weeds, as Figure 20.7 suggests, the decrease was highly significant ($F_{2,354}$=31.790, P<0.001) and again there was no significant difference beween species plots ($F_{1,177}$=2.827, P>0.05). For the proportion of bare ground (which must be related to the cover of weeds), the increase was also significant ($F_{2,354}$=40.794, P<0.001) although there was significant variation between species ($F_{1,177}$=4.853, P<0.05).

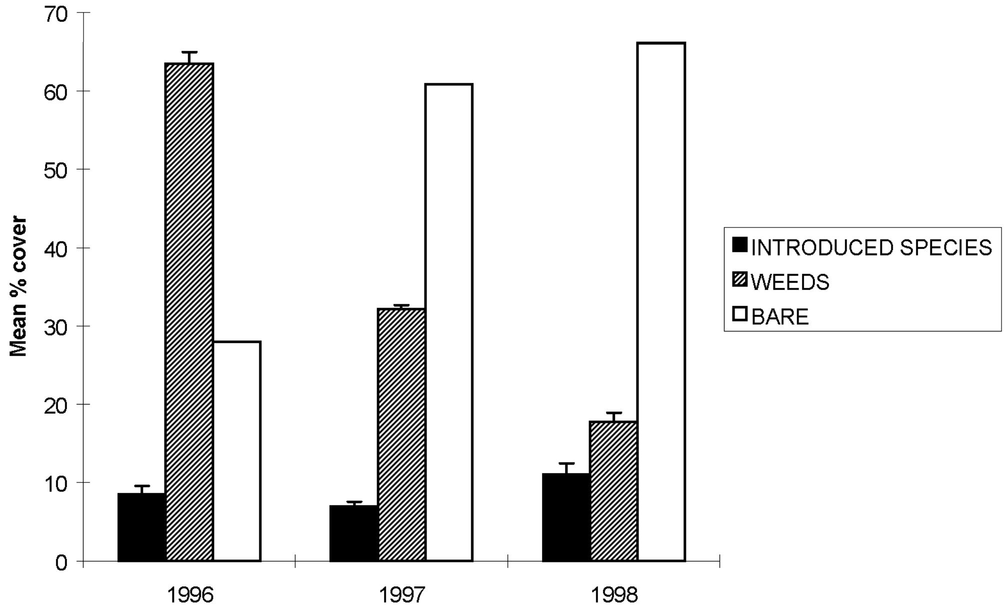


Figure 20.7 Mean % cover of weeds, introduced species and bare ground 1996-7

FIGURE 20.5 NOT AVAILABLE ELECTRONICALLY

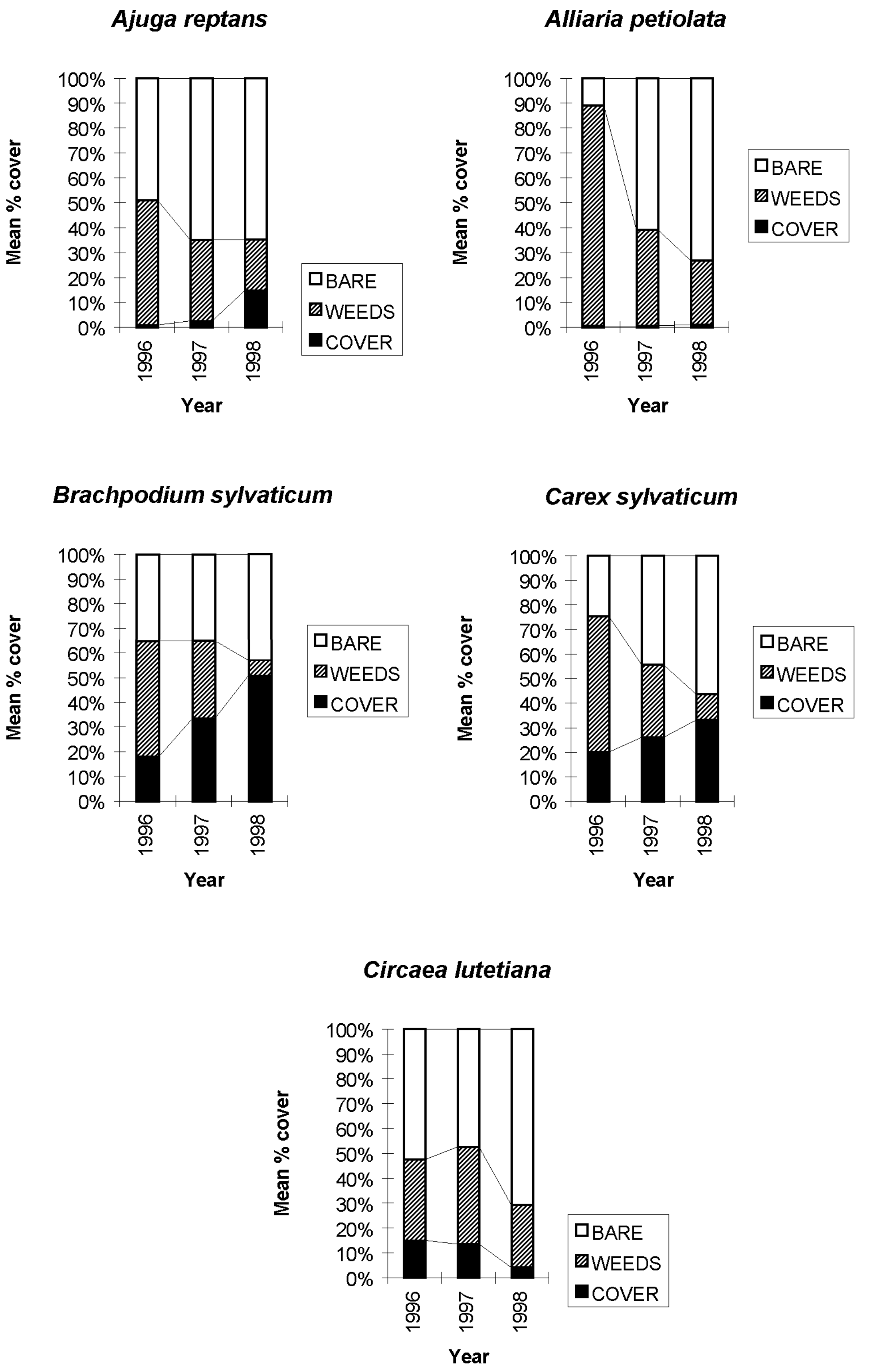


Figure 20.6 Changes in percent cover of bare ground, weeds and the introduced species (cover) 1996-7.

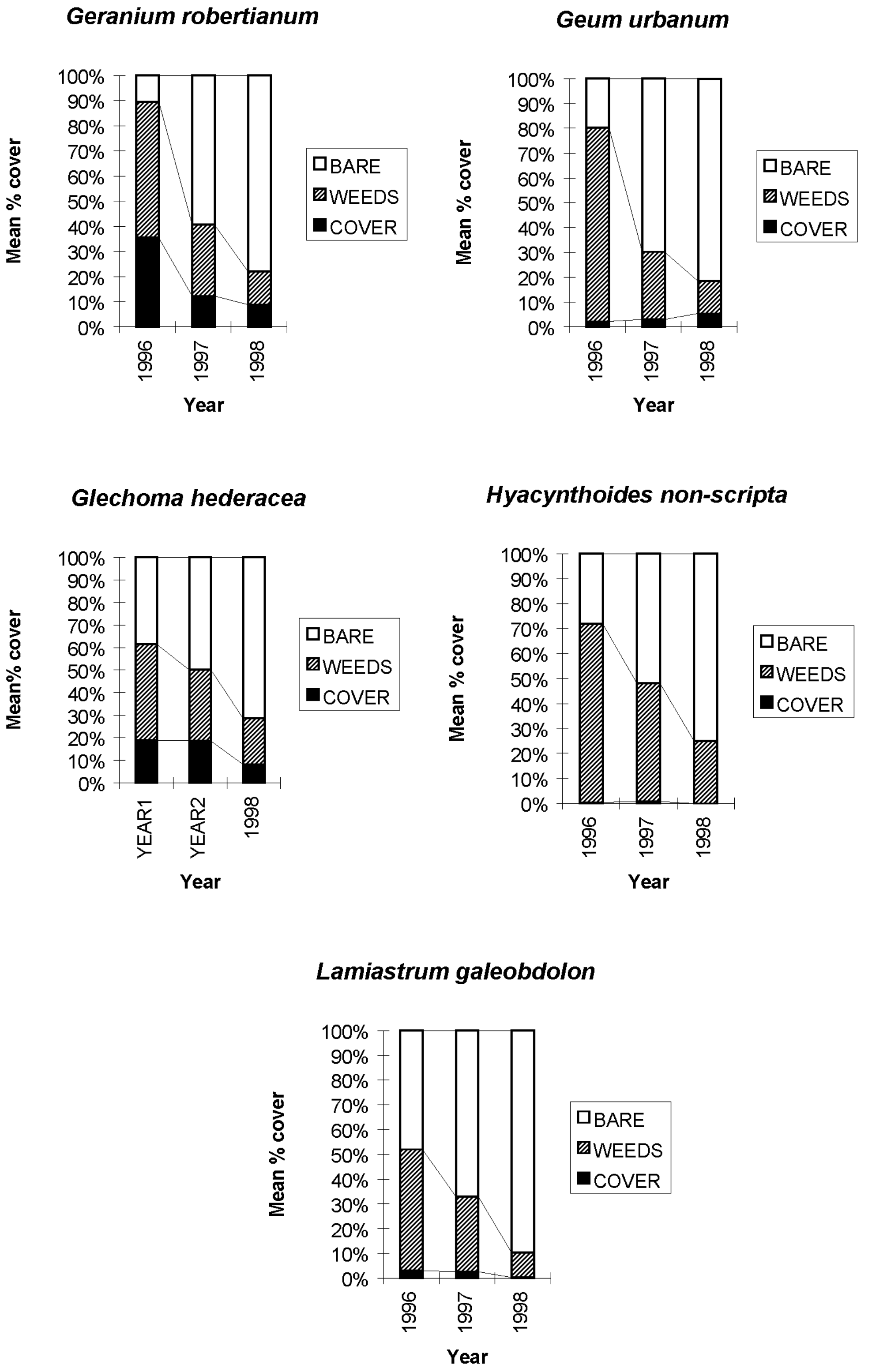
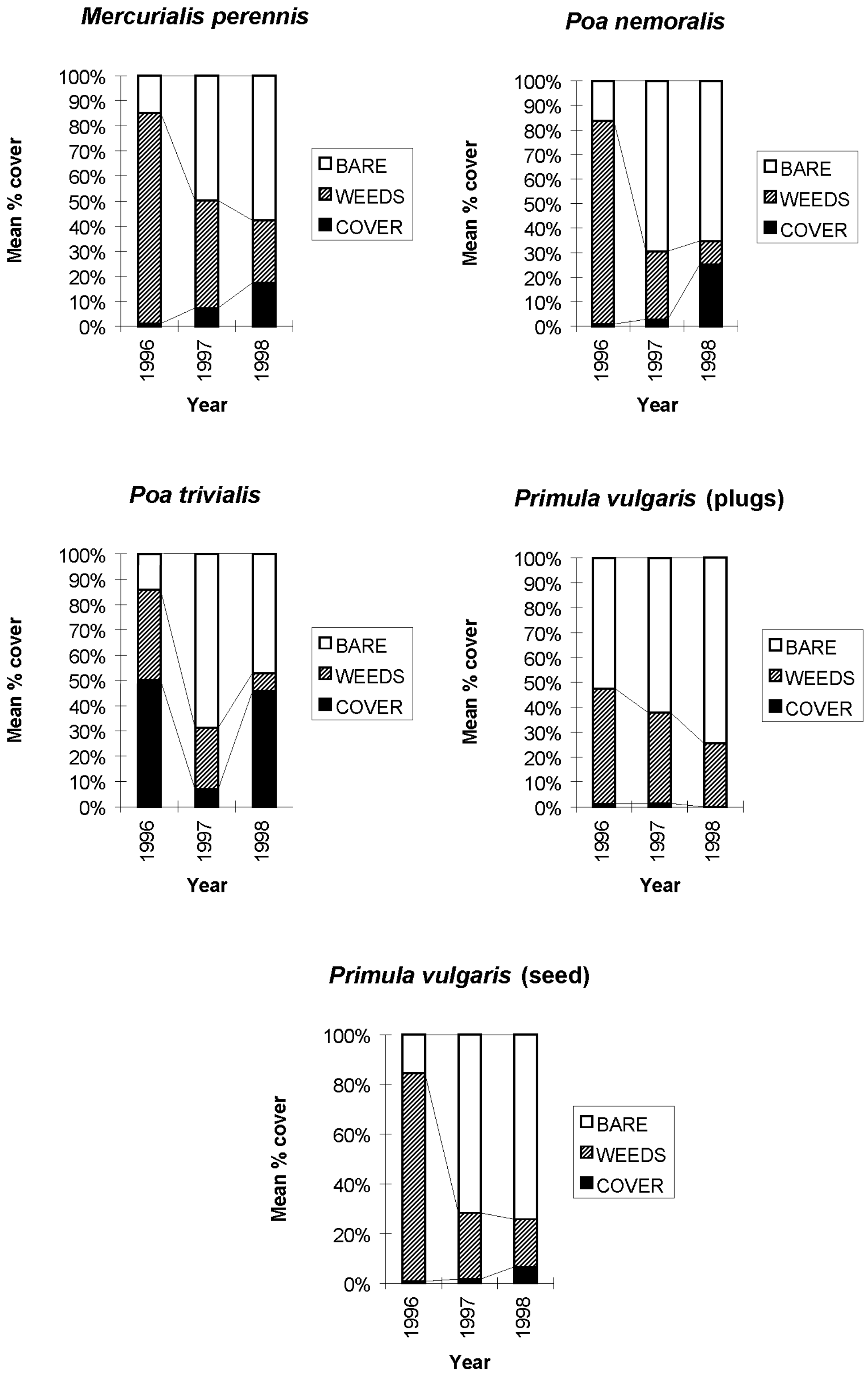


Figure 20.6 (cont.) Changes in percent cover of bare ground, weeds and the introduced species (cover) 1996-7.



