Ecological and socio-economic impacts of military training on Salisbury Plain

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by

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Abstract

Chalk grasslands are a habitat with high European importance for both flora and fauna. The largest known expanse of unimproved chalk grassland in NW Europe lies within the Salisbury Plain Training Area (SPTA) in SW England, where sole use of the land for military purposes since the end of the nineteenth century has limited the ecological damaging impacts of modern intensive agriculture. Organisational changes in the British Army may now paradoxically be threatening this unique ecological resource. In this thesis, some of the ecological and socio-economic impacts of military disturbance of chalk grassland are investigated using a variety of approaches including historical studies, field and laboratory experimental studies, and qualitative research techniques.

Spatial analysis of historical aerial photographs enabled an estimation of high intensity disturbance on SPTA at a local landscape scale over a 50-year period. Although trends in disturbance varied across the SPTA for the time period under investigation, the average annual increase in bare ground since WWII has been in the region of 25.5ha. These trends suggest that disturbance is occurring at a greater rate than natural regeneration, representing a significant threat to the chalk grassland through habitat loss and fragmentation.

The historical aerial photographs provided the framework for a chronosequence approach for an investigation of habitat resilience to military disturbance. Species and soils data were collected from sites disturbed over a 50-year period, from both CG3 (*Bromus erectus*) and MG1 (*Arrhenatherum elatius*) grasslands. The mesotrophic grassland communities displayed greater resilience to disturbance than the calcareous communities, with more rapid colonisation of bare ground and species re-assembly. MG1 sites typically took 30-40 years to recover full species assemblage whereas CG3 sites took at least 50 years. The inclusion of seed banks in these estimates increased minimum exclusion times to at least 50 years for both grassland types.

A controlled conditions experiment was used to investigate the effects of different military vehicles on the soils and vegetation of a tall chalk grassland community. The CG3d community sampled proved relatively resistant to wheeled vehicle disturbance but significantly less resistant to tracked vehicles, with post-disturbance changes in vegetation composition being primarily related to the area of bare soil exposed. Multiple passes of tracked vehicles and tracked vehicle slews exceeded a disturbance threshold beyond which chalk grassland recovery is less predictable.

The relative contributions of the seed bank and seed rain to the re-establishment of chalk grassland were also investigated on the experimental site. It was shown that the surface vegetation had little in common with the soil seed bank, with the majority of propagules originating from the seed rain. The results are important for management as they imply that large swathes of undisturbed grassland are needed for successful spontaneous recovery following disturbance.

Questionnaire and interview surveys were used to investigate the impacts of military training on the activities of MoD tenant farmers. Responses suggested that in recent years farmers have experienced heightened levels of disturbance, and although systems for damage assessment and recompense were satisfactory for land eligible for compensation, there was increasing discontent among farmers about non-eligible disturbance. In order to secure both successful future management of Salisbury Plain, and farming livelihoods, it may be necessary for the discourse between MoD and its tenant farmers to be reassessed.

CONTENTS

1. GENERAL INTRODUCTION TO THE THESIS

1.1 THE IMPORTANCE OF DISTURBANCE IN NATURAL SYSTEMS

Introduction and nomenclature

Disturbance is a feature of all natural communities as heterogeneous systems are both spatially and temporally dynamic (Miles, 1979; White, 1979; White and Pickett, 1979). Fluctuations in external and internal environments provide varying opportunities for species recruitment, reproduction and survival, creating variation in biological interaction and resource availability.

Temporal and spatial variability is an integral part of community ecology studies. There is much evidence to suggest that many species or communities rely on spatial and temporal variability in order to persist, and disturbance is a major source of such variation. It is, for example, well documented that intermediate levels of disturbance increase species diversity (Grime, 1973; Horn, 1975; Connell, 1978; Huston, 1979; Sousa, 1984), when competitive exclusion of pioneer and later successional species is balanced.

However, ecological disturbance is not an easy phenomenon to describe. Reliance on variability for persistence means that few communities exist at a near-equilibrium state, and it can be difficult to distinguish between those which are more so than others. Additionally, structural changes can be caused by forces varying from the negligible to the extreme, and the response to such a force can vary greatly between communities. It can therefore be difficult to decide objectively what degree of change constitutes a disturbance. Sousa (1984) provides a reasonable description, defining disturbance as "*a discrete, punctuated killing, displacement, or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established*" (p356). In conservation management terms, it is also necessary to distinguish between 'controlled' disturbance through purposeful intervention (such as grazing or mowing), and stochastic, unpredictable disturbance from external sources.

Disturbance ecology

Agents of disturbance in natural systems are usually categorised as being from physical, biological or human sources. Physical agents are the most frequently considered disturbance sources, including wind, fire and water motion. Biological agents are more complex, involving disease and changes in predation and herbivory. However, disturbance does not just occur from so called 'natural' means. Expanding economies are continually consuming 'natural' spaces, and a whole host of human activities are responsible for often considerable ecosystem disturbance, including agriculture, forestry, industrial development, urban expansion, construction works and recreational activities. Many of these conflicts at the human-nature interface, and the increased need for environmental accountability in all aspects of economic activity, have been the impetus for the rise in disturbance ecology studies over the past decade (see Figure 1.1).

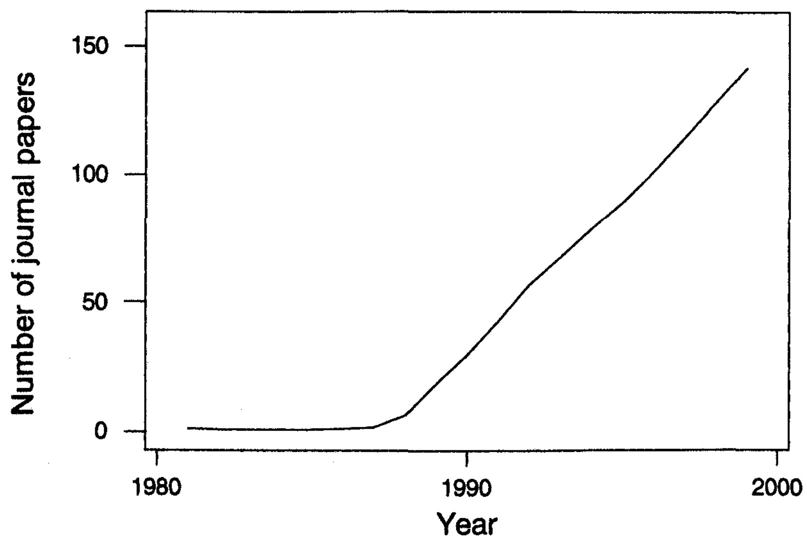


Figure 1.1 Number of scientific journal papers including the phrase 'disturbance ecology', using Web of Science records (http://wos.mimas.ac.uk), 1981-1999.

1.2 ENVIRONMENTAL IMPACTS OF MILITARY TRAINING

The military sector is perhaps one major industry whose environmental impacts have not been greatly scrutinised before (Vertegaal, 1989). Restricted access, both institutionally and physically, has hampered independent investigation of this sector. Public awareness of UK military training areas has increased over the past 20 years, due to issues such as restricted recreational access, associated noise and traffic, and other negative aesthetic problems for local communities (Doxford and Hill, 1998). High profile debates such as the Otterburn public inquiry, concerns regarding damage to heritage and natural resources on Salisbury Plain, and public access to ranges on Dartmoor and Castlemartin have also amplified concerns in the UK (Doxford and Hill, 1998; Rowe, 2000).

Nevertheless, restrictions imposed by military training have also had unexpected benefits, namely the protection of localities from intensive agriculture. This has resulted in areas of unusually high nature conservation interest, and the preservation of extensive farming systems. In Britain, the Ministry of Defence (MoD) is the second largest landowner (Doxford and Hill, 1998), and in 1991 two-thirds of its 243,000 ha estate was managed for training purposes (Farrington, 1995). This includes two National Nature Reserves (NNRs), 219 Sites of Special Scientific Interest (SSSIs), 33 Special Protection Areas (SPAs – for birds) and over 500 Scheduled Ancient Monuments (SAMs) (Doxford and Hill, 1998). Britain is not unique in Europe in this respect. In the Netherlands, 7.5% of woods and wildlife areas are owned by the military, as is 21% of the 'Veluve', the largest continuously forested area, and one-third of all heathland (Vertegaal, 1989). Economically, the military sector also provides employment opportunities, often in otherwise declining rural areas, and supports services such as school and shops (Woodward, 1996).

Managing military disturbance

Military training is both an intensive and extensive type of land use. As with any form of disturbance, certain levels of military training are not only sustainable, but in the absence of other management may be beneficial. The direct effects that military activities have on the landscape and natural systems, including those of high ecological value, pose an intriguing land use problem for those responsible for the management of military training areas. Much of the work on the management of military lands has been carried out in semi-arid areas of the United States and Australia, where susceptibility to soil erosion is high. The US Army Construction Engineering Laboratory (USA-CERL) have developed a land classification scheme to assess and minimise the damage caused to military lands by training exercises (Tazik *et al.*, 1990). Based on the Universal Soil Loss Equation (USLE), this work has been incorporated into the Land Condition Trend Analysis Program (LCTA) which now forms the major component of the US Army Integrated Training Area Management (ITAM) Program, co-ordinated by the Center for Ecological Management of Military Lands (CEMML) (Diersing *et al.*, 1988; Diersing, Shaw and Tazik, 1992; Tazik *et al.*, 1990).

The US Army is responsible for the management of around 4.8 million hectares of land. Much of the ecological work of LCTA was initially executed on the Pinon Canyon Maneuver Site in Colorado (Shaw and Diersing, 1989 & 1990) but now covers approximately 75% of US military lands, involving 32 army installations across the continental United States, in addition to US Army training areas in Germany (see Shaw *et al.*, 1990; Aplet *et al.*, 1994; Shaw and Douglas, 1995; Shaw, Close and Schnell, 1995; Shaw 1997; Shaw and Castillo, 1997). In contrast, there have been few empirical pedological or ecological studies on UK army training areas. In the mid 1970s, a study was carried out by the Institute of Terrestrial Ecology (ITE, now the Centre for Ecology and Hydrology), on the Porton Ranges lying on the Hampshire-Wiltshire border (Wells *et al.*, 1976). This sought to identify some of the relationships between vegetation soils and land use history in order to explain current vegetation community patterns. Around this time, the then Nature Conservancy Council also commissioned ITE to survey the Stanford training area in East Anglia (Hooper, 1978). Given current public concerns regarding military training, and the importance of rigorous scientific information for successful management, the development of this type of study is long overdue.

1.3 THE SALISBURY PLAIN TRAINING AREA

This study is concerned with military disturbance on the Salisbury Plain Training Area (SPTA) in southern England (Figure 1.2). Salisbury Plain lies across the county of Wiltshire, stretching from Warminster in the west to the Hampshire border in the east, and from the Pewsey Vale in the north, almost to Stonehenge in the south (Brown, 1995) (see Figure 1.3). It is predominantly underlain by Cretaceous chalk bedrock, supporting an unprecedented area of unimproved chalk grassland. Although the term 'Plain' implies flat ground, the area is composed of a series of coombs and dry valleys; its three broad ridges being remnants of a plateau that has been extensively eroded.

The military presence on Salisbury Plain began during the late 19th Century. The involvement of British troops in a number of conflicts across the globe during this time prompted Crown acquisition of land for permanent, large-scale troop training. The chalk downs of Wiltshire were ideally suited for this, being of only marginal agricultural potential (James, 1987). The large areas of undulating countryside were perfect for both cavalry and infantry manoeuvres.

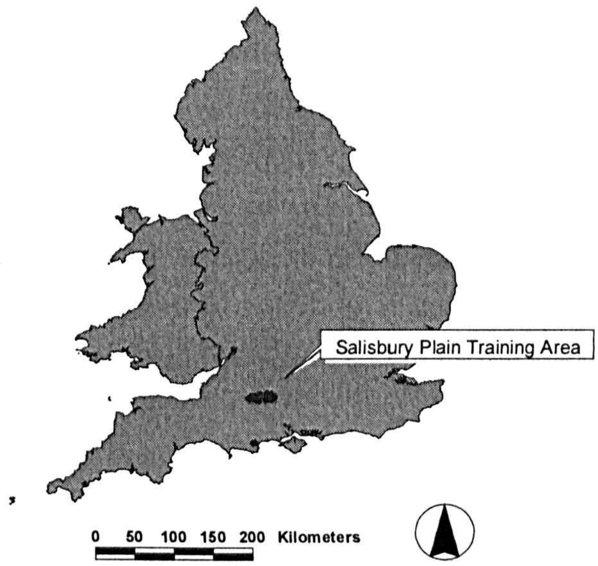


Figure 1.2 Location of the Salisbury Plain Training Area.

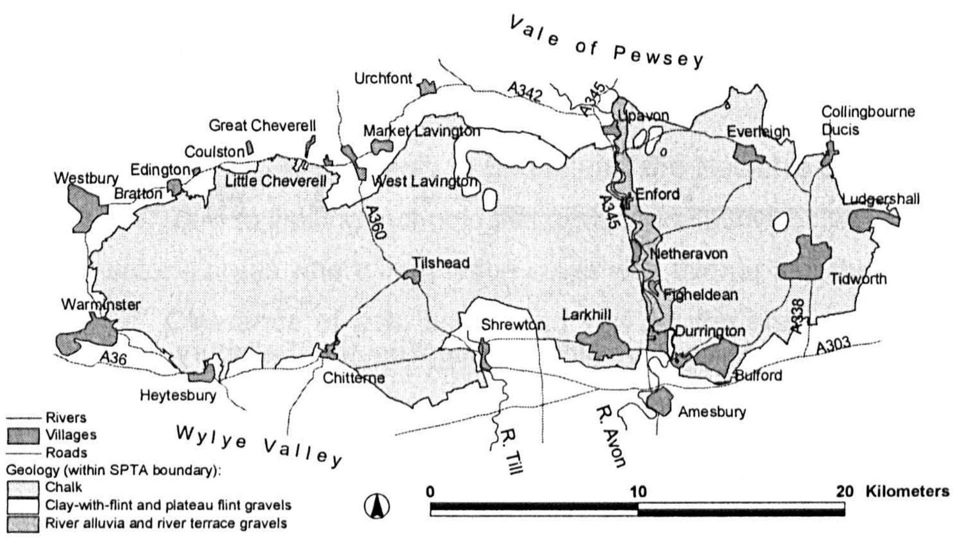


Figure 1.3 Towns and villages in and around the Salisbury Plain Training Area, and underlying geology.

This was not the only military training area to be acquired at this time as significant land purchases were also made around Okehampton on Dartmoor and Aldershot in Hampshire. In 1897, 13,661 acres of Salisbury Plain had been acquired, and by 1902 a further 28,268 acres had been added to this. Purchases continued during the 20th Century and by 1995 what is now known as the Salisbury Plain Training Area (SPTA) covered over 93,000 acres (c.38,000 hectares) (Brown, 1995).

The SPTA is now the largest of the UK military training areas. It is particularly valuable to the MoD as it is the only training area sufficiently large enough, and with suitable geology, for full-scale armoured vehicle manoeuvres. It is home to the Royal School of Artillery at Larkhill and infantry training facilities at the Warminster Training Centre. There is also a purpose-built complex for Fighting in Built Up Areas (FIBUA) and a Cross Country Driving Area (CCDA - for training tank drivers) (Figure 1.4). A variety of danger areas allow live firing of both small arms and a range of artillery pieces, including AS90 and MLRS.

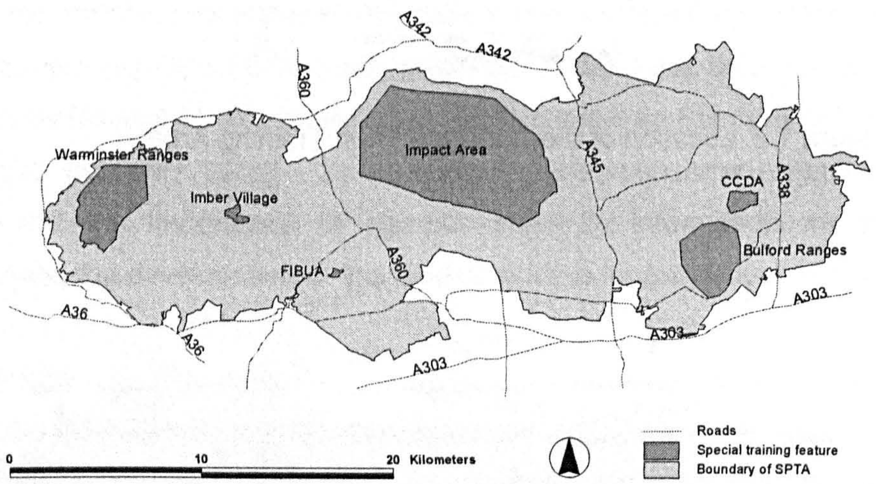


Figure 1.4 Military training facilities on the Salisbury Plain Training Area.

The Ministry of Defence is assisted in the management of its estate (including land and buildings) by an executive agency called Defence Estates (DE). The predecessor of Defence Estates, the Defence Estate Organisation (DEO) was plagued by a lack of clarity over its role, particularly since the break up of the Property Services Agency in 1990 (www.mod.uk/de/ accessed 15.03.00). The Agency was relaunched in 1999 as Defence Estates following reassessment of the outputs required by the organisation and the reorganisation necessary for their implementation. A team of Defence Estates staff are solely responsible for the management of the Salisbury Plain Training Area, based at Westdown Camp in Tilshead. This comprises ecologists, foresters and archaeologists, in addition to general estate managers. The team works closely with military staff to ensure optimal use of the chalk grasslands for training purposes.

1.4 CHALK GRASSLANDS

Origins

Chalk grasslands are thought to be one of the oldest, relatively stable managed ecosystems in western Europe (Bowen, 1961; Wells, 1967) and their rich flora and fauna has long attracted the attention of biologists (Tansley and Adamson, 1926; Hope-Simpson, 1941; Thomas *et al.*, 1957). Many countries in north-west Europe have underlying Cretaceous chalk deposits, notably southern England, north-west France and the Netherlands. Soils that have developed on this bedrock characteristically have a high free calcium carbonate and exchangeable calcium content. This typically gives a soil pH range of 7.0-8.4 (Wells, 1967; Rodwell, 1992), although the precise chemical nature of the soils depends on other physical aspects such as superficial deposits, slope and aspect (Perring, 1959). These soils are usually described as protorendzinas and rendzinas (Kubiena, 1953, in Wells, 1967) or as rendzinas and calcimorphic loams (Avery, 1958, also in Wells, 1967).

Soil tillage and pastoralism did not begin in Britain until the Neolithic period (around 2000BC). However, due to limiting technologies agricultural activities were confined to chalk and limestone areas where vegetation cover was thinner and the soils were light (Pike, 1975). Clearance of ash, beech and yew on the shallow soils of the chalk and limestone accompanied the development of downland settlements, and hence large areas of chalk grassland were formed (Tansley, 1953). The maintenance of these grasslands was aided by the grazing of cattle and sheep. Despite the shift to the lowlands by Iron Age settlers, agriculture on the chalk downlands continued right through the Roman occupation (Crawford and Keiller, 1928). The grassy swards that have developed under this system differ across the country due to variation in climate, soils and grazing regimes. Early descriptions of these different chalk grassland communities (such as the work of A G Tansley) have been superseded in the UK by the phytosociological categorisation of the National Vegetation Classification (NVC) (Rodwell, 1992).