Mercurialis perennis

Poa nemoralis

Poa trivialis

Primula vulgaris (plugs)

Primula vulgaris (seed)

Figure 20.6 (cont.) Changes in percent cover of bare ground, weeds and the introduced species (cover) 1996-7.

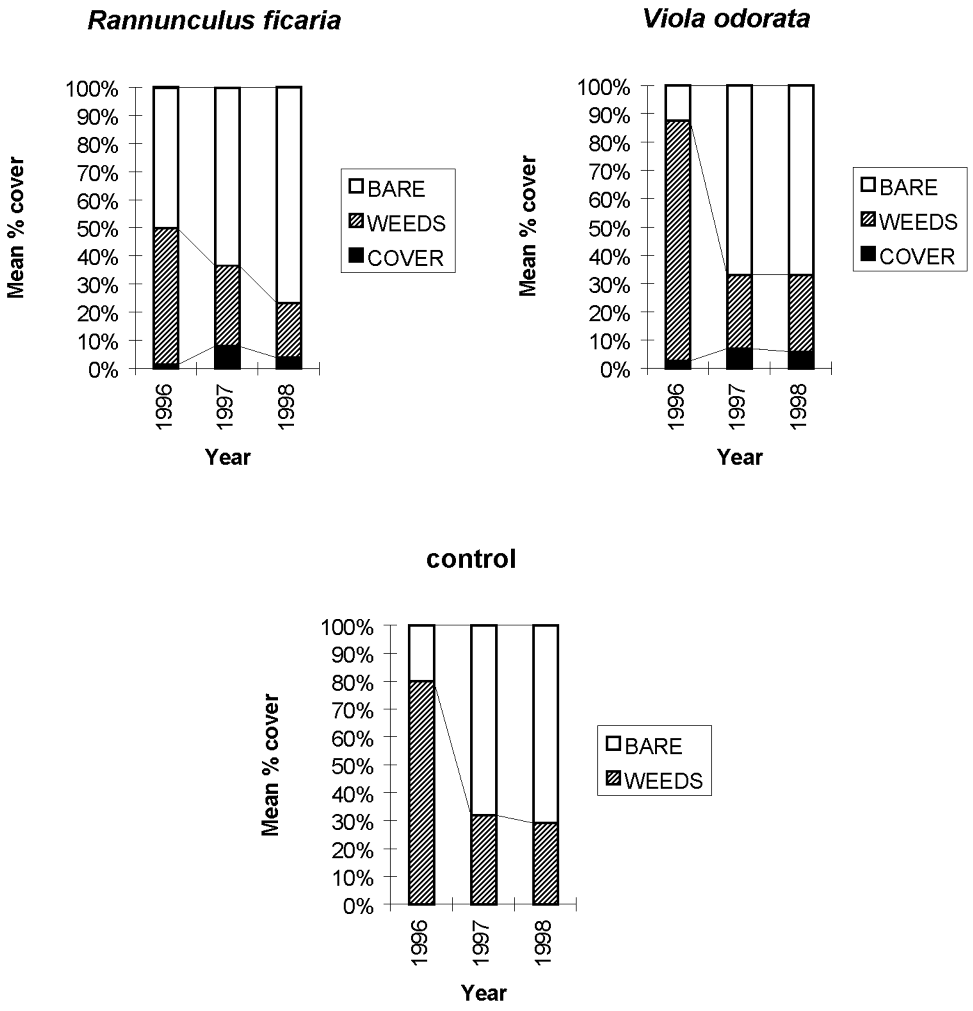


Figure 20.6 (cont.) Changes in percent cover of bare ground, weeds and the introduced species (cover) 1996-7.

Table 20.2. Weed species present within the introduction plots at Rove's Farm in May-June 1996.

		Clay Furlong		**Stepstones**	
Scientific Name	**English Name**	% of plots	Mean % cover	% of plots	Mean % cover
Arctium lappa	Greater burdock	0.6	<0.1	0	0
Brassica rapa	Wild turnip	2.8	0.2	0	0
Capsella bursa-pastoris	Shepherd's purse	1.1	0.4	0.6	<0.1
Cardamine flexuosa	Wavy bitter-cress	0	0	1.1	<0.1
Cardamine hirsuta	Hairy bitter-cress	4.4	0.2	0	0
Cirsium arvense	Creeping thistle	36.1	7.0	48.9	6.3
Cirsium vulgare	Spear thistle	11.1	0.8	2.8	<0.1
Crataegus monogyna	Hawthorn	0.6	<0.1	0	0
Epilobium montanum	Broad-leaved willowherb	95.6	14.3	98.3	40.6
Galium aparine	Cleavers	14.4	0.3	46.1	0.6
Geranium dissectum	Cut-leaved cranesbill	23.9	2.7	65.6	2.8
Myosotis arvensis	Field forget-me-not	5.0	0.1	7.2	<0.1
Picris echioides	Bristly oxtongue	3.3	0.1	1.1	<0.1
Plantago major	Greater plantain	0.6	<0.1	0	0
Ranunculus repens	Creeping buttercup	0	0	18.3	3.9
Rubus fruticosus	Bramble	0	0	0.6	<0.1
Rumex crispus	Curled dock	0.6	0.1	1.1	0.2
Scrophularia nodosa	Common Figwort	0.6	<0.1	0	0
Senecio jacobaea	Common ragwort	3.3	<0.1	0	0
Senecio vulgaris	Groundsel	13.9	0.1	1	<0.1
Solanum dulcamara	Bittersweet	0.6	<0.1	0	0
Sonchus arvensis	Perennial sow-thistle	0	0	36.7	1.3
Sonchus asper	Prickly sow-thistle	0.6	<0.1	1.1	<0.1
Stellaria media	Chickweed	0	0	0.6	<0.1
Taraxicum officinale	Dandelion	8.9	0.1	0	0
Trifolium repens	White clover	30	0.8	0	0
Tripleurospermum inodorum	Scentless mayweed	11.1	0.7	3.3	0.1
Veronica persica	Common field speedwell	0	0	0.6	<0.1
Veronica polita	Grey field speedwell	1.7	<0.1	1.1	<0.1
Veronica serpyllifolia	Thyme-leaved speedwell	0	0	1.7	<0.1
Viola arvensis	Field pansy	2.8	<0.1	15.6	0.2
Alopecurus myosuroides	Black grass	31.7	4.4	83.3	7.9
Bromus sterilis	Sterile brome	2.8	0.3	5.6	<0.1
Cynosurus cristatus	Crested dog's-tail	0	0	3.3	<0.1
Elytrigia repens	Couch	66.7	14.5	36.7	3.7
Holcus lanatus	Yorkshire fog	0	0	1.1	<0.1
Lolium perenne	Perennial rye grass	3.9	0.1	0.6	<0.1
Poa annua	Annual meadow grass	56.1	6.4	67.2	12.7
Poa trivialis	Rough meadow grass	16.7	1.2	8.9	<0.1
Carex hirta	Hairy sedge	0	0	0.6	<0.1

Table 20.3. Flowering and spread of introduced species by spring 1997

Species	**% of plots showing evidence of flowering**	**Maximum spread from edge of plot**
Ajuga reptans	50%	0m
Alliaria petiolata	20%	0m
Brachypodium sylvaticum	100%	0m
Circaea lutetiana	0[1]	0.25m
Carex sylvatica	100%	0m
Geranium robertianum	90%	>2.00m
Geum urbanum	0	0m
Glechoma hederacea	80%	>2.00m
Hyacynthoides non-scripta	50%	0m
Lamiastrum galeobdolon	0	0m
Mercurialis perennis	60%	1.00m
Milium effusum[2]	0	0m
Poa nemoralis	70%	>2.00m
Poa trivialis	100%	>2.00m
Primula vulgaris (plugs)	60%	0m
Primula vulgaris (seed)	30%	0.50m
Ranunculus ficaria	90%	1.00m
Viola odorata	80%	0m

Notes.

[1] A substantial proportion of plots were likely to have produced flowers after the date of the survey

[2] This species did not germinate at all in the plots

20.5 Discussion

Despite being hampered by both floods and drought in the first year, the establishment of plant species representative of a woodland flora has been achieved. The problems caused by weather did, however, effectively result in the redcution in replicates by half. In spite of this good results were achieved; all introduced species (excepting wood millet) survived for the three years and many flowered, set seed and spread.

A feature of most of the introduced species is that they are relatively slow growing perennials (Grime, Hodgson & Hunt, 1988) and consequently would not compete to a great extent with the crop. The ground cover they provide may serve to maintain a higher soil moisture content particularly after cutback when the soil surface would otherwise be exposed to sun and wind. A covering of plants with its associated root mat would also bind the soil so that during harvesting, smearing and compaction may be lessened. This would result in less damage to the coppice stools and their root system ensuring healthy stools which may support greater re-growth the following spring.

There is the potential problem, however, that the plants will not grow quickly enough to consolidate ground and serve the purpose for which they have been introduced. It is interesting to note that if the crop is growing well, the shade cast gives the introduced species an advantage until the crop is cut. Figures 20.6 and 20.7 show that as the crop grows and the ground becomes more shaded, the woodland introductions tend to consolidate ground. The arable weed species present, however, decrease in almost every case. This is a result of their not being adapted to the shady conditions (i.e. not stress-tolerators, see Section 19.3.2 and Grime, Hodgson & Hunt, 1988). This period when ruderal weed cover declines is an ideal window in which the introduced species may increase relatively unimpeded. This they have done and it is extremely unlikely that these perennial species will relinquish their ground in the few months when light reaches the plantation floor after harvest. By covering ground they occupy a niche and prevent other species from germinating there. Thus this slow but steady increase of the introduced woodland plants will eventually exclude the majority of ruderal weeds.

One species completely failed to grow; wood millet. This is surprising as it is a species well adapted to growth in shady conditions and was at one time widely sown in woodlands for both ornamental purposes and as a food for pheasants (Hubbard, 1968). Seed of this species sown in trays and grown in optimal conditions also failed to germinate and it must therefore be assumed that the seed supplied was not viable. As a consequence of its failure in this study, it is difficult to draw conclusions about the potential success of this species as an introduction to SRC. It is likely however, given its proven shade tolerance and former use in woodland, that it could be successfully introduced. It would be a desirable species, especially for a coppice plot incorporated into a pheasant shoot. Its inclusion in seed mixtures intended for sowing beneath SRC should therefore not be ruled out.

The list of species which achieved a good level of cover was dominated by those introduced as plug plants. The two species which achieved the greatest cover were, however, introduced as seed; herb robert and rough meadow-grass. These two species germinated well from the introduction and produced a cover of up to 50% in the first year. Subsequently the area covered by these species dropped dramatically so that they each only covered an area of around 10% in the second year. In the third year of the study, herb robert continued to decline. This might initially be assumed to be a result of insufficient seed set or high seed mortality resulting in viable seed being fewer than that necessary to maintain and increase cover. There is an alternative hypothesis relating to the highly developed seed dispersal mechanism of herb robert. This involves the seed capsule splitting violently, hurling the seeds not inconsiderable distances. This method of seed dispersal is highly effective and results in a wide distribution of progeny. This was recorded in both 1997 and 1998 when, despite decreasing cover in the introduction plots, plants were recorded some distance from those plots (Table 20.3). This is not the expected pattern for a species which is in decline and would suggest that herb robert is very successfully colonising a large area with sparsely distributed plants. Rough meadow grass, unlike herb robert, increased once more in its plots in 1998 to a level similar to that in 1996. Why this fluctuation should occur is uncertain, it does not have a complex dispersal method like the previous species. It's revival in 1998 on a large scale does seem to be more likely due to seed set in its first year when it was plentiful than in 1997 when it was scarce. It is possible that seed lay dormant through 1997 because of unsuitable conditions for germination. Rough meadow grass was also recorded to have spread well outside of its introduction plots.

The majority of the other species showed a statistically significant, although not particularly large increase from 1996 to 1998. Of particular note were proportionally substantial increases observed in wood false-brome (more than doubling its cover), dog's mercury (7-fold increase), wood meadow-grass (more than 30-fold), lesser celandine (more than 5-fold before a slight drop) and sweet violet (more than doubling and then stabilising). The primrose is an interesting species in that the plug plants which were introduced have decreased in cover and seem on the verge of dying out completely. The plants introduced via seed, however, have overtaken them and have even spread outside of the plots (Table 20.3). This reflects the fact that plug plants can be planted in positions which may be unsuitable - the microclimate may not be quite right. Seeds , on the other hand, tend to germinate where and when conditions are right and can quickly develop an effective root system to support them during spells of less ideal conditions. A plug plant may never have the opportunity to do this.