Chalk grassland, fragmentation and conservation importance

Historical ploughing of calcareous grasslands has been occurring for at least 300 years in the UK (Smith, 1980), relating to fluctuating grain prices. The remaining area of this plagio-climax habitat has not only been greatly reduced but is also becoming increasingly fragmented. Blackwood and Tubbs (1970) estimated the minimum area of English chalk grassland to be 43,546 ha in 1966, and a repeat survey by the Nature Conservancy Council between 1982-8 revised this figure to 36,682 ha (Keymer and Leach, 1990). Chalk grassland is now identified in Annex 1 of the EC Habitats Directive as part of the *Festuco-Brometalia* grasslands and is considered to have Community significance (DETR, 1998). The majority of the surviving areas of chalk grassland in the UK are confined to slopes too steep to reclaim for agriculture, and military training areas.

The chalk grasslands of Salisbury Plain

The long association of the military with Salisbury Plain has limited many of the recent human-induced changes common to lowland grasslands (agricultural improvement, urban expansion and industrial development). Salisbury Plain now contains over 14,000 hectares of unimproved chalk grassland (Figure 1.6), representing the largest known expanse of this threatened habitat type in north-west Europe (English Nature, 1993). The area has a particularly rich flora, with 30-40 species per square metre of grassland in some locations, including 12 species of nationally rare or scarce plants and nearly 70 rare or scarce invertebrate species (Walker and Pywell, 2000).

During 1996 and 1997 a vegetation survey identified some 20 NVC communities on the Salisbury Plain Training Area (Walker and Pywell, 2000), including both calcareous and mesotrophic grassland types. This mosaic of vegetation communities is the result of considerable spatial variation in current and historical grazing by stock, rabbits and deer, and other forms of management, or its absence. Grazing, particularly of sheep and more recently cattle, has occurred on Salisbury Plain for at least the last 1,600 years (Smith, 1980). 19th and 20th century maps show that much of SPTA remained rough pasture even during periods of particular agricultural prosperity or strategic uncertainty (Walker and Pywell, 2000). However, heightened military use of the area has decreased stock numbers on SPTA, especially in the West and Centre ranges where hazards to livestock are greatest and access for farmers is often impeded. Consequently, areas of short chalk turf are thought to have declined and ranker grassland increased.

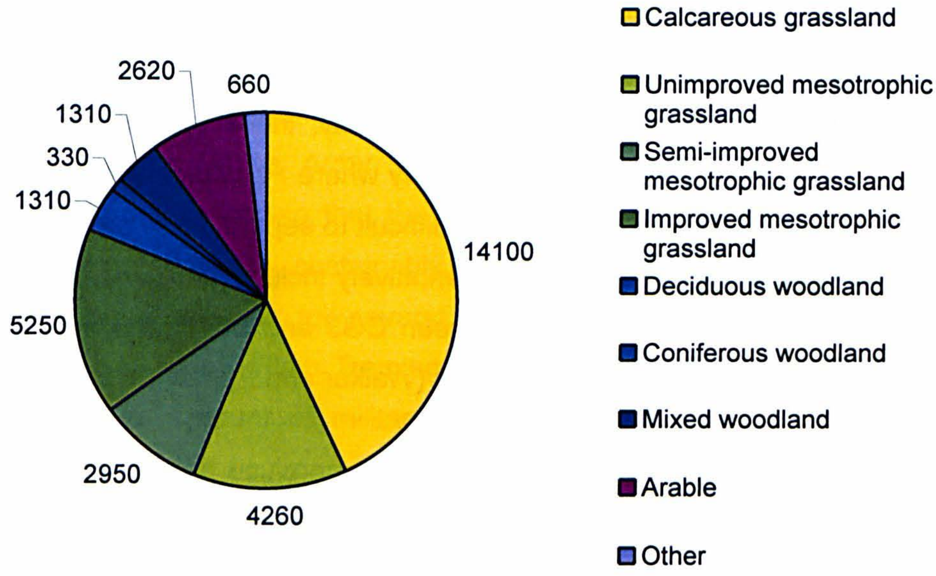


Figure 1.6 Approximate area (hectares) of main vegetation types found on the Salisbury Plain Training Area (Pywell, 1998).

By far the most abundant community on the SPTA is the *Bromus erectus*[1] (CG3) grassland, where *Bromopsis erecta* (formally *Bromus erectus*) comprises at least 10% of the cover, and whose variants account for 27% of the area surveyed (Walker and Pywell, 2000). This community tends to form extensive 'prairies' across the training area, where grazing is of low intensity or absent. The proximity of the Salisbury Plain grasslands to the Atlantic has led to a marked regional character of CG3, with higher constancy of certain forb species such as *Serratula tinctoria*, *Stachys officinalis*, *Succisa pratensis* and *Thesium humifusum* (English Nature, 1993).

Significantly smaller areas of other chalk grassland communities were also recorded on the SPTA, including the species-rich *Festuca ovina – Avenula pratensis* (CG2) and *Festuca ovina – Hieracium pilosella – Thymus praecox* (CG7) communities, in

[1] The nomenclature of vascular plants follows that of Stace (1997). The exception to this is in the usage of National Vegetation Classification community names (Rodwell, 1992), where the community names given by Rodwell, based on *Flora Europaea* (Tutin *et al.*, 1964 *et seq.*), have been adopted.

addition to more rank and tussocky communities, dominated by coarse grass species such as *Brachypodium pinnatum* (CG4), *Bromus erectus - Brachypodium pinnatum* (CG5) and *Avenula pubescens* (CG6).

After CG3, the largest unimproved grassland community on the SPTA is MG1, the *Arrhenatherum elatius* grasslands, comprising over 12% of the area surveyed. Although classified as a mesotrophic community, these grasslands show a close affinity to calcareous grasslands, particularly where *Pastinaca sativa* is abundant in the sward (Porley, 1986), and it is often difficult to separate this community from the rank CG3 swards. Smith (1980) also tentatively included *Arrhenatherum elatius* as a chalk grassland type. Mosaics between CG3 and MG1 also form a significant proportion (14%) of the SPTA grasslands (Walker and Pywell, 2000).

In the chalk grasslands of the south and east, bryophytes tend to vary in their frequency and abundance (Rodwell, 1992). Most common on Salisbury Plain are the pleurocarp mosses such *Pseudoscleropodium purum* and *Homalothecium lutescens*. Less frequent are species such as *Calliergon cuspidatum* and *Campylium chrysophyllum*, and on areas of bare ground *Weissia* sp. and other acrocarps. Lichens, on the whole, tend to be rare.

In 1993, about 20,000 hectares of the Salisbury Plain Training Area were designated by English Nature as three large Sites of Special Scientific Interest (SSSIs), for their quality and contiguity of chalk grassland. This is the largest area of SSSI in the UK. Part of the area is a European Special Protection Area (SPA) for birds (Carter and Rankine, 1993), and a Special Area of Conservation (SAC).

1.5 STRIKING A BALANCE

Since the end of the Cold War there has been a scaling down of NATO forces in Europe and the loss of many training facilities in these regions (MoD, 1997). This has resulted in increased use of UK military training areas, including Salisbury Plain, and consequently a potential increase in habitat disturbance. As with any large industry, there is increased pressure on the MoD to be more environmentally accountable, and although the MoD's overriding priority must be to provide effective training in order to meet national security and foreign policy objectives, it has stated that:

> *'All training activities must . . . take into account the requirements of conservation. This is particularly important in the many areas which have statutory protection'.* (MoD, 1997, p.4)

The MoD are now faced with a paradox of potentially conflicting priorities: as both a responsible land owner in terms of farming and conservation, and meeting the training needs of the British Army. Defence Estates is developing ways of improving their management so that the plethora of activities that occur on their land are co-ordinated more sustainably. Integrated Land Management Plans (ILMPs) are being introduced for several training areas, following an initial trial conducted on the Salisbury Plain Training Area. It is intended that the ILMPs will enable the optimum amount of military training to be carried out in the most consistent, economic and environmentally acceptable way. The main elements of the ILMP for each training area are:

- mapping and describing training and environmental resources;
- identifying the main objectives for the training areas including military requirements, conservation heritage and other relevant objectives such as the maintenance of biodiversity;
- identifying the need for environmental protection, damage protection and measures to mitigate and compensate for any damage caused;
- identifying the necessary measures to monitor military training and the effectiveness of management;
- defining appropriate management information systems including GIS requirements; and

- identifying priorities for the implementation of ILMPs.

(MoD, 1997)

Despite this, there is however a great deal of uncertainty about how the chalk grassland ecosystem of Salisbury Plain is responding to disturbance caused by the military, and thus how increased levels of training will alter this. It is not possible to say what percentage or frequency of disturbance ceases to be beneficial and hence damaging. Given the conservation status of SPTA (Toynton *et al.*, 1994; Coe, 1997), it is necessary to establish whether military disturbance causes irreversible changes in plant communities and a long-term reduction in biodiversity. However very little is known about the disturbance ecology of chalk grasslands and in order to provide appropriate advice for land managers, detailed research into the responses of chalk grassland to disturbance are necessary. This thesis goes part-way in addressing this imbalance.

1.6 PROJECT RATIONALE, AIMS AND OBJECTIVES

Previous vegetation surveys of SPTA, including the 1996-7 survey for the ILMP (Pywell, 1996), specifically avoided areas of disturbance, focusing on the need to quantify 'pristine' grassland resources. There is an increasing need in conservation management to understand ecosystem stability and factors controlling resistance to disturbance and habitat resilience, so as to manipulate and manage early successional communities effectively (Grace, 1999; Mitchell, *et al.*, 2000). Disturbance on SPTA, however, is interesting from both a natural history point of view, as well as being an important component of the ecosystem.