That the presence of these plants is beneficial for wildlife and farmland biodiversity cannot be doubted. Figure 20.7 shows that the ground cover provided by weed species decreases with time. While this would have been due mainly to shading, competition for space with the introduced shade tolerant species may also have had an effect, and in the longer term the results of Section 19.0 indicate that this would occur. A woodland-type flora helps to keep some ground cover and so provides the niches for many species which need this sort of habitat including invertebrates, small mammals and ground-nesting birds. Ground cover does not just supply refuge for these species but also food, mostly in the form of seeds. Nectar is also a source of food for some invertebrates and the plants themselves can be food for some butterfly larvae - the caterpillars of various fritillaries (*Boloria* spp. and *Argynnis* spp.) feed on violets for example. These species benefit from a coppicing regime as they are particularly associated with clearings amidst woodland. Most fritillaries are decreasing nationally and although it may be difficult for individuals to colonise isolated areas of coppice, it would be impossible without the larval foodplant (violets) and adult nectar sources (especially bugle) (Thomas, 1986).

It is likely that a stable ground flora will play a role in the integrated pest management of SRC. Of concern to many growers is the prevalence of several species of pest invertebrate, particularly defoliating chrysomelid beetles. These can cause serious economic damage to short rotation coppice (see Section 8.0, Christersson, Ramstedt & Forsberg, 1993 and Sage & Tucker, 1995). There is evidence to suggest that the major pest species are hosts to a number of hymenopteran and Tachinid parasitoids (see Section 9.0 and Kendal, Wiltshire & Butcher, 1996). It has been shown that parasitoid activity is enhanced by the provision of nectar sources resulting in an extension of the life span of females and an increase in the number of eggs laid. Nectar sources positioned where otherwise there would be none can encourage questing females into new areas (Idris & Grafius, 1995, Jervis *et al.*, 1993 and Van Emden, 1963). A ground flora which provided nectar sources within the heart of the crop could therefore be expected to increase the range and effectiveness of parasitoids away from flower-rich hedges where they might otherwise be restricted. In this way a degree of biological control may be achieved, reducing the need for chemical intervention to control pest numbers and thus reducing costs to the grower. In this study one particular nectar plant, herb robert, established and spread very successfully and in such a way that its scattered nature is likely to encourage foraging Hymenoptera to disperse widely throughout the crop.

In a similar way that nectar sources increase the range and effectiveness of parasitoids, tussocky vegetation can encourage predatory beetles and spiders further into a crop (see Section 9.0). This has been demonstrated in cereal fields where strips of tussocky grasses are sown through the centre of large cereal fields to encourage the movement and distribution of predatory invertebrates away from surrounding hedges into the centre of the field. A reduction in the need to employ an insecticide for the control of cereal aphids has been attributed to the presence of these strips, termed beetle banks (Hill *et al.*, 1995 and Thomas, Wratten & Sotherton, 1991). It seems likely that such tussocky refugia growing as a ground cover beneath short rotation coppice willow will have a similar effect.

In choosing species for a wild flower mix to be sown below SRC, many things must be considered. The soil type and location are both important. At Roves Farm these two variables were the most important factors in defining the species considered as they dictated which woodland NVC type should be used as a model (Rodwell, 1991). Most potential SRC plots are likely to be on medium pH, lowland agricultural soils with moderate to poor drainage (certainly not sharply draining) (Bates, 1995). Calcareous soils are likely to be too dry for good willow growth but would, perhaps, be more suited to poplar. In these circumstances, the types of species introduced at Roves Farm are likely to succeed. Many of these species are generalist woodland plants and may occur in a range of woodland NVC types (see Rodwell, 1991). Potential SRC ground flora seed mixes should ideally be composed of a range of these generalists which have slightly different ecological niches so that those most suited to individual plots and to the slightly different conditions present at different locations within each plot can find their own balance. In respect of these factors, a suitable seed mix for introduction to SRC is given in Appendix 20B. Any proprietary woodland wildflower seed mix may be suitable but that listed in Appendix 20B includes species selected with SRC in mind to provide the amenity and wildlife benefits of a standard seed mix but also to provide the specific benefits for the crop that have been discussed in this section.

20.6 References

Christersson L., Ramstedt M., Forsberg J. (1993) Pests, diseases and injuries in intensive short rotation forestry. In *Ecophysiology of short rotation forestry crops*, pp 185-216. Eds C P. Mitchell, J B. Ford Robertson, J. Thinckley, L. Sennerby-Forsse. Elsevier Applied Science Publications.

Clay D V. 1996. Weed management in short rotation coppice: current status and future requirements. *Report of the Energy Technology Support Unit, Department of Trade and Industry.* 24pp.

Clay D V., Dixon F L. 1996. Report on experiments on weed management in coppice - 1994-1995. *Report of the Energy Technology Support Unit, Department of Trade and Industry.* 89pp.

Grime, J P., Hodgson, J G. & Hunt, R. (1988) *Comparative plant ecology: A functional approach to common British species*. Unwin Hyman, London. 742pp.

Hill, D A., Andrews J., Sotherton N W., Hawkins J. (1995) In *Managing habitats for conservation*, pp. 230-266. Eds W J. Sutherland and D A. Hill. Cambridge University Press, Cambridge.

Hubbard, C.E. (1968) *Grasses*. Penguin Books, London.

Idris A B., Grafius E. (1995) Wildflowers as nectar sources for *Diadegma insulare* (Hymenoptera: Ichneumonidae), a parasitoid of diamondback moth (Lepidoptera: Yponomeutidae). *Environmental Entomology* **24**, 6: 1726-1735.

Jervis M A., Kidd N A C., Fitton M G., Huddleston T., Dawah H A. (1993) Flower visiting by hymenopteran parasitoids. *Journal of Natural History* **27**: 67-105.

Kendall D A. Wiltshire C W. Butcher M. (1996) Phenology and population dynamics of willow beetles (Coleoptera: Chrysomelidae) in short rotation coppiced willows at Long Ashton. *Report of the Energy Technology Support Unit, Department of Trade and Industry.*

Kerr, G., Harmer, R. and Moss, S.R. (1996) Natural colonisation: a study of Broadbalk Wilderness. *Aspects of Applied Biology*. **44**, Vegetation management in forestry, amenity and conservation areas, pp. 25-32.

Kershaw, K.A. & Looney, J.H.H. (1985) *Quantitative and Dynamic Plant Ecology.* 3rd Edition. Edward Arnold, London.

Rodwell J S. (1991a) *British Plant Communities. Volume 1: Woodlands and Scrub.* Cambridge University Press, Cambridge.

Rodwell J S. (1991b) *British Plant Communities. Volume 2: Mires and Heaths.* Cambridge University Press, Cambridge.

Rodwell J S. (1992) *British Plant Communities. Volume 3: Grasslands and Montane Communities.* Cambridge University Press, Cambridge.

Rodwell J S. (1995) *British Plant Communities. Volume 4: Aquatic Communities, Swamps and Tall-herb Fens.* Cambridge University Press, Cambridge.

Sage, R.B. (1995) Factors affecting wild plant communities occupying short rotation coppice crops on farmland in the UK and Eire. *Proceedings of the Brighton Crop Protection Conference 1995 - The rôle of weed control in landscape change,* 7D, pp. 980-985.

Sage R.B., Robertson P.A. and Poulson J.G. (1994) Enhancing the conservation value of short rotation biomass coppice - Phase 1 The identification of wildlife conservation potential. *ETSU B/W5/00277/REP*, Harwell Laboratories, Oxford, pp. 44.

Sage R B., Tucker K. (1995) Integrated flora management and pest control in short rotation coppice. In *Woodfuel - the green debate*, pp 21-29. Harwell Laboratories, Oxford.

Thomas, J.A. (1986) *Butterflies of the British Isles*. Country Life Books, Twickenham.

Thomas M B., Wratten S D., Sotherton N W. (1991) Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: Predator densities and emigration. *Journal of Applied Ecology* **28**. 906-917.

Van Emden H F. (1963) Observations on the effect of flowers on the activity of parasitic Hymenoptera. *Entomologist's Monthly magazine* **98**:265-270.

Wilson, P.J. and Aebischer, N.J. (1995) The distribution of dicotyledonous arable weeds in relation to distance from field edge. *Journal of Applied Ecology.* **32**, 295-310.

Appendix 20A. Full list of species considered for introduction according to the criteria described in Section 20.4.3

Within crop.

Herbs

Ajuga reptans	bugle.
Geum urbanum	wood avens.
Geranium robertianum	herb Robert
Geranium pyrenaicum	hedge cranesbill.
Glechoma hederacea	ground ivy.
Veronica chamaedrys	germander speedwell
Veronica montana	wood speedwell
Viola odorata	sweet violet
Viola riviniana	dog violet.
Stellaria holostea	greater stitchwort
Circaea lutetiana	enchanters nightshade.
Ranunculus ficaria	lesser celandine.
Mercurialis perenis	dogs mercury.
Primula vulgaris	primrose.
Allium ursinum	ramsons
Hyacinthoides non-scripta	bluebell.
Sanicula europaea	sanicle.
Lamiastrum galeobdolon	yellow archangel

Grasses

Milium effusum	wood millet.
Poa nemoralis	wood meadow grass.
Poa trivialis	rough meadow grass.
Holcus mollis	creeping soft grass.
Carex pendula	pendulous sedge.
Carex sylvatica	wood sedges.
Festuca rubra L. subsp. *rubra*	strong creeping red fescue.
Brachypodium sylvaticum	wood false brome.
Melica uniflora	wood melick.

Crop edge zone

Herbs

Alliaria petiola	garlic mustard.
Filipendula ulmaria	meadowsweet.
Stachys sylvatica	hedge woundwort.
Potentilla anserina	silverweed.
Hypericum hirsutum	hairy St. Johns wort
Hypericum perforatum	perforate St. Johns wort
Hypericum tetrapterum	square stalked St. Johns wort.
Silene dioica	red campion.
Prunella vulgaris	selfheal.
Valarian officinalis	common valerian.

Grasses

As within crop.

Agrostis capillaris	creeping bent.
Cynosurus cristatus	crested dog’s tail.

Headlands and rides.

Umbellifers

Anthriscus sylvestris	cow parsley.
Angelica sylvestris	wild angelica.
Torilis japonica	upright hedge-parsley.
Heracleum sphondylium	hogweed.
Daucus carota	wild carrot
Pastinaca sativa	wild parsnip.

Other herbs

Centaura nigra	black knapweeed
Centaura scabiosa	greater knapweed
Leotodon autumnalis	autumn hawkbit.
Leucanthemum vulgare	oxeye daisy.
Succisa pratensis	Devils-bit scabious.
Achillea millefolium	yarrow.

Grasses

Dactylis glomerata	cock’s-foot.
Holcus lanatus	Yorkshire fog.
Festuca rubra	creeping red fescue.

Appendix 20B: List of species considered suitable for inclusion in a wild flower seed mix for use in SRC

Herbs

Ajuga reptans	bugle.
Allium ursinum	ramsons
Angelica sylvestris	wild angelica.
Anthriscus sylvestris	cow parsley.
Circaea lutetiana	enchanters nightshade.
Geum urbanum	wood avens.
Geranium robertianum	herb Robert
Glechoma hederacea	ground ivy.
Hyacinthoides non-scripta	bluebell.
Hypericum hirsutum	hairy St. Johns wort
Hypericum perforatum	perforate St. Johns wort
Hypericum tetrapterum	square stalked St. Johns wort.
Lamiastrum galeobdolon	yellow archangel
Mercurialis perenis	dogs mercury.
Primula vulgaris	primrose.
Prunella vulgaris	selfheal.
Ranunculus ficaria	lesser celandine.
Silene dioica	red campion.
Stellaria holostea	greater stitchwort
Torilis japonica	upright hedge-parsley.
Viola odorata	sweet violet
Viola riviniana	dog violet.

Grasses and sedges

Brachypodium sylvaticum	wood false brome.
Carex sylvatica	wood sedge.
Festuca rubra L. subsp. *rubra*	strong creeping red fescue.
Melica uniflora	wood melick.
Milium effusum	wood millet.
Poa nemoralis	wood meadow grass.
Poa trivialis	rough meadow grass.

21.0 WEED COMPETITION AND GROWTH IN ESTABLISHED WILLOW COPPICE

21.1 Summary

We investigated the extent and causes of different levels of weed competition on the growth of established willow coppice. By using a randomised block design experiment incorporating 600 separate assessment stools we achieved a high degree of statistical power. Consequently, for the first time in SRC crops, and probably for any young tree species, we were able to quantify the relationship between coppice growth loss and a wide range of weediness levels, over one and two years.

The experiment was conducted at an established willow SRC plantation on a clay loam soil in Oxfordshire. We measured coppice growth in 30 weedy and 30 weeded plots, each containing 10 assessment coppice stools and around 25 guard stools. Comparisons between plot types were made at the end of one and two years using destructive and/or non-destructive assessment methods. In all cases of measuring annual growth increments, before and after comparisons were made. Weediness was quantified non-destructively by measuring weed height and ground cover and calculating a mean weed volume. Assessments of weed species were also made. Comparisons were made between weedy and weeded plots.

Measurements of other growth characteristics such as crop height, stem number and canopy shade were also measured in all plots. Environmental site variables such as soil moisture and nutrient status were recorded in some plots. These data enabled a thorough investigation of the likely causes of these growth losses.

During the first year of growth following cut-back, stool biomass was affected by weediness. The relationship between coppice growth reductions and weed volume was linear with a close-to-zero intercept. Coppice growth was reduced by about 40 % in the weediest plots, with a mean weed height of around 0.5 m and 100 % ground cover (very weedy). For plots with half this level of weediness, either 0.5 m plus 50 % cover or 0.25 m at 100 % cover, the growth reduction was also halved, to around 20 %, and so on.

During the second year, differences between the weedy and weeded plots decreased but still remained large compared

to the weeded plots (x 10 or more). Despite this, coppice growth was not affected by weediness in this year and in some plots growth was actually greater with weeds. Where stools doubled in size in the weeded plots, equivalent stools in the weedy plots also doubled in size. Consequently growth losses over the two year study period reflected only the effect of weediness in year one.

Soil moisture content did not differ between weedy and weeded plots when measured at the end of June in each year. Soil nutrient content did not differ when measured in July of the second year. The canopy density, as measured by recording the percentage of active radiation (PAR) penetrating the canopy was related to variety type and weediness. PAR was reduced in the weeded plots, i.e. canopy density was greater. Crop height was also closely related to variety and to weediness when measured at the end of June 1996. Stem extension was actually greater in the weedy plots. The mean number of stems per stool in each plot was also related to variety and to weediness. Stools growing in weedy conditions contained significantly fewer stems.

An investigation of these results strongly suggests that the reductions in biomass recorded during this trial were due solely, or at least mainly, to competition with weeds for light and space during the first half of year one. We hypothesis that weediness has the same effect as increasing stool planting density on individual stool growth. In good soils where the soil moisture retention capability is high, i.e. clay and clay loams, weeds will not necessarily reduce water and nutrient availability to coppice stools under normal conditions. In drought conditions, where nutrient depletion has continued for many years or in poorer lighter soils, competition for these resources by weeds may be important.

21.2 Introduction

Useful applied research has already been undertaken on the subject of weed competition and weed management strategies in SRC crops. In particular, work undertaken by Avon Vegetation Research, summarised in Clay (1993) & Clay & Dixon (1996), has investigated a wide range of issues related to SRC and weeds and provided much quantitative information on for example the need for weed control at establishment, on the effectiveness of herbicides and other methods to control weeds, and on the impact of herbicide applications on the crop itself.

In summarising some of this work Clay thought that weed competition is probably most severe in early summer (April, May, June), when weeds are at their most vigorous, though the occurrence of perennial weeds and the long growing season for SRC means that the growth of these crops can be affected all year. At establishment, weed competition can reduce early development of a planted cutting that effects growth and therefore yields for years to come. Poorly established cuttings are more susceptible to drought. Short cuttings and planting depth exacerbates the effect of weed competition. Ineffective weed control at establishment will also lead to a greater requirement for weed control in subsequent years. Invasive perennial weeds can effect second year growth (after cut back). If shading is reduced during the growing season after first cut back, perennial weeds often quickly re-appear. This is affected by planting spacing, stress (disease, pest attack, drought). After the first harvest, many weeds are capable of exploiting the open conditions. In terms of control methods, herbicides are considered to be the best methods at least in the UK (e.g. Clay 1993). New plantings are aimed at ex-arable land of high fertility with large weed seed populations. Initial weed control for SRC usually involves pre-ploughing contact (foliar acting) herbicides to reduce perennial weeds and post planting residual (soil acting) herbicides to prevent annual weeds germinating from the seed bed. Subsequent applications are also usually used. Pre and post planting herbicides are recommended at establishment. Selective contact herbicides are also used to control post planting weed emergence in the first year and after cut-back it is usual to apply a selective/directed contact herbicide and/or a residual ‘to make sure’.

This last point is the area of weed management in SRC crops about which least is known. The need to make these preventative herbicide applications stems from a lack of quantitative information on the effects of weeds on established coppice and the desire to reduce risk in crop production. Clay (1993) thought that calculating damage thresholds was an important future requirement of research 5 years ago but by 1996 he reported that still there was little quantitative information on the need for weed control after harvesting coppice. This is the subject of the study described in this section of the report. We aimed to quantify the effects of weed competition on established SRC. The original trial design and treatment applications were undertaken in conjunction with David Clay. The work ties in with flora introduction trials, where we aimed to identify ground flora species which provide certain benefits to crop environment without causing significant reductions to crop growth.

This study manipulates weediness and makes assessments of competition and growth increments in 600 established willow coppice trees in one trial. This degree of replication facilitated a statistically rigorous analysis of the relationship between the mean response of willow coppice re-growth to a sliding scale of weediness over a two-year period. Weediness was assessed non-destructively, by calculating a measure of weed volume within plots each summer. Coppice growth was also assessed non-destructively in winter, by measuring stem diameters and calculating an index of volume of individual coppice stools based on cross-sectional area (Neilson 1982; Sage *et al.* in prep). This approach enabled differences in the coppice response between years to be quantified separately, i.e. between stem growth from the cut stools in year one and additional growth on those stems in year two.

21.3 Methods

21.3.1 Study sites

The trial was conducted in a 4-hectare willow coppice plantation which occupied around one third of a field at Roves Farm near Swindon in North Wiltshire. The field (Stepstones) was on level ground at an altitude of 100 m and had previously been in a cereal and grass ley rotation. Roves Farm was also used for the ground flora introduction trials described in Section 20.0 with one group of introductions in the same field (Figure 21.1).

Soil sample analysis undertaken by an undergraduate student at Wye College, London University. The soil was classified as a silty clay-loam with pH 5.9 and relatively poor drainage. This is considered suitable for growing high-yielding willow varieties (Anon. 1996) and is typical of sites in lowland England..

Following soil cultivation's a the end of 1993, willow cuttings approximately 20 cm long were planted in double-rows at 20,000/ha. Twelve different willow varieties were planted in strips of three double-rows (Figure 21.1). The plantation was then sprayed with 4 l/ha of Simazine and 5 l/ha of Pendamethalin to control weed growth during the establishment year. The first-year growth was cut back to the ground during winter 1994/5.

Post establishment surveys of the plantation during the second year of re-growth and prior to this trial indicated good site capture by the crop with few poorly established stools, the development of a competitor/ruderal flora (Grimes 1988) typically found in young SRC crops (Sage *et. al.* 1994), and a lack significant insect pest or disease problems.

21.3.2 Trial design

Following leaf fall in November 1995, sixty plots were marked out within the coppice area using coloured posts representing four different treatments, and then numbered sequentially. At that time the coppice consisted of one-year-old stems on two-year-old stools. Four plots were laid out end-to-end in each of 15 double-rows of coppice (Figure 21.2). The trial incorporated 10 different willow varieties with one or two double-rows of each. Each row of four plots

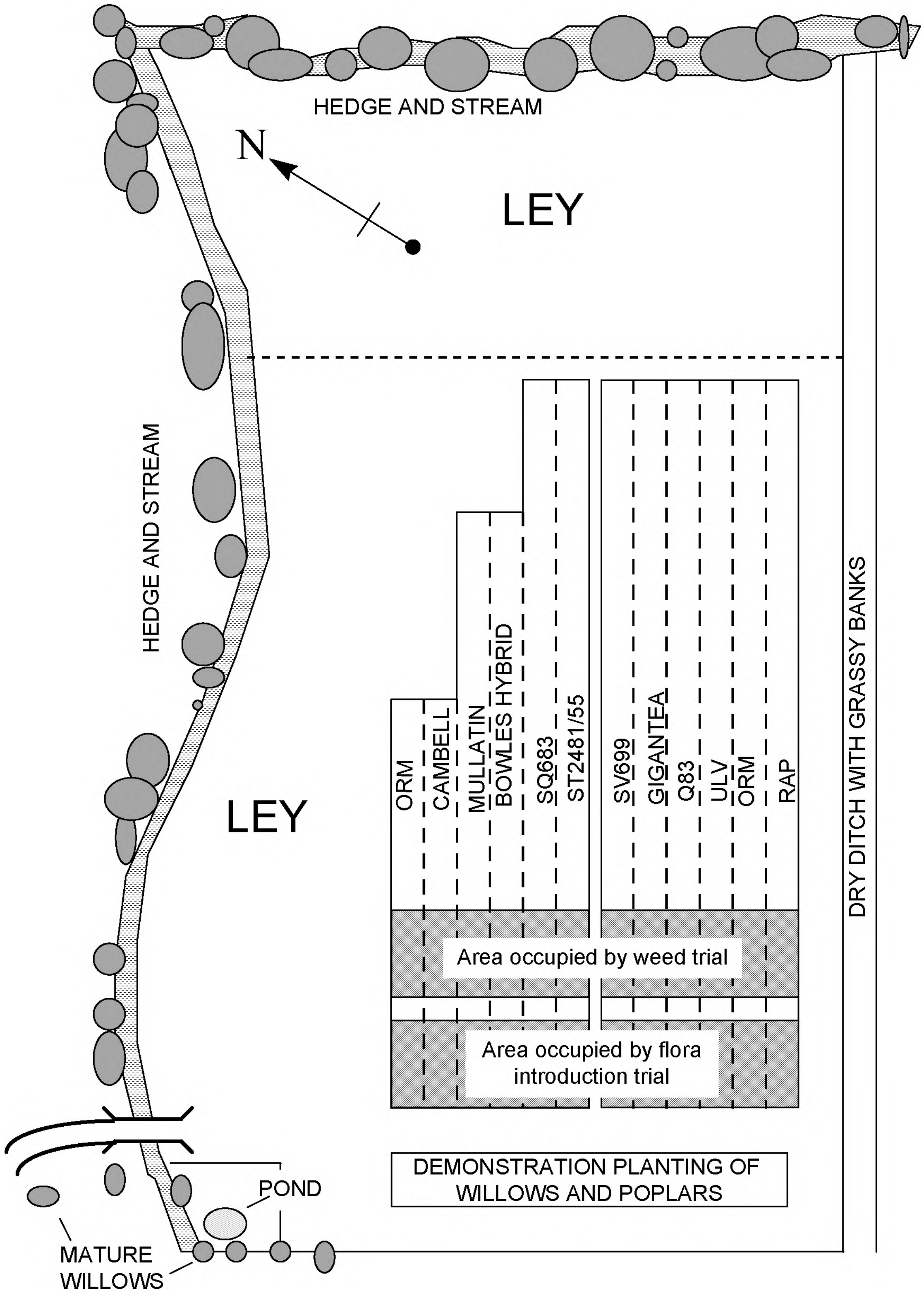


Figure 21.1. Plantation design and layout of the weed effect trial in Stepstones field, roves Farm Oxfordshire. The flora introduction trial (Section 20 is also shown)

FIGURE 21.2 NOT AVAILABLE ELECTRONICALLY

was separated from adjacent rows by a further double-row of coppice to maintain independence of treatments between rows. Each plot contained around 36 coppice stools, of which the middle 10 were assessed (600 stools in total for the trial). Stools at the end of each plot were not included in the experiment but were used to maintain independence between plots along rows. The trial occupied an area 60 m x 18 m within the coppice plantation, at least six metres from any plantation edge.

21.3.3 Treatments

During spring 1996, following cut-back of the trial area in March, treatments were applied to the trial to encourage variations in weediness - two types of weeded plots and an equivalent number of un-weeded plots (Table 21.1). Each weeded treatment and two un-weeded plots were randomly allocated to one of the four plots in each of the 15 rows (Figure 21.2). Both un-weeded plots in each row had no treatments applied. Weed control in the other two plot-types began in April 1996 and continued until June 1996. Treatment 1 was a combination of contact herbicide and hand weeding and treatment 2 included both residual and contact herbicides with no hand weeding (Table 21.1). The treatments were considered to be the most effective contact with/without residual herbicide formulations normally available following cut-back to SRC growers and were formulated and applied by D.V. Clay of Avon Vegetation Research, Bristol. These herbicide applications have been found to cause no long-term (i.e. several months) effects on coppice growth (Clay *et al.* 1993; Clay & Dixon, 1996) . No further treatments were applied to the trial, reflecting the practical difficulties in managing weeds in these crops following canopy closure in the first year.

21.3.4 Coppice growth

The 10 stools in each of the 60 trial plots were cut and weighed individually during March 1996, after the trial had been marked out but before treatments were applied. These data enabled any differences in above and below ground stool growth between treatment plots that may have existed before treatments were applied, to be accounted for in subsequent analysis (see below). The guard stools at the ends of each plot and in the between plot rows were also cut but not measured. Subsequent measures of crop biomass and of weediness, except for crop biomass at the end of the trial, needed to be undertaken non-destructively.

For crop growth during the first year, a measure of relative biomass was estimated in February 1997, by measuring the diameter at half stem-length, of all stems over 1 m in length and 5 mm in diameter, on the same ten stools in each plot. This single measure was found to give a good indication of within-variety relative biomass in a pilot study of two willow varieties in 1995 (Section 4.0) and is similar to methods based on cross-sectional areas developed in Sweden by Nilsson (1982) and by the Forestry Commission in the UK (reviewed in Armstrong *et al.* 1997). At the end of year two in

Table 21.1. Treatments applied to the weeded trial plots.