Understanding this disturbance of the high conservation importance grasslands on Salisbury Plain is therefore crucial to the MoD's successful management of SPTA, other military training areas and situations where habitat disturbance is both a chronic or acute problem. To this end, this thesis seeks not to describe the natural history of disturbance on SPTA, but to answer specific functional questions:

- How much disturbance is occurring on SPTA? How does this compare to past rates of disturbance?
- How long does it take grassland to recover spontaneously from disturbance?
- How resistant is grassland to disturbance from different sources?
- What are the specific mechanisms of habitat recovery?
- How does military disturbance affect the farming contribution to conservation on SPTA?
- How can we use this information to aid better management of SPTA, and other high disturbance habitats?

The thesis is organised as a series of papers, each addressing one or more of the above issues using a range of approaches; from landscape assessment of habitat disturbance through to evaluation of species response to disturbance and recovery. Some issues are considered in more than one chapter. Beginning at landscape scale, Chapter 2 explores the impact that the changing intensity of the military use of the SPTA has had on habitat disturbance, particularly since the end of the Cold War. Such an historical approach provides the framework for a space-for-time substitution study of habitat recovery over a 50 year period (Jenny, 1980). The chronosequences investigated in these papers (Chapters 3 and 4) use surface vegetation, soil chemistry and seed bank dynamics to estimate habitat resilience, and the implications that these may have for the management of disturbance across the habitat mosaic of the SPTA grasslands. Chapters 5 and 6 focus on the vegetation dynamics of recovery following disturbance. A field experiment is used to investigate the characteristics and mechanisms of chalk grassland recovery from small-scale localised disturbance events, under controlled conditions.

Broadening out the perspective again, qualitative research methods are used in Chapter 7 to investigate how disturbance affects farming activities. Maintenance of the high conservation interest of the SPTA grasslands requires effective management of the undisturbed grassland resource through grazing and cutting, as well as understanding and managing the disturbance, and this is mostly carried out by farming tenants of the MoD. The final chapter provides further discussion of the inter-relatedness of many of the ecological and socio-economic processes covered in previous chapters, considering policy implications and recommendations for future research perspectives.

Tracks on the Cross Country Driving Area

2. ASSESSING HABITAT DISTURBANCE USING AN HISTORICAL PERSPECTIVE: THE CASE OF SALISBURY PLAIN MILITARY TRAINING AREA

SUMMARY

Chalk grasslands are a habitat with high European importance for both flora and fauna. The largest known expanse of unimproved chalk grassland in north-west Europe lies within the Salisbury Plain Training Area (SPTA) in southern England, where sole use of the land for military training since the end of the 19th century has limited the ecologically damaging impacts of modern intensive agriculture. Organisational changes in the British Army may now paradoxically be threatening this unique ecological resource. In this study, historical aerial photograph analysis was carried out for SPTA using images from the 1940s through to the mid 1990s. Image analysis software enabled the creation of a model that analysed the extent and pattern of high intensity military disturbance on SPTA at a local landscape scale. Although trends in disturbance vary across the SPTA for the time period under investigation, the average annual increase in bare ground since WWII has been in the region of 25.5 ha. These trends indicate that disturbance is occurring at a greater rate than natural regeneration, representing a significant threat to the chalk grassland through habitat loss and fragmentation.

2.1 INTRODUCTION

There is a growing research field for landscape historians to provide easily accessible information on historical landscape changes (Iverson and Risser, 1987; Iverson, 1988; Pedroli and Borger, 1990). The development of Geographical Information Systems (GIS) has greatly improved the handling of spatial data, although difficulties due to limited functionality for handling historical data have been noted (Burrough, 1990; Kienast, 1993). Analysis of historical aerial photographs can provide a detailed and extensive record of landscape and vegetation change (Coombe, 1977; Fuller, 1983), and along time series beyond the capability of modern advanced sensors such as the LANDSAT Thematic Mapper (TM) or Compact Airborne Spectrographic Imager (CASI).

Chronosequence studies using aerial photography provide useful insights for the management of particular sites, and have been conducted for a number of purposes, including investigation of changes in land use (Garrity and Agustin, 1995; Mack *et al.*, 1995) and habitat extent following management or its cessation (Lyon and Greene, 1992; Kadmon and Harari-Kremer, 1999), and waste management studies (Pope *et al.*, 1996).

Military training is a land use whose intensity can be highly variable through time and space. Effective management of military lands is therefore complex, requiring knowledge of land condition and the impact of different types of training activities (Jones and Bagley, 1998), and the ability to respond to changing technologies and military priorities. The Salisbury Plain Training Area (SPTA) is both the largest and most important of the UK training areas in terms of the variety and scale of training facilities it offers. This has been particularly so since the post-Cold War scaling down of NATO forces in Europe and the loss of training facilities on the Continent. As SPTA also contains the largest known expanse of unimproved chalk grassland in north-west Europe (English Nature, 1993), concerns have been raised about potential increases in disturbance of this threatened habitat as a result of military training. Although a primary objective for land managers on Salisbury Plain is to establish and minimise the potential ecological impacts of military training, very little is known about the extent and intensity of disturbance across Salisbury Plain, and how it has fluctuated over the past half a century. The aims of this study were therefore two fold:

- to investigate the balance between habitat disturbance and recovery across the Salisbury Plain Training Area since WWII; and,
- to consider the management implications of observed changes in the disturbance regime in a UK and European context.

The Salisbury Plain Training Area has an exceptionally good historical aerial photographic record throughout the 20th century, due in part to its military connection, but also from aerial survey of archaeological monuments. Pixel analysis of aerial photographs can be utilised to assess local landscape scale changes across SPTA over a longer time frame than that provided by other remote sensing techniques. Although not as sensitive as other techniques for processing high-resolution imagery such as image segmentation (Lobo *et al.*, 1998), pixel-based processing of aerial photographs can provide sufficiently accurate estimates for certain aspects of landscape-scale ecological research, such as widespread and intensive disturbance of land (Mather, 1987). In this way, changes in the disturbance regime on Salisbury Plain can be tracked over a period of half a century.

2.2 AREA UNDER INVESTIGATION

For the purpose of this investigation, six tetrads (2x2 km) were selected using stratified random sampling from a grid placed over the Salisbury Plain SSSIs. Three tetrads were chosen from the SPTA western ranges and three from the east (Figure 2.1). The tetrad is the commonly used area for landscape assessment (Countryside Commission, 1993). This gave a total study area of 2400 ha representing approximately 12% of the SSSI, or 6.3% of the whole training area. The sample tetrads covered a range of habitat types (tall and short chalk grassland, unimproved mesotrophic grassland, woodland and scrub) and heavily and less heavily used parts of the training area.

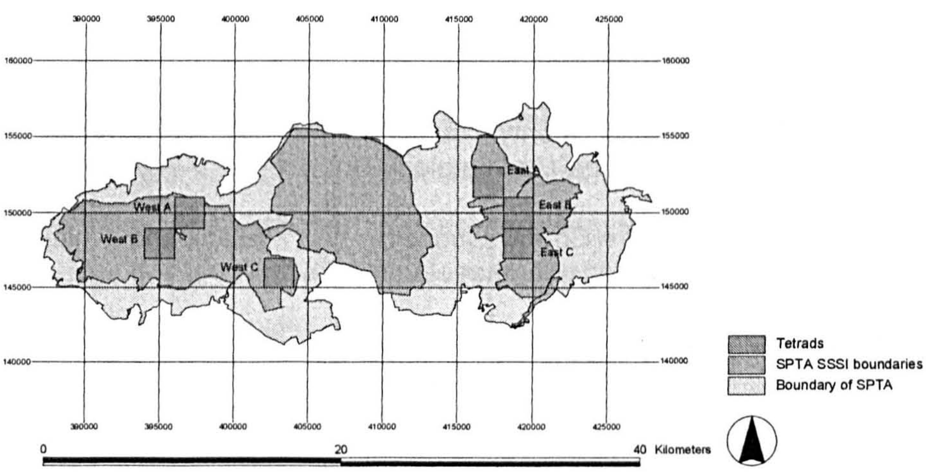


Figure 2.1 Location of tetrads on SPTA used in historical aerial photograph analysis.

2.3 METHODS

Preparation of aerial photographs

Vertical aerial photographs of the areas under investigation were collected for 8 dates between 1945 and 1995 (Table 2.1). The photographs were scanned to create digital images and imported into ERDAS Imagine software (ERDAS, 1997). Each photograph was geo-corrected using the ERDAS Imagine camera correction model. This model combined the flying height of the plane, camera lens focal length and the position of fiducials marked on the image to adjust distortion on the aerial photograph. A prepared list of 10 figure grid references derived from the 1:25,000 scale Ordnance Survey map was used to identify control reference points on the raw images. The success of each correction was assessed using a digitised line-work file for SPTA, originally designed for a vegetation survey of Salisbury Plain (Pywell, 1996). Some difficulty was experienced with the geo-correction due to a lack of constancy between features on the images and the Ordnance Survey base map. Once geo-corrected and geo-referenced, mosaics of the images were created to achieve coverage for the tetrads under consideration.

Table 2.1 Source and type of images used in analysis.

Year of photograph	Flight date	Source	Image type
1945	25 Sept 45	Royal Commission on the Historical Monument	Black and White
1955	13 Sept 55	Royal Commission on the Historical Monument	Black and White
1971	07 Sept 71	Wiltshire County Council, Trowbridge (Archaeology Unit)	Black and White
1981	02 Aug 81	Wiltshire County Council, Trowbridge (Archaeology Unit)	Black and White
1984	23 Apr 84	Defence Estates, Durrington	Black and White
1991	19 Aug 91	Wiltshire County Council, Trowbridge (Archaeology Unit)	Black and White
1994	14 Aug 94	English Nature, Devizes	Colour
1995	04 Aug 95	English Nature, Devizes	Colour

Identifying areas of disturbance

Using the ModelMaker tool within ERDAS Imagine, a model was created that identified areas of disturbed grassland on aerial photographs. The model re-coded each pixel in the raster created from an aerial photograph according to the pixel's ability to meet a colour frequency threshold. Pixels brighter than a given threshold (within the 256 colours recognised by the computer) were re-coded as white, and those darker as black. In this way, a monochrome image was derived depicting areas of bare chalk (or disturbed soil with a high chalk component) created by severe disturbance events as white pixels, and less disturbed areas as black. It was necessary to mask out ploughed areas on the photographs to eliminate any disturbance from agricultural sources. Although not common, this occurred in tetrads on the periphery of SPTA where tenant farmers can occasionally be granted ploughing consents.