Date	Plot	Product name	Active ingredient	Dose, l/ha	Method	Hand weeding
3/4/96	1	Challenge	Glufosinate	5	Directed spray to alleys	Around stools
	2	Unicrop Flowable Stomp 400 Weedazol TL	Simazine Pendimethalin Amitrole	4.5 5 20	Overall spray Overall spray Overall spray	None
24/4/96	1	Gramoxone 100	Paraquat	5	Spot	Around stools
	2	None	-	-	-	None
3/6/96	1	Gramoxone 100	Paraquat	5	Spot	Around stools
	2	Dow Shield	Clopyralid	1	Spot to thistles	None
25/7/97	*1*	*None*	-	-	-	*Remaining weeds*
	2	*None*	-	-	-	*Remaining weeds*

December 1997, stool biomass in all trial plots was assessed by measuring stem diameters at half stem length, and by cutting and weighing each stool. Relationships between these data are described in Section 4.0.

The height of the coppice was measured in each plot when the weed assessments were taken in June 18 - 19 1996. Six measurements of shoot height (i.e. not length) were taken to provide a mean for each plot. These data were compared between plot types.

21.3.5 weediness

The ground flora within each plot was surveyed during 18 - 19 June 1996 and 28 - 30 June 1997. Each plot was split into three sections, separated by the coppice rows, to ease the estimation of species and overall cover. The abundance of each weed species was recorded using the five point DAFOR scale (where 1 = (R)are (0 - 5 % cover), 2 = (O)ccassional (5 - 10 % cover), 3 = (F)requent (10 - 25% cover), 4=(A)bundant (25 % - 50 % cover), 5= (D)ominant (50% - 100 % cover)) in each section and overall cover as a percentage compared to bare ground. These data were combined to give an estimate of species cover and overall cover per plot. Weed height was measured at three random locations within each section using a point quadrat. This involved randomly locating a measuring stick within the plot and noting the height at which the weeds touched the quadrat. This gave nine measurements of weed height per plot.

21.3.6 Soil survey

Soil gravimetric water content in the trial plots was measured in June 1996 and 1997. Each year, a Dutch soil auger sampling 15 cm of soil was used to collect three cores from each of a sample of plots, one from each inter-row space. Six plots of each treatment were selected at random in 1996 and four of each in 1997. Samples was weighed, oven dried at 100 - 110 C then weighed again (Brady & Weil 1996).

Soil fertility was measured by collecting a further 20 soil cores from another sub-sample of 10 plots with two from each un treated control and three of each treatment plot in June 1997. The soil was air dried for one week at room temperature. Nitrate-nitrogen was extracted from each sample using a saturated calcium sulphate solution and phosphorous using a sodium bicarbonate solution. Analyte determinations were carried out using a Burkard SFA2 auto-analyser (ADAS & MAFF 1986).

21.3.7 Percentage active radiation

Measurements of the active radiation penetrating the coppice canopy were also collected. A custom made light metering system designed and manufactured by Stan Burridge at London University, Wye College, Kent was used. The equipment compared the incident light within and outside the SRC. The difference between the two levels enabled a proportion to be calculated, the percentage of active radiation (PAR), representing the reduction in light levels within the coppice.

A 1 m-long integrated light meter which averaged the light levels along its length (this accounted for local variations in light levels) was used. This meter was held within the coppice and linked via a cable to a second light meter mounted on a tripod and stationed outside of the coppice. This meter measured ambient light. The difference between this measurement and that within the coppice was calculated and displayed as a percentage on a meter held by the operator. Two readings were taken at the centre of each plot, one perpendicular to the other, at a height of approximately 0.5 m (if weeds in the vicinity of the meter exceeded this height the meter was raised slightly to prevent any shading effect by the weeds) One hundred and twenty measurements were therefore taken with two readings from each of the 60 trial plots.

21.3.8 Analysis

An index of weediness was calculated for each plot in both years and used in subsequent investigations of the effect of plot weediness and coppice-stool growth.. The index was based on the proportion of ground within the trial plots covered by weeds, multiplied by the mean height of the weeds in metres. Two types of treatment plots were not essential for the purposes of this study and assessments of subtle differences in weed species composition and growth in the two weeded plots are reported in detail elsewhere (Clay, in prep). Consequently, where differences in weediness between the two treatment (weeded) plots were not significant, and the magnitude of weediness was negligible compared to weediness in the un-weeded plots, the intention was for the two weeded treatments to be combined to give a two level comparison between plot types. Species composition and DAFOR data were used in this study to ensure that plots that contained similar weediness indices were not dominated by species with differing competition potential, i.e. seedling relative growth rates and established strategies (after Grimes 1988).

The stem diameters taken in February 1997 were converted to a relative measure of biomass for each plot which had the same dimensions as mass (i.e. r^3, Sage *et al.* in press). The coppice-stool growth increment for 1996 was then calculated by taking the ratio of the mean stool biomass of each plot, as recorded in February 1996 (before cut-back), and the relative measure of biomass from February 1997.

This index of coppice growth was used as the dependant variable in a regression analysis undertaken on a per row basis. The mean growth increment in both un-weeded plots in each row were compared directly with the increment in both weeded plots by calculating the ratio of growth increments for the two plot types in each row. This gave a proportion representing the loss in growth in the un-weeded plots, compared to the weeded plots. This provided a linear regression model, based on 15 data points, describing the relationship between coppice growth and weediness. By combining plots in this way the number of data points in this comparative analysis is 15 and the number of stools in each plot type is 20 (40 stools in total per row). As we have already seen in Section 4.0, around 20 stools per plot type is a minimum number for detecting a reasonably small difference (10 %) with a reasonable degree of certainty ($P<0.1$) in willow SRC varieties of this type. Each data point in this regression then has substantial statistical power.

This analytical procedure was repeated for quantifying the effect of weediness on coppice growth increment during year two, taking account of year one growth, and on the coppice growth increment over the two-year period taking account of pre-treatment growth. The assessments of coppice stool biomass by either cutting and weighing stems, or by calculating stem volumes were used interchangeably. Differences in soil moisture, nitrogen and phosphorous content, number of stems per stool, PAR and crop height between treatment plots and between rows were investigated using ANOVA. All analyses were conducted using Systat (Wilkinson, 1990).

21.4 Results

21.4.1 Weediness

In June 1996, the mean index of weediness (% cover x mean height) in the 30 un-weeded plots was 36.00 (SD=16.92). The number of species recorded per plot was 9.88, SD=2.83 with all but one species with a mean cover of > 5 % occurring in 70% or more of all un-weeded plots (see Table 21.2 and 21.3 for weed species summary data).

The index of weediness was not different in the two weeded plots when measured in June 1996, following treatment (0.191, SD=0.301 and 0.069 SD=0.096 respectively), t test $t_{28}=1.496$, $P>0.1$). The number of species recorded per plot was different (3.58, SD=1.042 and 1.73, SD=0.51, $t_{28}=6.162$, $P<0.001$). Weediness in these plots was however extremely low compared to the un-weeded plots and in subsequent analyses comparing crop growth increments and weediness, and other effects, the two weeded plot types were not considered separately.

The mean index of weediness for the weeded plots increased significantly in 1997. In June 1996, the 30 weeded plots contained on average 8.4 % cover at 0.01 m high, giving a mean index of weediness of 0.13, SD=0.23. By June 1997, weed cover in these plots had increased to 22.3 % (significant difference between years, $t_{29}=4.551$, $P<0.001$) at 0.10 m high with an index of 4.21 SD=8.70 ($t_{29}=2.610$, $P<0.05$). This increase was particularly apparent in

Table 21.2. Plant species recorded in all trial plots in 1996 (year one) with mean abundance index (see below) for each plot type per row (n=15). Of the 23 plant species recorded in the un-weeded plots in 1996, only one, *Alopecurus Myosuroides*, was significantly more common in one weeded plot type than the other (t_{28}=1.83, $P<0.05$). In 23 tests, a significant difference in one species would be expected by chance at P=0.05. Data for the two un-weeded plots in each row, although identical, are shown separately.

Weed species	Un-weeded plots, abundance index				Weeded plots, abundance index			
	Two plots per row				Plot type 1		Plot type 2	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Epilobium spp.	2.200	1.125	2.200	1.118	0.556	0.272	0.022	0.086
Alopecurus myosuroides	1.511	0.562	1.111	0.392	0.311	0.427	0.089	0.198
Poa annua	1.333	0.882	1.000	0.701	0.267	0.314	0.000	0.000
Agropyron repens	0.933	1.063	0.800	0.764	0.289	0.278	0.133	0.246
Rannunculus repens	0.689	0.886	0.733	1.236	0.133	0.169	0.044	0.117
Cirsium palustre	0.556	0.514	0.711	0.576	0.556	0.466	0.533	0.414
Geranium molle	0.533	0.414	0.689	0.388	0.022	0.086	0.022	0.086
Galium aparine	0.600	0.402	0.333	0.333	0.622	0.353	0.644	0.367
Lactuca seriola	0.467	0.414	0.444	0.371	0.178	0.305	0.067	0.187
Viola arvensis	0.489	0.375	0.289	0.305	0.111	0.206	0.000	0.000
Myosotis arvensis	0.311	0.344	0.178	0.278	0.044	0.172	0.000	0.000
Poa trivialis	0.267	0.422	0.133	0.246	0.000	0.000	0.000	0.000
Sonchus arvensis	0.244	0.295	0.178	0.278	0.000	0.000	0.000	0.000
Matricaria maritima	0.111	0.206	0.200	0.246	0.044	0.117	0.000	0.000
Polygunum persicaria	0.067	0.187	0.089	0.198	0.289	0.396	0.000	0.000
Taraxacum officianalis	0.067	0.138	0.022	0.086	0.000	0.000	0.000	0.000
Rubus fruticosus	0.000	0.000	0.044	0.117	0.022	0.086	0.000	0.000
Carex hirta	0.000	0.000	0.044	0.172	0.000	0.000	0.000	0.000
Crysosorus cristatus	0.044	0.172	0.000	0.000	0.000	0.000	0.000	0.000
Lotus corniculatus	0.022	0.086	0.000	0.000	0.000	0.000	0.000	0.000
Senecio jacobia	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.086

The index of abundance is based on the DAFOR scale, where 1 = (R)are (0 - 5 % cover), 2 = (O)ccassional (5 - 10 % cover), 3 = (F)requent (10 - 25% cover).

Table 21.3. Forbes and grasses recorded in the un-weeded trial plots in June 1996 (following treatments). Seedling relative growth rate (RGR) and established strategy after Grimes et al. (1988). The first five or six species in the list were sufficiently abundant (mean cover see below) and widespread (% of un-weeded plots) to contribute significantly to the weediness index. While some other species occurred in a high percentage of plots they always occurred sat less than 5 % mean cover (see below), except *Carex hirta*, which occurred at 5 - 10 % in one plot.

Species	Seedling RGR	Established strategy	Percent occurrence in plots	Mean cover in plots
*Epilobium spp.**	-	CR	100	2.47
Alopecurus myosuroides	1.0 - 1.4	C to CSR	100	1.42
Poa annua	1.5 - 1.9	R	93	1.52
Agropyron repens	1.0 - 1.4	C to CR	77	1.55
Ranunculus repens	0.5 - 0.9	CR	43	2.09
Cirsium palustre	-	CSR	73	1.16
Geranium molle	-	R to SR	80	1.04
Galium aparine	1.0 - 1.4	CR	73	1.02
Lactuca seriola	-	-	70	1.00
Viola arvensis	-	R	67	1.00
Myosotis arvensis	-	RS	47	1.00
Poa trivialis	1.0 - 1.4	CSR to CR	33	1.00
Sonchus arvensis	-	CR	40	1.00
Matricaria maritima	-	R	37	1.00
Polygunum persicaria	1.0 - 1.4	R	17	1.00
Taraxacum officianalis	1.0 - 1.4	R to CSR	13	1.00
Rubus fruticosus	-	S C	7	1.00
Carex hirta	-	C to CSR	3	2.00
Cynosorus cristatus	1.5 - 1.9	CSR	3	1.00
Lotus corniculatus	1.0 - 1.4	CSR to S	3	1.00
Senecio jacobia	1.0 - 1.4	R to CR	0	.

- data not available. * *E. ciliatum & hirsutum*

The mean cover index is the mean DAFOR rating (where 1 = (R)are (0 - 5 % cover), 2 = (O)ccassional (5 - 10 % cover), 3 = (F)requent (10 - 25% cover)) of plots in which species occurred (minimum=1). The weed community in the trials area was dominated by species that had a high RGR and a competitor and/or ruderal established strategy. These species typically exploit productive habitats, exhibit high relative growth rates and are short-lived. Few species are intermediate stress-tolerators. These strategists typically exploit unproductive habitats, exhibit low growth rates and are long lived.

areas of the trial containing the most weeds (variety-sets 11 - 14, Figure 21.3).

FIGURE 21.3 NOT AVAILABLE ELECTRONICALLY

In contrast, the mean index of weediness for the un-weeded control plots decreased significantly over the period. Weed cover reduced from 82.0 % to 61.1 % (t_{29}=5.208, P<0.001), and weed height from 0.42 m to 0.31 m giving mean indices of 36.00 SD=16.92 and 22.02 SD=18.24 respectively (t_{29}=5.67, P<0.001). Despite this significant mean response, the weediness index in the weediest plots (variety-sets 12 and 13, Figure 21.3) did not decrease. Overall, the difference between weeded and un-weeded plots, and hence the competition effect on coppice growth, reduced between years.

21.4.2 Pre-treatment stool growth

Stool biomass accumulated during the 1995 growing season (prior to treatments), measured by cutting and weighing in February 1996, did differ between plot types in some rows (Table 21.4). Pre-treatment biomass data were included in subsequent analyses of growth increments and weediness to account for these differences.