Due to the varying exposure between and within photographs, it was necessary to alter the threshold at which this re-coding took place for each sample square and each time period. In the cases where two or more photographs were used to compile the complete coverage for the sample tetrad, it was also common for the exposure of the component photographs to vary. In these instances it was necessary to divide the image and run the component parts separately through the threshold model.

The threshold model was run for each tetrad at a number of different thresholds. A visual comparison of the monochrome image with the original photograph was made, to ascertain when a 'realistic' depiction of the disturbance had been reached. To reflect this uncertainty, a range of threshold values resulting in the most 'realistic' disturbance images was recorded.

The number of black and white pixels in each re-coded image was recorded after each run of the threshold model using the ERDAS Imagine frequency histogram tool. The number of white pixels in each monochrome image provided a systematic estimate of the amount of disturbance in each tetrad for that time period. A mean was derived from the values recorded from the range of threshold values to provide the estimate for bare ground in each tetrad for each time period. For sample tetrads with incomplete aerial photographic coverage, an estimate of the total number of pixels representing disturbed areas was derived using the proportion of white pixels present in the image for which photographs were available.

Digitising the track network

The disturbance model described above recorded disturbance from a whole range of military sources. Given that future changes in the usage of Salisbury Plain

Training Area will principally be associated with tracked vehicles, more detailed analysis was conducted on disturbances related to this source.

Aerial photographic coverage for the sample tetrads was imported into ArcView software (ESRI, 1992). The on-screen-digitising facility in this program was used to digitise the track network shown on each geo-referenced image. ArcInfo (ESRI, 1992) was then used to generate summary statistics regarding the landscapes described by the track network vector files. Data were derived describing lengths of tracks and areas of polygons bordered by the tracks over the time period under investigation.

Data analysis

The recorded data for bare ground, lengths of tracks and area of parcels of grassland were plotted against date of photograph to produce trends through time. Simple linear regression was used to describe observed trends in these data. Data for disturbed ground and track lengths were found to be normally distributed but polygon size data required a log transformation prior to analysis.

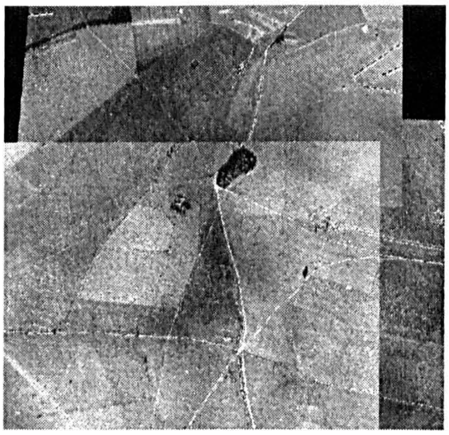
2.4 RESULTS

Aerial photograph chronosequence

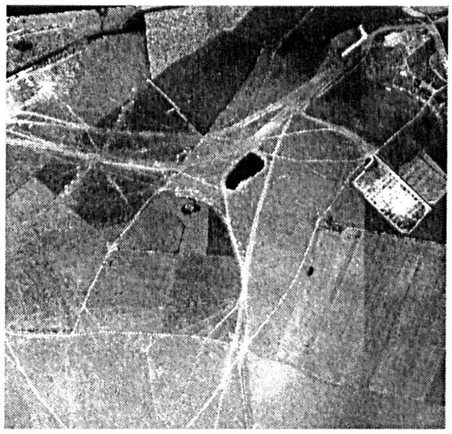
An example of the aerial photograph chronosequence derived for one of the sample tetrads, West C, is shown in Figure 2.2. This tetrad illustrates many of the local landscape scale changes common to the whole of the Salisbury Plain Training Area over the 50 year period under investigation. These changes include the development of the track network, the planting of strategic woodland, the deterioration of older woodland stands, and the encroachment of scrub over previously open downland.

Disturbance images chronosequence

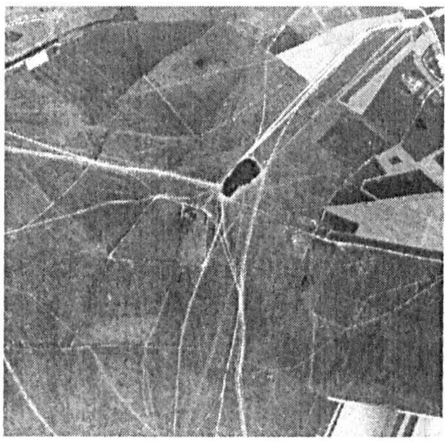
An example of the chronosequence of images depicting disturbed grassland is shown in Figure 2.3. Plots of total disturbance through time for the individual tetrads are shown in Figure 2.4. All tetrads demonstrate a net increase in recorded bare ground over this 50 year period, although there is substantial inter-and intra-tetrad variation.



1945



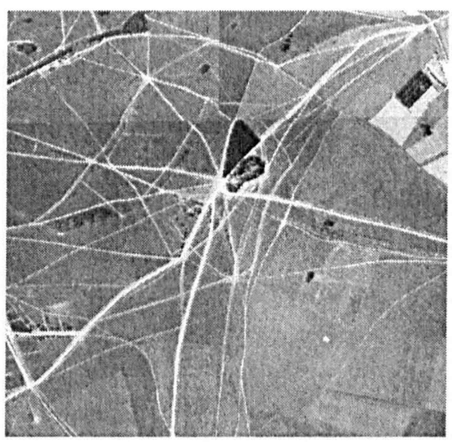
1955



1967

1981

1991



1995

Figure 2.2 Chronosequence of aerial photographs for tetrad West C.

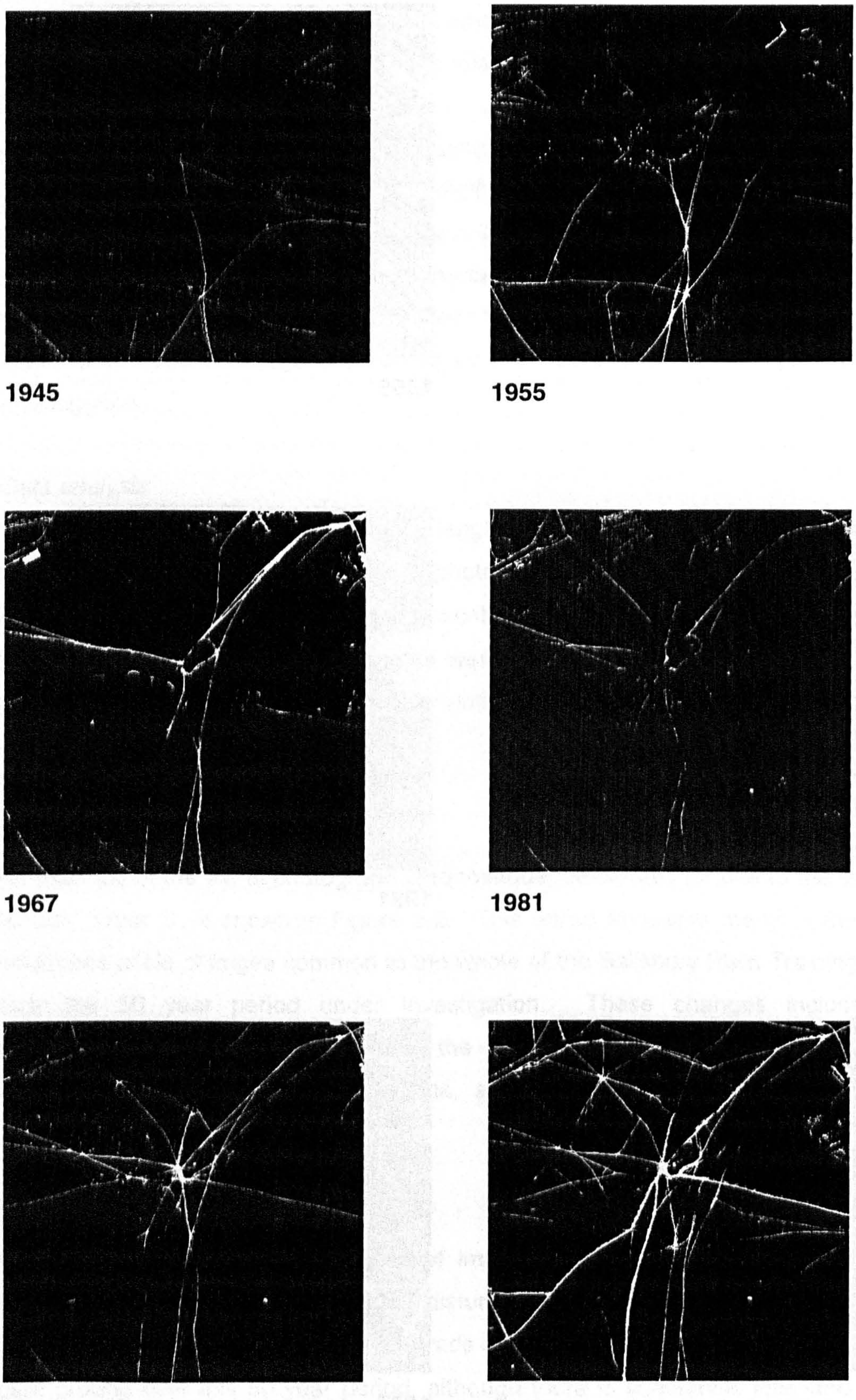


Figure 2.3 Chronosequence of monochrome disturbance images for tetrad West C.

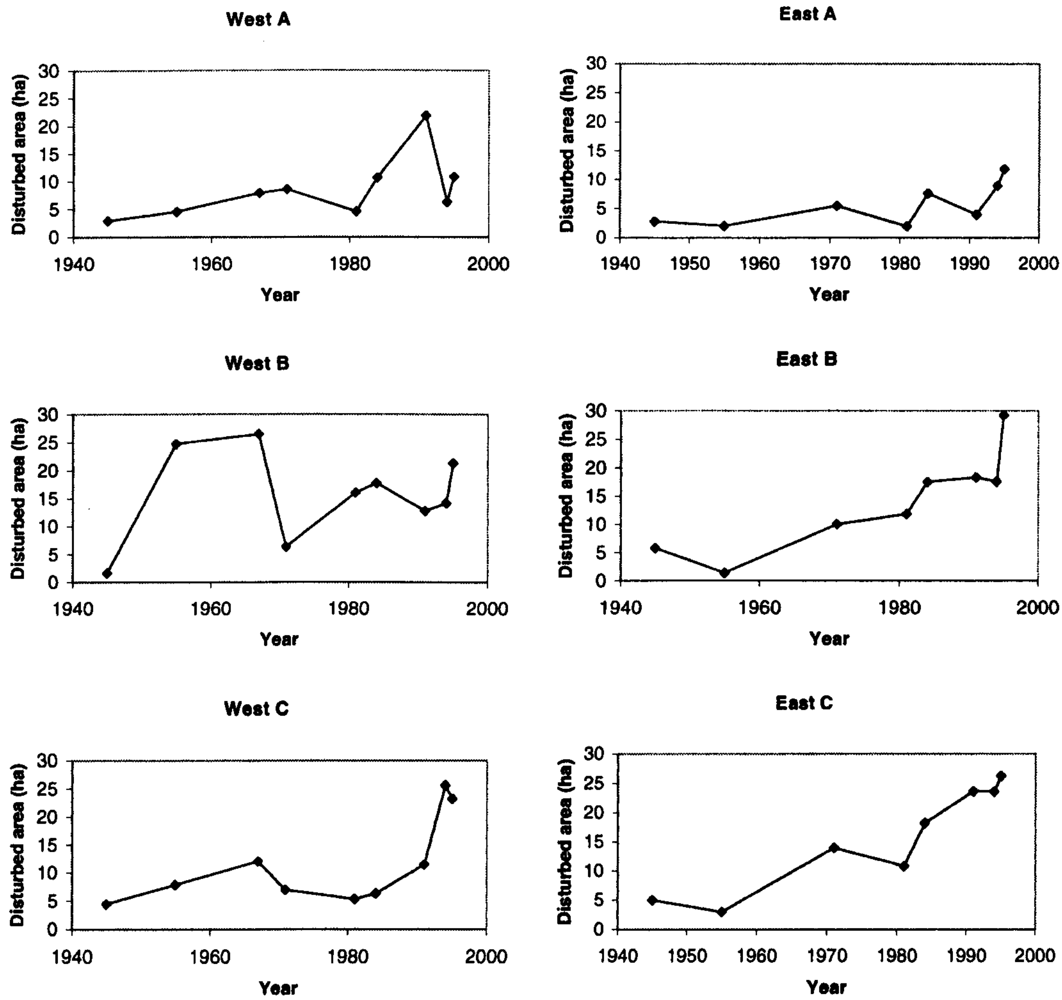


Figure 2.4 Plots of military disturbance against time for individual tetrads.

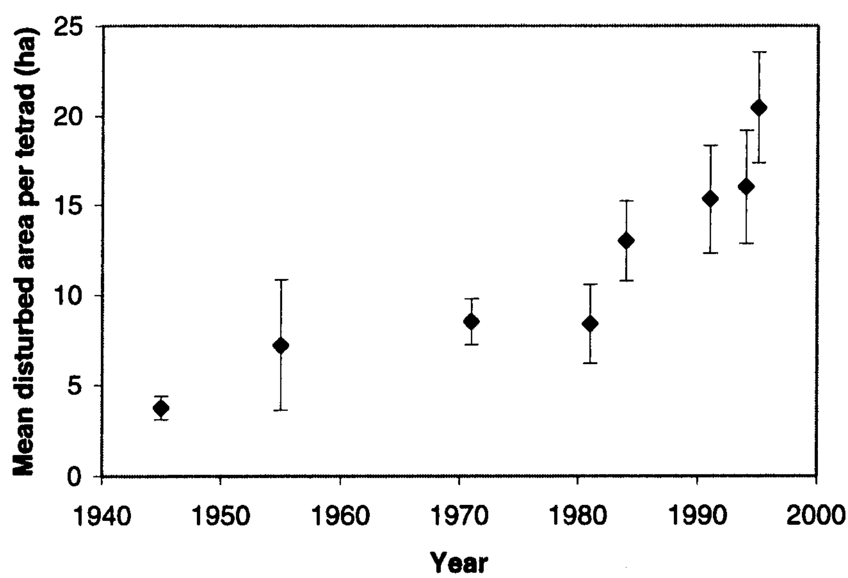


Figure 2.5 Mean disturbed area for all tetrads, 1945-1995. Bars shown are standard error of the mean.

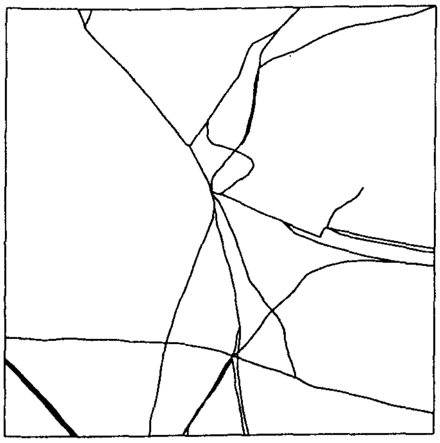
The plot of mean disturbed area per tetrad for military disturbance (Figure 2.5) shows a steady rise in the area of disturbed land on SPTA since 1945. The year-on-year fluctuation probably reflects a post WWII rise in training, a levelling off as a result of the transferral of many training units to NATO army field training areas in continental Europe, and subsequently, an increase following the end of the Cold War and the closure of these same NATO training areas. A simple linear regression on these data suggests that between 1945 and 1995, the average annual net increase in bare ground across the whole of SPTA due primarily to military activity was approximately 25.5 hectares ($Y = 0.269X - 520$, $R^2 = 36.3\%$, $p<0.001$). The loss of grassland between 1994 and 1995 was around 12 times this rate.

Analysis of the track network

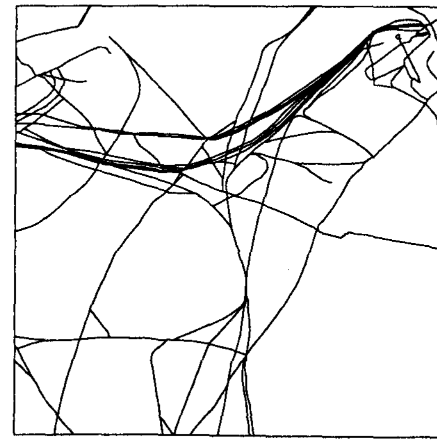
The development of the track network for sample tetrad West C is shown in Figure 2.6. These diagrams illustrate the change from relatively open downland in 1945 through to a more subdivided landscape in recent years. The immediate post-WWII rise in disturbed ground identifiable in 1955 has substantially decreased by the early 1980s, from when subdivision of the landscape rises again.

A graphical representation of mean track length per tetrad can be found in Figure 2.7. A simple regression model through the same data points suggests that the average increase in the length of tracks over the entirety of Salisbury Plain Training Area, during this 50 year time period, is approximately 40 km per year ($Y = 0.425X - 803$, $R^2 = 38.0\%$, $p<0.001$). The rate of increase during the 1990s is clearly greater than this, probably reflecting the increased usage of SPTA by tracked vehicles displaced from continental NATO training areas.

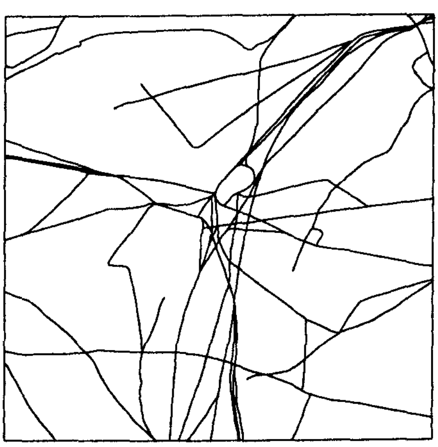
Related to the increase in the length of tracks is the degradation of the open chalk grassland into more numerous, smaller parcels of land. All tetrads displayed a trend of decreasing polygon size, and hence an increase in subdivision of the landscape. The overall trend for all tetrads is shown in Figure 2.8. The plot mirrors that of the length of tracks (Figure 2.7) and again the data can be described by a simple linear regression model. This implies that between 1945 and 1995, parcels of grassland on average have been decreasing in size by 0.1 ha each year ($\log Y = 28.1 - 0.012X$, $R^2 = 39.3\%$, $p<0.001$), from a mean of 14 hectares in 1945, to 3.6 hectares in 1995.