Pre-treatment stool biomass varied considerably between varieties (Table 21.5). The highest yielding variety in 1996 ‘Ulv’ (*Salix viminalis*) weighed 0.826 kg per stool, while the lowest, ‘Gigantea’ (S….) weighed 0.304 kg per stool.

21.4.3 Stool growth during year one

For each of the 15 rows, the mean growth of the 20 stools in the two weedy plots was less than the mean growth of the equivalent stools in the two un-weeded control plots. The ratio of growth in the two plot types correlated with the difference in weediness indices between the two plots. As this weediness index increased, the proportion of growth in the weedy plots compared to that in the control plots decreased (Figure 21.4, $F_{1,13}$=32.33, P<0.001, r^2=71.3).

This relationship, for coppice growth increment on established stools during the first year following cut-back and for indices between about 5 and 60, is defined by the expression:

$G_{0-1} = 1.01304 - 0.00774 \times I_{0-1}$ (Equation 1.)

G_{0-1} = Stool growth, as a proportion of stool growth with no weeds
I_{0-1} = Weediness index (% area x mean height)

21.4.4 Stool growth during year two

The ratio of stool growth at the end of year two to the growth of at the end of year one in each plot (10 stools) was not related to plot type. For each of the

Table 21.4. Mean biomass of 20 stools for each plot type in each row, prior to the application of treatments, February 1996. A comparison is made between plot types using ANOVA of measurements taken in February 1996 (* is significant difference). Biomass is per stool in grams.

Row	Variety	Biomass, weeded plots	Biomass, Unweed plots	S.e.	F-ratio, df=1, 38	P	T
1	Orm	828.5	824.0	61.49	0.003	0.959	0.052
2	Cambell	550.0	485.0	46.05	0.996	0.324	0.998
3	Cambell	499.5	456.5	52.18	0.340	0.564	0.583
4	Mallatin	529.0	517.0	40.16	0.045	0.834	0.211
5	Mullatin	559.0	713.5	51.73	4.461	0.041*	-2.112*
6	Bowles	802.0	699.5	76.81	0.891	0.351	0.944
7	Q683	567.0	576.0	46.25	0.019	0.891	-0.138
8	Q683	514.5	435.5	49.39	1.279	0.265	1.131
9	ST2481/55	411.0	351.0	50.20	0.714	0.403	0.845
10	SV699	480.0	607.0	41.98	4.576	0.039*	-2.139*
11	Gigantea	466.5	497.0	33.99	0.402	0.530	-0.634
12	Gigantea	328.0	279.5	20.95	2.681	0.110	1.637
13	Q83	489.0	404.5	50.53	1.399	0.244	1.183
14	Ulv	495.5	402.5	49.00	1.801	0.188	1.342
15	Ulv	810.5	603.0	48.07	9.317	0.004*	3.052*

Table 21.5. The mean biomass of the one-year-old stems on the 40 stools in each trial row, prior to the application of treatments in February 1996. Biomass is per stool in grams and was recorded immediately following cutting.

Row	Variety	Biomass, all plots, gms	s.e., P<0.05
1	Orm	826.3	42.9
2	Cambell	517.5	32.6
3	Cambell	478.0	36.6
4	Mallatin	523.0	28.0
5	Mullatin	636.3	38.2
6	Bowles	750.8	54.2
7	Q683	571.5	32.3
8	Q683	475.0	35.0
9	ST2481/55	381.0	35.4
10	SV699	543.5	31.0
11	Gigantea	481.8	23.9
12	Gigantea	303.8	15.1
13	Q83	446.8	35.9
14	Ulv	449.0	35.0
15	Ulv	706.8	37.4

Table 21.6 Relative biomass in winter 1996/97, after one years' growth. Rmass is relative biomass based on stem diameter measures.

Row	Variety	Rmass, plot 1/2	SD	Rmass, plot 3/4	SD
1	Orm	953.9	281.5	945.3	265.2
2	Cambell	665.4	201.0	612.8	187.6
3	Cambell	617.1	213.1	597.6	180.6
4	Mallatin	830.2	190.6	715.8	136.1
5	Mullatin	905.2	174.5	647.8	238.7
6	Bowles	812.1	249.9	755.7	293.8
7	Q683	826.1	224.2	700.5	166.7
8	Q683	828.7	256.8	698.2	220.0
9	ST2481/55	818.5	305.1	679.4	318.8
10	SV699	862.7	201.6	670.7	308.0
11	Gigantea	793.5	222.3	504.7	106.6
12	Gigantea	680.6	218.6	415.1	101.9
13	Q83	823.8	367.3	415.1	223.8
14	Ulv	804.6	238.0	611.0	233.2
15	Ulv	1000.1	244.8	773.6	156.9

FIGURE 21.4 AND 21.5 NOT AVAILABLE ELECTRONICALLY

15 rows, the mean growth of stools in the weedy plots, expressed as proportion of growth in year 1, was approximately the same (within ± 20%) as the mean growth in the two un-weeded control plots during the second year (Figure 21.5).

21.4.5 Stool growth over two years

The ratio of stool growth at the end of year two to the pre-treatment growth in each plot was related to the to plot type. For each of the 15 rows, the mean growth of the 20 stools in the two weedy plots was again less than the mean stool growth in the two un-weeded control plots (Figure 21.3) and the ratio of growth in the two plot types correlated with the mean (year one and two) difference in weediness indices (Figure 21.6, $F_{1,13}=15.27$, $P<0.005$, $r^2=54.0$).

This relationship for coppice growth on established stools during the two years following cut-back, for mean (of year one and two) indices between about 5 and 60, is defined by the expression:

$G_{0\text{-}2}=0.98824 - 0.00879 \times I_{0\text{-}2}$ (Equation 2)

$G_{0\text{-}2}$ = Stool growth, as a proportion of stool growth with no weeds
$I_{0\text{-}2}$ = Mean weediness index for year one and two (% area x mean height)

Using the year-one only index of weediness in this regression provides a similar significant result (Figure 21.7, $F_{1,13}=16.87$, $P<0.005$, $r^2=56.5$). This allows a comparison between the relationship for coppice growth in year one, $G_{1\text{-}0}$ equation 1 above, and the relationship for coppice growth during the two years over the same X-axis range (weediness indices $I_{1\text{-}0}$):

$G_{0\text{-}2}=1.00776 - 0.00711 \times I_{0\text{-}1}$ (Equation 3)

$G_{0\text{-}2}$ = Coppice growth, as a proportion of stool growth with no weeds
$I_{0\text{-}1}$ = Weediness index for year 1 (% area x mean height)

Differences in stool growth between rows over the two years are illustrated in Figure 21.3. Variety type in each row are given in Table 21.5.

21.4.6 Soil analysis

Soil moisture did not differ between plots when measured in 1996 ($T_{22}=1.568$, $P>0.1$) or 1997 ($T_{14}=1.428$, $P>0.1$) although it was different between years. Soil nitrogen and phosphorous did not differ between plots when measured in 1997 ($T_{18}=0.488$, $P>0.5$, $T_{18}=0.463$, $P>0.5$).

21.4.7 Number of stems per stool

Using ANOVA, the mean number of stems per stool for each plot (10 stools) at the end of year one (1996) was related to the row and to plot type

FIGURE 21.6 AND 21.7 NOT AVAILABLE ELECTRONICALLY

($F_{14,30}$=6.422, P<0.001, $F_{1,30}$=11.563, P=0.002 respectively) while the interaction term was not significant (set x plot type, $F_{14,30}$=0.884, P=0.582). By including the continuous weediness index variable in the model, the variation in stem number explained by plot type was removed ($F_{1,43}$=0.009, P=0.925) and weediness became significant ($F_{1,43}$=14.937, P<0.001, row, $F_{14,43}$=8.957, P<0.001). This model explained 78.1% of the variance in the mean number of stems per stool in each plot during year 1. For 1997 a similar relationship was apparent. Stem number was related to the row and to plot type ($F_{14,30}$=4.242, P<0.001, $F_{1,30}$=10.257, P=0.003 respectively) while the interaction term was not significant (set x plot type, $F_{14,30}$=0.781, P=0.680). By including the continuous weediness index variable in the model, the variation in stem number explained by plot type was removed ($F_{1,43}$=0.288, P=0.594) and weediness became significant ($F_{1,43}$=19.963, P<0.001, row, $F_{14,43}$=6.230, P<0.001). This model explained 74.7% of the variance in the mean number of stems per stool in each plot during year 2.

In 1996, the first year of coppice re-growth, the mean number of stems per stool throughout the trial was 14.76 (SD=5.31). This reduced to 11.68 (SD=4.41) in 1997. In 1996, the weed-free plots contained 15.68 (SD 5.51) stems per stool, significantly more than in the weedy plots (13.85, SD 4.94). Similarly in 1997, the weed-free plots contained 12.49 (SD 4.51) stems per stool and the weedy plots 10.87 (SD 4.15) (Figure 21.8).

21.4.8 First year crop height

The mean crop height for each plot (10 stools) was related to the row and to plot type ($F_{14,30}$=8.932, P<0.001, $F_{1,30}$=9.106, P=0.005 respectively). The interaction term was not significant in this model (set x plot type, $F_{14,30}$=0.656, P=0.797). By including the continuous weediness index variable in the model, the variation in stem number explained by plot type was removed ($F_{1,43}$=0.127, P=0.724). The model (weedi, $F_{1,44}$=15.053, P<0.001, row, $F_{14,44}$=11.484, P<0.001) explained 79.2% of the variance in the mean PAR per stool in year 2.

Throughout the trial, the mean crop height, as measured in late June 1996, was smaller in the un-weeded plots (96.39, SD=14.57) than in the weeded plots (101.66, SD=14.43). Mean shoot height was greater in the un-weeded plots in all but two rows (Figure 21.10). The mean weed height in the un-weeded plots was typically around half crop height when measured (Figure 21.8), although the error bars indicate that many individual weeds were considerably taller than the mean.

21.4.9 Canopy light penetration

The mean PAR for each plot (10 stools) was related to the row and to plot type ($F_{14,30}$=6.749, P<0.001, $F_{1,30}$=19.317, P<0.001 respectively). The interaction term was also significant in this model (set x plot type, $F_{14,30}$=7.147, P=0.009). By including the continuous weediness index variable in the model, the variation in stem number explained by plot type was removed ($F_{1,43}$=0.500, P=0.483) and weediness became significant. The model (weedi, $F_{1,43}$=14.534, P=0.004, row, $F_{14,43}$=7.487, P<0.001, row x weedi, $F_{14,43}$=5.063, P<0.001) explained 90.1% of the variance in the mean PAR per stool in year 2. Throughout the trial, the mean percentage of active radiation (PAR) penetrating the crop canopy, as measured in late June 1997, was greater in the un-weeded plots (7.711, SD=3.331) than in the weeded plots (5.902, SD=2.694) (Figure 21.10).

FIGURE 21.8, 21.9, 21.10 NOT AVAILABLE ELECTRONICALLY

21.5 Discussion

21.5.1 The relationship between growth losses and weediness

The relationships between coppice growth and weediness quantified in this study, (Equations 1 - 3 and Figures 21.4 - 21.6) enable a proper assessment of the effect of weediness on crop growth. The relationships have been developed to provide a measure of the growth loss, given a certain weediness, and are expressed as a proportion of the growth expected in weed-free plots. Growth in any one plot is calculated from the ratio's of biomass before and after the period of interest (this includes growth during the first year of re-growth following cut-back where it was assumed above ground differences in stool biomass that existed in plots before treatments were applied were reflected in root biomass). We needed also to make an assessment of differences in the competitive effect of different weeds across the trial area. In cereals, production losses varied between weed species with grossly different seedling relative growth rates (RGR's) and established strategies (Wilson and Wright, 1990, Grimes 1988)). In this study however the main weeds that were abundant and widespread in the trial area listed in had similar RGR's and established strategies (Table 21.3).

Consequently the analysis provides reliable and accurate information on the relationship between coppice growth loss and a wide range of weediness levels, over one and two years for the first time in SRC crops. The relationships can be easily interpreted to assess the economic cost of weeds in SRC and hence the economic threshold for weed control measures.

The weediness indices is simply an area by height measure and is equivalent to the volume of weeds. An index of 20 is equivalent to 100 % ground cover with a mean height of 0.2 m. It is also equivalent to 50 % cover at 0.4 m high and so on. The weediest plots in this trial had an index of 50 or more, equivalent to 100 % cover and mean height of 0.5 m. Although annual and perennial weeds can easily exceed this height, it is unlikely that weediness indices in excess of 80 or so would occur in anything but the most extreme circumstances. An index of 50 then represents an abundant and vigorous weed community.

According to the model in Equation 1 for the linear regression in Figure 21.4, given a weediness index of 50, the growth of willow coppice stools in this trial after one year following cut back would be 62.6 % of that in a weed-free plot. This a significant loss of biomass (37.4 %) but as already indicated weediness is very high. For an index of 20, the same model would predict growth of 85.8 % of that in a weed free plot, i.e. a loss of 14.2 %, and for an index of 10 growth would be 93.6 % or a loss of 6.4 %. At these lower (but still substantial) levels of weediness the consequent losses of biomass are relatively small. It may in fact be that the cost of controlling the weeds exceeds the value of the biomass increase that results. This economic threshold is easy to calculate.