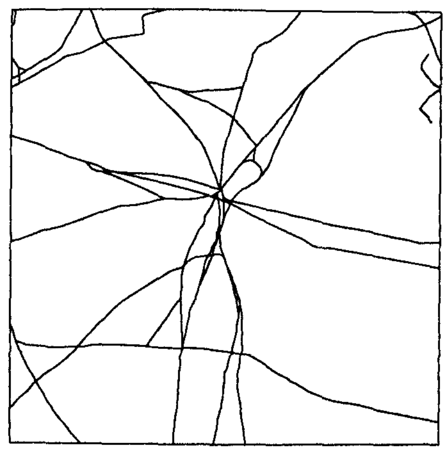
1945



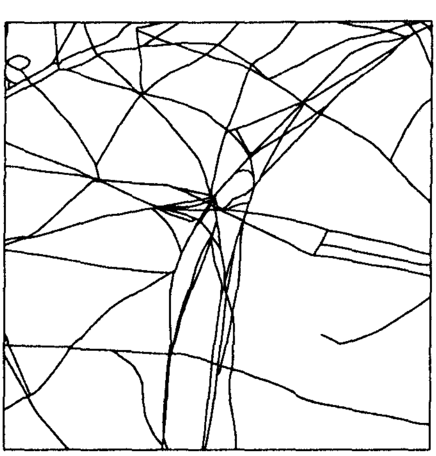
1955



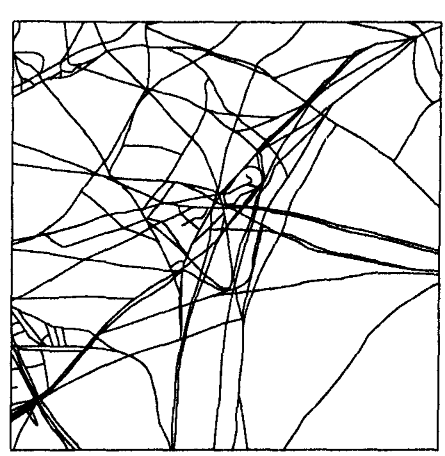
1967



1981



1991



1995

Figure 2.6 Chronosequence of track network images for tetrad West C.

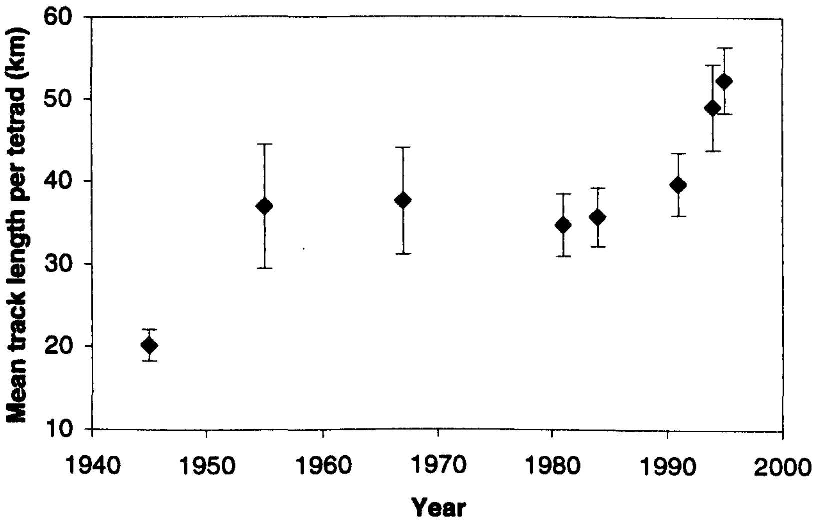


Figure 2.7 Length of tracks in sample tetrads on the SPTA, 1945-1995. Bars shown are standard error of the mean.

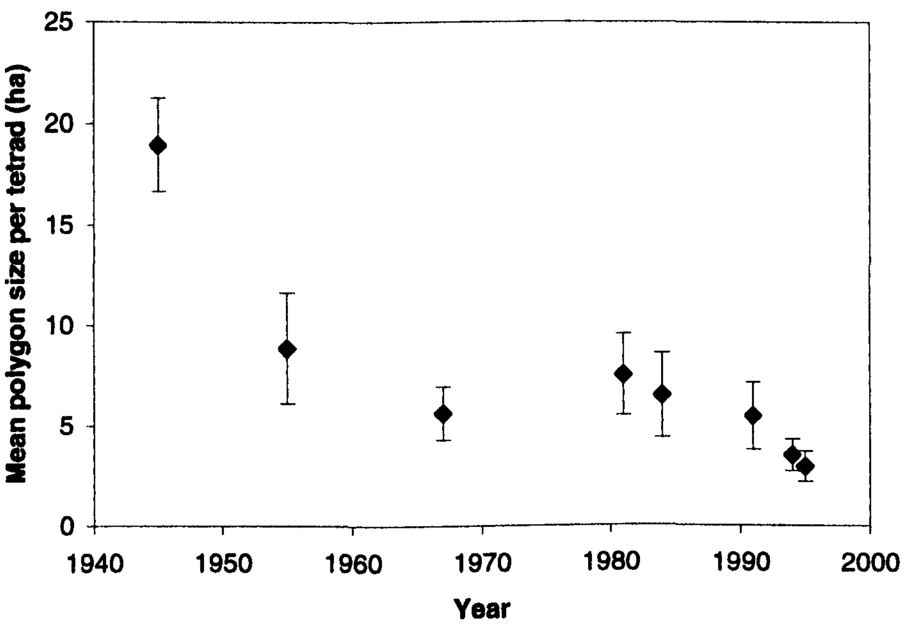


Figure 2.8 Area of polygons of grassland in sample tetrads on the SPTA, 1945-1995. Bars shown are standard error of the mean.

2.5 DISCUSSION

Changing disturbance patterns on Salisbury Plain

The historical aerial photograph analysis described here indicates that military disturbance on the Salisbury Plain Training Area has been increasing throughout the latter half of the 20th century. Changes have been particularly rapid since the early 1990s, and between 1994 and 1995 loss of grassland to disturbance was some 12 times the average rate recorded for the entire time period of the study. The general trends in recorded disturbance reflect the changing weaponry and training needs of the British Army as it responded to the fluid geo-political circumstances of the last century (see Farrington, 1995; Doxford and Hill, 1998). Analysis of the disturbance regime of individual tetrads, however, reveals much inter- and intra-tetrad variation, both temporally and spatially. Locally, disturbance is influenced by the creation of training features (plantation woodland, camps, etc.) and the acquisition of new mobile weapons (for example, the preferential firing of AS90 self-propelled artillery from specific locations). As different parts of the training area are used for different activities, and with different intensities, it is logical to expect spatial variation in the disturbance regime. Tetrad East A, for example, is located on the edge of SPTA East, and showed no significant increase in disturbance until the 1990s, when it is assumed that pressures on SPTA necessitated more peripheral and traditionally quiet sections of the training area be drawn into regular usage.

The magnitude of this loss of grassland may seem small when expressed as a proportion of the whole of SPTA (0.07% annually). Nevertheless, an average annual loss of 25.5 ha does not compare favourably when over three-quarters of all chalk grassland fragments in England are less than 20 ha in area (Keymer and Leach, 1990), and the entire and heavily protected Netherlands resource totals just 24 ha (Willems, in Wallis de Vries, 1999). The analysis demonstrates that at the local scale, recorded disturbance for individual tetrads decreased, as well as increased, between years. This suggests that the grasslands of Salisbury Plain had at these times a capacity for self-regeneration.

The disturbance recorded in this study includes sites which were both previously disturbed and undisturbed. The relative contributions to the increase in bare ground of (i) continued disturbance of already disturbed areas and the addition of new areas, and (ii) the disturbance of completely new areas simultaneous with the recovery of old areas, are not known. However, the continuing rise in bare ground, most notably during the 1990s does imply that disturbance was occurring at a rate exceeding that of the natural regeneration of the grassland, and that the training area was not being managed in a sustainable fashion.

The frequency threshold model described is restricted to the identification of disturbances that result in the creation of bare chalk. It does not easily detect less severe disturbances on Salisbury Plain such as single vehicular passes or tank turns where the soil surface horizons are exposed, but not bare chalk. The estimates derived for bare ground therefore represent that for severely disturbed land, and are an under estimate of the total area of disturbed grassland. A survey of the SPTA in 1996 using CASI data recorded approximately 4000 ha for bare ground and built up areas combined (Gerard *et al.*, 1999). The derived figure for 1995 from this study was 2336 ± 481 ha. Accommodating for one additional year of disturbance, and low intensity events, total disturbance may be 33% greater than the estimates presented here. (It is also possible that some bare areas were created by events other than anthropogenic disturbance, such as drought or disease. However, our experience of SPTA is such that these are extremely rare causes of bare ground.)

Implications of military disturbance

In the absence of other forms of management, low intensity disturbance on Salisbury Plain, such as the passage of a single vehicle, is probably important for maintaining the heterogeneity of the sward and the prevention of excessive scrub encroachment (Hirst *et al.*, 2000b). The creation of bare ground and the 'grazing' of grass by tanks helps to maintain habitat mosaics and encourages plant and animal species that otherwise would be absent from, or greatly reduced in number in the ecosystem.

Bare soil can, for example, create favourable habitats for invertebrate species because it can warm up more rapidly (Key, 2000). Threatened chalk grassland thermophilic species such as the Silver-spotted Skipper (*Hesperia comma*) and the Wartbiter Bush-cricket (*Decticus verrucivorus*), both of which are listed in the UK Biodiversity Action Plan are known to seek out areas of unshaded bare soil in order to lay their eggs (Key, 2000). Salisbury Plain is the centre of the UK population of Fairy Shrimps (*Chirocephalus diaphanus*), a fresh water crustacean protected under Schedule V of the Wildlife and Countryside Act 1981. It is found in Southern England in temporary pools no more than 300mm deep and on Salisbury Plain thrives in the scrapes made by tanks and other heavy military vehicles (Gillam and Pile, 1992). It is also possible that the eggs are transported from pool to pool by the vehicles themselves. Other larger animal species also benefit from military training: 12% of the British population of stone curlew (*Burhinus oedicnemus*) nest on SPTA, where the bare or sparsely vegetated ground it needs, away from regular human contact, can be purposefully created (English Nature, 1993).