A comparison of the slope in Equation 3 with the slope in Equation 1 (same X-axes), indicates that over the two years, the growth reduction of the coppice caused by plot weediness as measured in year one, was roughly the same and if anything, slightly less than the reduction observed in the first year. It is not useful to compare the relationship for coppice growth during the two years in equation 2, where the mean weediness was used, with equation 1 (year-one growth and weediness) as the two equations are based on different X-axes. This similar growth in the two plot types is indicated by the relationship illustrated in Figure 21.5 for year two where the trend was insignificant due to the small effect compared to data variance. This means that during the second year, stools in plots with a high index of weediness grew the same or slightly more vigorously than stools in plots with a low index. The actual stool growth or biomass increase in all plots reflected the size of the stool at the beginning of that year and weediness had no net effect.

Over two years then, the proportionate loss in growth is roughly the same as over one year - if anything slightly less. The model in Equation 3 indicates that for a weediness index of 50 in the first year, the growth over two years will be 65.2 % of that in a weed free plot. For an index of 20, the growth reduction will be 86.6 % and for an index of 10, 93.7 %. As before these losses of biomass are relatively small. It may in fact be that the cost of controlling the weeds exceeds the value of the biomass increase that results.

As with any other single site study, there are however qualifications to made when applying these relationships to other situations. The growth response documented here may differ considerably depending on site conditions. It is likely for example that weediness may have a greater competition effect in lighter soils, weed type, local climate, planting density, the presence of other pest problems can all be important.

21.5.2 Causes of growth losses

In many situations, it is thought that competition for water between weeds and trees causes reductions in the growth of trees. Clay & Dixon (1996) thought that weed competition is probably most severe in early summer (April, May, June), when weeds are at their most vigorous (although he also points out that the occurrence of perennial weeds and the long growing season for SRC means that the growth of these crops can be affected all year). Soil moisture was measured at the end of this period in this study in 1996 and 1997 for this reason. No differences were however found between the plot types in either year. This perhaps is not surprising - rainfall was about average for the first half of the summer in both years and the clay loam soil is capable of holding a high moisture content (Davies 1987). Soil moisture was however different between years, indicating that soil moisture was below the field capacity in at least one year (1997). Nevertheless this did not appear to lead to competition for moisture between the weeds and the crop during the main growing period of the weeds in both years (April to June). Some moisture competition may have occurred later in the season (Davies 1987) although we did not measure this. As already indicated however, water use by the weeds would be reduced during this period. Water use by the crop, which would have been roughly similar in all plots, would have continued.

We did however find differences in other measured plot parameters. The higher PAR in the un-weeded plots, indicates that the coppice canopy was intercepting less radiation than in the weeded plots, i.e. that the un-weeded plots had a reduced leaf area (Section 3.0). Although the stool biomass was smaller in these plots, as usual with year-one SRC, canopy cover was complete throughout the trials area suggesting that some aspect of canopy density was reduced in the un-weeded plots rather than its overall 'size', for example leaf size or the number of leaves. This is commonly caused by moisture stress. By producing less foliage, un-weeded trees reduce their water needs compared to weeded trees (Davies 1987). Moisture stress also causes the stomata of trees to stay closed for longer and for tree growth to be halted prematurely in the season.

While all these responses will cause a reduction in growth, as already indicated, coppice growth was not actually affected by weediness in year two. The reduction in PAR recorded must therefore reflect only the smaller size of stools caused by weediness in year one. In year one, a reduction in leaf area may have occurred due to moisture stress but it was not possible to measure PAR beneath the canopy in this way. Soil moisture was however lower in year two than year one when measured. If moisture competition between weeds and the coppice was important in year one, some sort of response would have been expected in year two. It seems likely therefore that a reduction in the availability of water to the coppice caused by weediness did not occur in either year. While it is also possible that root interference in the weedy plots reduced the water uptake capability of the coppice, this again would have had an effect in both years. What is lacking is a cause for the fundamentally different response in coppice growth to weediness between years.

The similar soil moisture levels when measured each year and the lack of effect of weediness in 1997 indicate that competition for moisture between weeds and coppice did not contribute significantly to the reduced biomass recorded in the weedy plots.
Weediness may have a greater competition effect in lighter soils which have a lower water holding capacity. Clay (1989) commented that it is generally accepted that weeds will reduce water availability to SRC in well drained soils in dry periods but indicated that experimental evidence is lacking. Davies

(1987) also concludes that it is likely that weeds will cause greater losses in the growth of young trees in poor soils.

In year one, we did find a small but significant difference in crop height between plot types. Stem extension during the first half of 1996, as measured a the end of June, was significantly greater in the weedy plots than the weed-free plots. This kind of growth response is caused by competition for light and is well documented. Many plants subject to shade will search for light and show exaggerated growth in one direction. The mean height of the weeds in the weedy plots was around half the coppice stem length when measured and some weeds in some plots matched coppice height. Young willow coppice shoots characteristically leaf along their entire length so clearly some shading occurred during year one. By the second year however, virtually all leafing of the willow occurred above the weed growth and competition for light no longer occurred.

Competition for light affects root growth and consequently above ground biomass. Davies (1987) thought that competition for light by weeds was relatively unimportant compared to underground interference in landscape trees as most trees make most growth at less than full sunlight. However, for potentially high yielding SRC varieties, growing in good soil conditions, competition for light may be the limiting factor in growth potential. In particular, it is necessary to consider the exceptionally high growth potential of willow SRC varieties compared to other trees. In ideal conditions, *S. viminalis* SRC varieties like some of those in this trial are capable of growing to a height of 5 m in one season from an established stool following cut-back. This extreme growth potential means that any limiting factor can cause exaggerated reductions in growth. The availability of water and nutrients in this trial meant that competition for light may have caused the measured reductions in biomass in the weedy plots.

As indicated the weeds caused, through shading, an increase in crop height when measured in 1996, yet biomass was lower at the end of the year. This apparent anomaly may have occurred for several reasons. First, stems in weedy plots may be taller but thinner. Davies (1987) commented that shading caused stem diameter reductions in trees. In this study however, the mean stem diameter after year one were not different between plots. Second, growth in the weed-free plots may have shown improved growth in the second half of the year and compensated for the reduced height measured in June by the end of the year. While this may have occurred, we do know that the third possible cause did occur. The number of stems on stools in the weedy plots were significantly lower than in the weed-free plots at the end of year one and year two. This reduction in stem number, as a proportion of stems in the weed-free plots, accounts for the recorded reductions in biomass.

Self thinning and stem die-back always occurs on stools in SRC plantations due to competition between stools. Verwist (1991) uses self-thinning curves to predict an average stem density per m^2 given a certain planting density, rotation and yield. This competition effect between stools has not been considered so far but in a sense, the effect on any one stool of the surrounding stools, is equivalent to (rather tall) vigorous perennial weeds.

In summary, we found no evidence for competition between weeds and coppice growth for moisture or nutrients over the period of the study. The high soil moisture retention capability and nutrient status prevented differences developing between plot types within years and over the two year period. Instead, stools growing in weedy plots competed for light and space with fast growing weeds during the first half of 1996. Stems that grew outwards from the coppice stools were curtailed by the surrounding weediness. This initiated a taller narrower coppice growth amongst weeds. This would also account for the difference in PAR measured in 1997. It is likely that root growth was also affected (Davies 1987). Weediness then has the same effect as increasing stem density in a plantation. Increasing stem density beyond around 10000 per hectare (20000 stools/ha in this experiment) does not lead to increased yields per hectare as competition for space and self thinning simply reduces the biomass production of individual stools. In this respect, weediness has the equivalent effect of increasing stool density.

These results suggest that in other situations, on reasonable soils which have a good soil moisture retention capability, i.e. clay and clay loams but also organic soils in the uplands, weeds will not necessarily reduce water and nutrient availability to coppice stools under normal conditions. In drought conditions, where nutrient depletion has continued for many years or in poorer lighter soils, which have a lower moisture retention capability competition for these resources by weeds may be much more important.

21.6 References

Anonymous (1994) *Sustainable Forestry, The UK Programme.* HM Government report. HMSO, London.

Anonymous (1991) *Forestry Policy for Great Britain.* Forestry Commission, Edinburgh.

Anonymous (1994) *Alternative Crops: New Markets.* Ministry of Agriculture, Fisheries and Food

Anonymous (1996) *Good Practice Guidelines: Short Rotation Coppice for Energy Production*, pp 46. ETSU, Harwell, England.

Ahman, I., Larsson, S. (1994) Genetic improvement of willow (Salix) as a source of bioenergy. *Norwegian Journal of Agricultural Sciences.* Supplement No. 18: 47-56.

Armstrong A., Johns, C., Matthews, R. & Straw, N. (1997) Second interim report on contract B/W2/00525/00/00 yield models for energy coppice of poplar and willow. Phase II May 1996 - May 1997. Forestry Commission research Agency.

Clay, D.V., Dixon, F.L., Goodall, J.S. & Parfitt, R.I. (1993) Effect of herbicide mixtures applied to newly-planted poplar and willow coppice. *Brighton crop Protection conference - Weeds - 1993*, 695-700.

Clay, D.V. & Dixon, F.L. (1996) *Report on experiments on weed management in coppice - 1994 - 1995*. ETSU report B/W2/00401/REP/2, pp 24. Harwell Laboratories, Oxfordshire.

Davies, R.J. (1985) The importance of weed control and the use of tree shelters for establishing broad-leaved trees on grass-dominated sites in England. *Forestry*, **58**: 167-180.

Davies, R.J. (1987*) Trees and Weeds: Weed Control for Successful Tree Establishment*. Forestry Commission Handbook 2, pp. 36. HMSO, London.

Davison, J.G. & Bailey, J.A. (1980) The effect of weeds on the growth rate of nursery stock species grown as liners and grown for two seasons. *Proceedings Conference of association of applied Biologists on weed Control in Forestry*, 33-34.

Grime J.P., Hodgson J.G., & Hunt R. (1988) *Comparative plant ecology*. Unwin Hyman, London.

McIntosh, R. (1980) The effect of weed control and fertilisation on the growth and nutrient status of sitka spruce on some upland soils. *Proceedings of the Conference on Weed control in Forestry 1-2 April 1980, Association of Applied Biologists*, 55-63.

Nilsson, L.-O. (1982). Determination of current energy forest growth and biomass production. *Swedish Energy Forest Project, Swedish University of Agricultural Sciences, Uppsala, Sweden*. Technical report no. 27.

Tabbush, P.M. (1984) Effects of different levels of grass-weeding on the establishment of Sitka spruce. *Crop protection in northern Britain 1984*, 339-344.

Verwijst (1991) Shoot mortality and dynamics of live and dead biomass in a stand of *Salix Viminalis. Biomass and Bioenergy*, **1**: 35-39.

Verwijst, T. & Nordh, N. (1992) Non-destructive estimation of biomass of *Salix dasyclados*. *Bioresource Technology*, **41**: 59-63.

Wilson, B.J. & Wright, K. (1990) Predicting the growth and competitive effects of annual weeds in wheat. *Weed Research* **30**, 201-211.

Wilkinson, L. (1990) *Systat, The System for Statistic.* Systat Inc. Evanstan, Illinois, USA.

22.0 INTEGRATED PEST MANAGEMENT - WEEDS

22.1 Summary

This section draws primarily on the findings of the previous 3 Sections (19.0 – 21.0) and develops an Integrated Pest Management strategy for weeds in SRC.

Previous work on weediness in newly planted SRC crops indicates that control is essential and that herbicide applications are the best method of managing these weeds.

Both extensive and intensive studies indicate that plant communities in SRC tend to become less competitive with time as invasive ruderal species are replaced by more stable perennial ones. Repeated applications of herbicide, particularly contact herbicides, slow or stop this beneficial process.

In established willow coppice planted on typical clay and loam type soils and under normal rainfall conditions, the tolerance of the crop to weediness, and hence the economic threshold for taking action to control weeds, is high.

Under these conditions, unless a complete ground cover of weeds above around knee height (or patchy weeds at increasing heights in proportion to the reduction in ground cover) is achieved, it is possible that a herbicide application after cut-back will not lead to a cost-effective increase in yield.

Weed competition in recently cut but established coppice, under typical soil and climate conditions, may be affected primarily by competition for light and space in spring. In this case, where weeds are abundant, a knock-back by cutting weeds in spring may be sufficient, although this has not been tested.

A reduction in the use of herbicides in SRC and the tolerance of other plants within these crops, will in time, lead to a reduction in the occurrence of invasive ruderal weed species and the development of a shade tolerating perennial flora. This will further reduce the competition potential of the coppice understorey vegetation, and have considerable benefits to wildlife use and potentially crop profitability as part of an ICM approach.

22.2 Introduction

The continued increase in the use of pesticides, including herbicides, has contributed to the substantial reductions in the abundance and diversity of all wildlife groups in farmland ecosystems. Herbicides reduce floral and hence insect diversity, and consequently reduce the abundance and diversity of other animals using crops that are sprayed.

Integrated Crop Management is the term used to describe a crop production system that is based on good husbandry and takes account of the impact of farming practices on the environment (Section 1.0). The intention is to integrate a range of farming practices in order to balance the economic production of crops with measures that preserve or enhance the environment. It is a pragmatic approach that recognises the over-riding importance of crop production and the profitability of the farm, and consequently it does not exclude the use of herbicides. SRC is particularly suited to IPM because of its high economic threshold to pest damage. It is also a perennial crop on, typically, a three year rotation, and as such it is a relatively stable habitat (compared to an annual crop).

The integrated approach to weed pest management (IPM) described here, would be an important component of an ICM strategy in SRC crops (Section 1.0). It would need to take account of the other impacts of a herbicide application, in particular the effect on non-target species, which may be playing a beneficial role in limiting the abundance of weeds and insect pests in the long term. For weeds, IPM aims to manage populations in such a way that their abundance remains below economic threshold levels.

In Sections 19.0 – 21.0 we have developed the basis for an Integrated Pest Management (IPM) strategy for weeds in SRC. In this section we pull the key points of this work together to form a proper integrated strategy for weed pest management. In other sections of this report, we have also developed our understanding of the use of this crop by wildlife and the importance of other plants to this, following on from our previous work on this (Sage *et al*, 1994). This work is important because an ICM approach contributes very little beyond a conventional crop management system if it does not take account of the impact to other plants and animals using the particular crop. We have also drawn on the work of others, in particular, Avon Vegetation Research who have developed weed management systems when planting SRC.

22.3 Weed competition at establishment

We have nothing further to add to the work by Avon Vegetation Research and others on weed management systems when planting SRC (e.g. Clay et al. 1993, Clay & Dixon, 1996). It is clear that unrooted willow and poplar cuttings do not compete well with other plants and new plantings are aimed at ex-arable land of high fertility with large weed seed populations. The risks associated with poorly established stools are too great. Weed competition at establishment can reduce the early development of planted willow and poplar cuttings that effect growth and yields for years to come.

In most instances the recommended combinations for initial weed control for SRC usually involve pre-ploughing contact (foliar acting) herbicides to reduce perennial weeds and post planting residual (soil acting) herbicides to prevent annual weeds germinating from the seed bed. Although there may be some scope to use mechanical methods of control, the initial use of herbicides when planting SRC is cost effective and in most agricultural situations not too damaging ecologically. There may however be scope to investigate the targeted use of selective herbicides in the future, to further reduce the ecological impact of these applications. As indicated in Section 19.0 and 22.5 below, these could be used to remove invasive ruderal species, but allow slower growing perennials to remain.

22.4 Weed competition in established coppice

Clay & Dixon (1996) point out that invasive perennial weeds can colonise second and subsequent years SRC growth, after the initial cut back and many growers see this happening. In the spring, many weeds are capable of exploiting the open conditions created by harvesting SRC and if they grow vigorously, they can compete with the growth of new coppice shoots. Later in the summer, especially if canopy closure in the coppice is not dense, the weeds can continue to grow within the coppice. While weed competition is probably most severe in early summer (April, May, June), the occurrence And growth of perennial weeds can continue throughout the summer. Although Clay & Dixon (1996) did not show conclusively that significant losses in yields occurred in these circumstances (and suggested that future work on economic thresholds in established SRC was an important requirement), it is usually recommended to apply a selective/directed contact herbicide and/or a residual after the first and subsequent winter harvests of SRC crops ‘to make sure’. Herbicide applications can only be applied following cut-back in established coppice. Without clearer information, the regular use of preventative herbicide applications stems from the need to reduce risks in production.

22.5 The development of plant communites in SRC

Section 19.0, which follows on from the work in Sage (1995), indicates that few SRC plots in Britain are completely devoid of other plants, despite the regular use of herbicides in many. Some supported a complete ground cover. Over 150 different plant species were recorded from a sample of 21 sites. Communities differed between SRC plots on ex-cropland in east and central Britain and on ex-grassland in west Britain and Ireland. These differences reflected the different land-use in the two regions. The age of establishment was also an important determining factor indicating that a stable situation has not been achieved in exisitng SRC plantations. In particular, the section indicates that there is a tendancy for the plant communities in SRC to change from a competitive ruderal community, to either a stress-tolerant woodland type or sparse ruderal community. The trend is towards a more stable and diverse community with fewer annuals and invasive perennials and more slower growing perennials. In the absence of herbicides this trend is likely to advance more quickly.

This result is reinforced by the analysis of the intensive flora introduction trial (Section 20.0), where 18 shade tolerant perennial species were introduced into two replicated trial plots of SRC. Over the three year study period ending in spring 1998, the proportion of ground covered by weed species decreased from 60% to less than 20%, while the introduced species showed a smaller but still significant increase.

This is an important finding as it suggests that the relative stability of SRC crops means that the weed community that develops in these crops becomes steadily less competitive. The perennial plants that are commonly found in shaded conditions are slower growing than the invasive ruderals that colonise bare or disturbed ground. They are also more stable and out-compete these ruderals once they are established.

Tolerating the presence of other plants in SRC crops will in itself contribute to the diversity of species using SRC crops, and will also vastly improve the value of these crops to other wildlife groups. Insect diversity for example would increase, with populations of species that feed on these plants rather than the crop itself. Some of these may predate on insects that are feeding on the crop itself and consequently have a pest controlling effect. For birds, The link between increased numbers of birds and the presence of a ground flora was shown in Sage et al. 1994. For small mammals, the presence of the crop itself is almost superfluous as it is the weediness alone that provides the cover they need.

Section 20.0 indicates the sort of plants that are most suited to the conditions within SRC plantations. While a community containing a substantial number of these species is unlikely to develop within a few rotations of a SRC plantations' life, the results of Section 19.0 indicates that plant communities containing similar perennial species do develop quite quickly. Where appropriate colonisation sources are absent, we tentatively suggest that there is an opportunity to introduce a non-competitive perennial ground flora, in certain circumstances. A cheap seed mix could be developed. This may seem a bit esoteric but the benefits of a stable, non-competitive perennial ground flora, discussed in more detail in Section 20.0 are considerable and include, ground cover protection from other weeds, soil integrity, nectar source for insects, bird nesting cover, game habitat, amenity and landscape value and enhancing the public perception of SRC and energy forestry as a whole. While there may also be negative interactions between a herbaceous ground cover and, in particular, crop pests and diseases none have as yet been identified.

Can this situation be achieved? It is clear that the application of, in particular, contact herbicides, effectively sets the development of a non-competitive plant community in SRC back to square one each time. The bare earth created is the main target of competitive ruderals. In Section 21.0, we attempt to address this by developing an economic threshold for weediness in SRC crops, which it is hoped, will reduce the risk of not applying herbicides to plantations following harvests. Despite the benefits of a stable perennial ground flora outlined above, an IPM approach to weeds needs to be an economic exercise, aimed at reducing the number of herbicide applications required over the life of an SRC plantation.

22.6 The economic threshold for weeds in established coppice

The contrast between a newly planted cutting and an established stool in terms of the initiation and extension of young shoots is enormous. It is this difference that creates an opportunity for an IPM approach to weed management in established SRC where one in newly planted SRC perhaps does not exist.

By providing economic thresholds for weediness in established SRC under typical climatic and soil conditions, and by demonstrating the mechanism by which weediness affects coppice stool growth, the study described in section 21.0 should enable growers to take a less precautionary approach to weed control. In particular, growers should have sufficient information to avoid the systematic application of herbicides in established SRC fields following cut-back. With this in mind, the findings in Section 21.0 are perhaps the most important of this entire study.

During this two-year study, we found no evidence for competition between weeds and coppice growth for moisture or nutrients. The soil moisture retention capability and nutrient status of the clay-loam soil at the study site, prevented differences developing between plot types within years and over the two year period. Instead, stools growing in weedy plots competed for light and space with fast growing weeds during the first half of 1996. Stems that grew outwards from the coppice stools were curtailed by the surrounding weediness. This initiated a taller narrower coppice growth amongst weeds. It is likely that root growth was also affected. Weediness then has the same effect as increasing stem density in a plantation. Increasing stem density beyond around 10-20,000 per hectare (20000 stools/ha in this experiment) does not lead to increased yields per hectare as competition for space and self thinning simply reduces the biomass production of individual stools. In this respect, weediness has the equivalent effect of increasing stool density.

These results suggest that in other situations, on soils that have a reasonable soil moisture retention capability, i.e. clay and clay loams but also organic soils in the uplands, weeds will not necessarily reduce water and nutrient availability to coppice stools under normal conditions. In drought conditions, or at sites where nutrient depletion has continued for many years or in poorer lighter soils, which have a lower moisture retention capability, competition for these resources by weeds may be much more important.

22.6.1 cost benefit analysis

To use the information on economic thresholds described in Section 21.0, a grower or crop manager would first need to develop an understanding of the pattern of weed growth in his or her SRC plantation. The grower needs to make an informed judgement about the extent of weed regrowth following a cut-back, when the weeds are opened to the light. This judgement can be based on the extent of the weediness present in the previous summer and a knowledge of the species involved.

The model in Section 21.4.3 (Equation 1, see also Section 21.5) predict that for a weediness index of 20, there will be a reduction in biomass production of 14 % compared to weed free conditions. An index of 20 is equivalent to a complete ground cover of weeds with a mean height of 20 cm (so with weeds of varying between ankle and knee height), or 50 % cover with a mean height of 40 cm and so on. Note that the reduction in biomass over one or two years was approximately the same, and was related to weediness in year one only.

For a coppice yield of 12 (dry) tonnes per hectare per year, this is equivalent to a production loss of 1.68 tonnes per ha per year, or 3.36 tonnes over a two-year rotation. If 3.36 dry tonnes is worth £100 (£30 per tonne at harvest), then a herbicide application must cost less than this to be cost-effective on a two year rotation. This analysis assumes that the herbicide application will be totally effective in removing all weeds and that there is no knock-back effect on the coppice growth by the herbicide. It is therefore likely that the herbicide application would need to cost significantly less than £100 to be cost effective.

Similar calculations can be made for different weediness levels. The analysis depends on the coppice rotation length, the coppice yield, the value of the crop and the cost of applying a herbicide. In the above, typical figures are used. Herbicides themselves vary greatly in price and the formulation used depends on the weed species present. Many contact herbicide applications would however cost in excess of £100 per hectare so for the scenario above, it would not be cost effective to spray the cut coppice.

In general, if the grower predicts dense fast growing weeds, with an index in excess of 20 or 30 (equivalent to 100 % cover at around knee height or 50 % cover at twice this height), it may be prudent to apply a herbicide to that area. Otherwise an application may simply be uneconomic - the cost of the product and the application may exceed the extra yield.

22.6.2 cutting weeds

Note that the work concluded that it is competition for light and space between the weeds and the coppice that caused the observed reductions in yield in the weedy areas of the trial. This of course may not always be the case and on poor soils or in particularly dry years, competition for water and nutrients may become important. Under typical conditions however this is not necessarily the case and where competition for space is the main restricting effect, simply cutting weeds in spring could become an economic alternative to herbicide applications in established coppice.

Cutting weeds around the base of tree saplings has been shown to cause growth losses in some situations (, 1987), particularly when establishing young trees for landscaping purposes. However the situation in SRC is very different. First it is usually broadleaf weeds that cause problems in SRC crops, which, unlike most grasses, decrease in vigour following cutting. Second, in most tree planting situations, cutting grass exposes otherwise open ground to rapid drying. This does not occur in SRC. Third, the studies have usually been undertaken on recently planted trees that have not established a deep root system.

For young SRC shoots growing from a recently cut established stool, cutting or harrowing weeds would prevent competition for space, which in the two-year trial described in this report, was the only cause of competition between weeds and the cut coppice stools. One cut would have been sufficient, providing the young coppice shoots were avoided. Previously, repeated cutting or hoeing of weeds was considered necessary to prevent the ingress of weeds. The practicalities of cutting or harrowing weeds in cut coppice would need further investigation although some work has been done (ref). This work indicates the feasability of the approach.

22.7 Fertilisation

Fertilsation is not a factor that has been considered in this study. We know that the nutrient demand of willow and poplar SRC is low compared to other arable crops, partly because nutrients are recylced through the leaf litter. However, the use of relatively small amounts of inorganic fertilisers has been shown to be economic in established coppice where soils nutrients are low (ADAS, 1995). When planting SRC, fertilisation can contribute to weed problems and is not considered useful.

The application of sewage sludge to SRC crops could provide the crop with fertiliser and provide a disposal route for sludge which remains a major problem in parts of Britain (Riddle-Black, 1995). The effect of sewage sludge on the habitat and wildlife value of SRC has not been considered. It is however likely to increase weed problems in established SRC and reduce the chances of a stable non-competitive flora developing.

Within an ICM strategy for SRC, the aim would be to identify the depletion of nitrogen and to top up the system with the minimum NPK amount required. If sewage sludge were to be applied, more as a disposal route that as a fertiliser, sludge may be applied in excess. While the wider environmental benefits of sewage sludge disposal on non-food crops may be clear (as opposed to for example disposal at sea), the local environmental impact of sludge applications to SRC crops need to be investigated before this practice can be considered part of a balanced ICM approach.

22.8 References

ADAS (1995)Arable energy coppice : a review of published R & D and discussion of the potential for widespread production on surplus agricultural land in the UK. Eds. Britt C., Heath M., & Buckland M. Adas, Oxford.

Clay, D.V., Dixon, F.L., Goodall, J.S. & Parfitt, R.I. (1993) Effect of herbicide mixtures applied to newly-planted poplar and willow coppice. *Brighton crop Protection conference - Weeds - 1993*, 695-700.

Clay, D.V. & Dixon, F.L. (1996) *Report on experiments on weed management in coppice - 1994 - 1995.* ETSU report B/W2/00401/REP/2, pp 24. Harwell Laboratories, Oxfordshire.

Davies, R.J. (1987*) Trees and Weeds: Weed Control for Successful Tree Establishment*. Forestry Commission Handbook 2, pp. 36. HMSO, London.

Riddle-Black D. (1995) Fertilization of SRC energy coppice using sewage sludge – phase 1. ETSU report B/W5/0215/REP.

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