Similarly, some plant species found on Salisbury Plain require mechanical soil disturbance for long-term survival. The tracks on Salisbury Plain are churned up every winter as the majority of roadsides were 100 years ago, and a great variety of declining species such as *Galeopsis angustifolia* thrive on the edges of earth tracks created by tanks. However, although it is well documented that intermediate levels of disturbance increase species diversity (Connell 1978, Huston 1979, Sousa 1984), typical disturbance plants that colonise the edges of tracks on Salisbury Plain such as *Echium vulgare*, *Sinapis arvensis*, *Agrostis stolonifera*, *Reseda lutea*, *Artemesia vulgaris* or *Potentilla anserina*, add to the diversity of the grassland as a whole, but are not traditionally considered typical or desirable components of chalk grassland. Nevertheless, some of these disturbance species are important food plants for specific invertebrates. The weevil *Ceutorhynchus geographicus*, for example, feeds on *Echium vulgare* (Key, 2000). The ecological quality of re-vegetating plant communities is therefore of key importance when evaluating the implications of habitat loss and fragmentation implied by these disturbance figures.

The *ad hoc* development of earth tracks may be more beneficial to ruderal species such as *G. angustifolia* than the construction of semi-metalled tracks, but it also reduces the area of the desirable grassland communities. The passage of a typical tank could theoretically remove 1400 m^2 of grassland per kilometre travelled. Semi-metalled tracks reduce the potential for this local habitat disturbance, but in doing so permanently destroy a substantial area of grassland and create new foci for vehicular movement on and off the area. Repeated and unchecked crossing of tracks as shown in Figure 2.6 results in the subdivision of grassland into smaller parcels, thus increasing the ratio of the inferior track-edge disturbance community to interior grassland, dust and pollution. Nevertheless, the wider spatial and temporal context of the issue of fragmentation should be appreciated. The UK chalk grassland habitat resource is much smaller now than it was at the turn of the century but is probably larger, and in bigger blocks, than it was 7,000 years ago

(Kirkby 1995). Moreover, when compared to other parts of the UK or NW Europe, the chalk grasslands of SPTA can hardly be considered fragmented.

Managing military disturbance

Determining just how much bare ground is appropriate in a habitat can be difficult. Key (2000) suggests that around 2-5% ought to be acceptable in almost any habitat, and an upper limit of 15% might be desirable in some. These figures must be balanced against the detrimental effects of habitat fragmentation, and the recognition that the edge effect of disturbed bare ground also decreases the area of intact habitat. According to the analysis presented here, approximately 5% of SPTA was disturbed ground in 1995, and hence the upper limit of the first band of acceptability proposed by Key has already been reached.

As English Nature defines damage (as opposed to disturbance) as being *'...loss and degradation of habitats and species for which Salisbury Plain was notified as an SSSI.'* (Wright, pers. comm.), the gradual deterioration of the landscape as a result of disturbance on the SPTA requires regular monitoring. The response to chronic disturbance is often more complex than remedial activity following acute, high intensity disturbance (Milchunas *et al.*, 2000). Recognising a general deterioration in the condition of plant communities should provide an impetus for the development of an environmental monitoring programme. In the case of military training areas the aim should be to preserve both the natural resource and the suitability of the area for realistic military training. Although there has, so far, been little systematic work on the resilience of the chalk grassland ecosystem to military disturbance, there is evidence to suggest that, with the exception of heather moorland and mire communities, grasslands generally display a greater response to disturbance than most other habitat types (Milchunas *et al.*, 2000; Charman and Pollard, 1995). Besides the issues of habitat degradation and loss, extensive areas of bare ground are often less useful for training purposes.

In 1994 the MoD proposed to increase the number of tracked vehicles using SPTA by 3-4 fold in order to accommodate training regiments displaced from continental Europe (RSK, 1994). This was clearly an area of concern for nature conservation and archaeological interest groups, and there is evidence here to suggest that substantial increases in total vehicle miles are already occurring. However, clarification of the thresholds at which the effects of disturbance on communities becomes irreversible are required, as is investigation of time periods of recovery and composition of regenerating grassland. Detailed studies of the timing and nature of habitat recovery following disturbance will be the subjects of subsequent chapters.

2.6 CONCLUSIONS

This study has successfully assessed the historical nature of the disturbance regime on the Salisbury Plain Training Area, and has provided a repeatable framework for future monitoring using aerial photographs. The techniques employed plotted changes in the extent and pattern of the more extreme types of disturbance found in the military training area over the past 50 years, and demonstrated that in recent years, increases in disturbance have been substantially above that of the average trend. Vehicular disturbance effects however are not restricted to military lands and aerial photographic techniques may provide a convenient monitoring tool in situations where digitally remotely sensed data are not readily available. Hirst *et al.* (2000) have demonstrated that even wheeled vehicles can have significant disturbance effects, and the increased use of off-road vehicles may impact on any part of the countryside with open access (Iverson *et al.*, 1981, Webb *et al.*, 1983). Outside SPTA, the chalk downlands of southern England are popular recreational areas, and habitat disturbance from a number of sources (vehicular and non-vehicular) pose particular management problems.

In the absence of other forms of management on Salisbury Plain, in particular grazing, small-scale disturbances are essential for the maintenance of the open chalk grassland habitat. However, the observed recent increase in more extreme disturbance should be of concern to those responsible for the management of the Salisbury Plain Training Area. The historical perspective taken in this study provides a context in which future changes in the usage of SPTA may be placed. If these changes are of the magnitude currently proposed by the Ministry of Defence, then they may present a serious threat to the chalk grassland flora and associated fauna. The importance of the Salisbury Plain Training Area cannot be understated.

MoD has acknowledged that military training areas, many of which lie within, or contain areas of, high nature conservation value, must now be managed in a more sustainable fashion. This study has provided evidence for military land managers as to the extent of the changes on SPTA in recent history, and has added impetus to the need to implement sustainable management through the Integrated Land Management Plan. It has also provided a framework for detailed scientific investigation of the precise trajectories of habitat recovery on Salisbury Plain following disturbance, in order to establish the absolute thresholds between disturbance from which recovery is known to be possible, and that which causes irreversible damage.

POSTSCRIPT

Work presented here published as:

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Military manoeuvres in the Imber Valley

3. ESTIMATING HABITAT RESILIENCE FOLLOWING MILITARY DISTURBANCE

SUMMARY

A chronosequence approach was used to investigate habitat recovery following military disturbance on the Salisbury Plain Training Area (SPTA), in southern England. SPTA is the largest of the UK military training areas and contains the greatest expanse of unimproved chalk grassland in NW Europe. Vegetation and soils data were collected from 82 sites disturbed over a 50 year period across both CG3 (*Bromus erectus*) and MG1 (*Arrhenatherum elatius*) grasslands. Re-vegetation time periods following disturbance were compared, and habitat resilience following disturbance investigated using both the succession of surface vegetation along the chronosequence, and the combined changes of vegetation and soil chemistry.

Mesotrophic grassland communities showed greater resilience following disturbance than calcareous grassland communities, with more rapid colonisation of bare ground and species re-assembly. Mesotrophic grassland sites typically took between 30 and 40 years to recover from disturbance, whereas calcareous grasslands took at least 50 years. However, even after these time periods, there remained subtle but significant differences in vegetation composition between the disturbed and undisturbed swards. These data can help land managers understand the current character of the grasslands of SPTA, and assist with the management of both future military exercises and the spontaneous restoration of disturbed habitats.

3.1 INTRODUCTION

Tracked vehicles are used in military and agricultural situations because they have better traction and mobility than wheeled vehicles (Braunack, 1986). This is primarily accredited to their lower ground pressure, and hence most research into their functioning is focused on mobility and performance, rather than their impacts on soil and vegetation. However, tracked vehicles are known to have cumulative and sometimes long-term effects on ecosystems (Gameda *et al.*, 1987; Voorhees *et al.*, 1986; Prose, 1985), and following disturbance vegetation communities can take many years to re-stabilise (Tilman, 1989; Milchunas and Lauenroth, 1995). Large military vehicles can change both the horizontal and vertical structure of vegetation communities through the crushing and cutting of vegetation (Severinghaus *et al.*, 1981; Milchunas *et al.*, 1998). Soil compaction effects decrease soil micro-porosity and rainfall infiltration capacity, altering the availability of nutrients, and restricting plant root growth (Braunack and Williams, 1993). Such changes in soil properties can delay or prevent re-establishment of the pre-disturbance plant communities (Shaw and Diersing, 1990). Increased exposure of bare ground and the churning of the soil surface create opportunities for both the re-colonisation of species in the original sward and the invasion and establishment of ruderals (Milchunas *et al.*, 1992).

The amount of disturbance caused by tracked vehicles is dependent on driving characteristics and antecedent soil conditions. Leininger and Payne (1980) showed that increasing the number of passes of a vehicle increased the amount of soil disturbance, and Lebedev and Sidorov (1965) showed that the action of a tracked vehicle caused a considerable shear force at the soil surface. Ayers (1994), in experiments in Queensland, Australia, demonstrated that lower turning radii (i.e. sharper turns), caused greater disturbance effects. In addition, the width of the rut created by a tracked vehicle was heavily dependent on the operating characteristics of the vehicle in question. Horn *et al.* (1989) demonstrated that slower speeds created more soil compaction and hence an increased impact on plant re-establishment and soil hydrology. Additionally, the season in which the disturbance occurs can influence the magnitude of the impact on the soil and vegetation. Wilson (1988) found that spring driving created more bare soil than summer driving. Increased soil moisture also leads to increased amounts of disturbance, especially in fragile ecosystems (Leininger and Payne, 1980; Braunack and Williams, 1993; Thurow *et al.*, 1993).

The response of vegetation communities to disturbance is usually separated into two components: **resistance** and **resilience** (Grimm *et al.*, 1992; Holling, 1973; Milchunas *et al.*, 2000; Mitchell *et al.*, 2000). Resistance to disturbance is a measure of the magnitude of the initial change in the community structure and composition immediately following the disturbance event. Resilience refers to the ability of a community to return to the pre-disturbance state. Habitat resilience is not easy to quantify. The speed of recovery of different components of a system following disturbance can vary. Changes in surface vegetation may, for example, occur at a different rate to changes in soil chemistry or microbial populations. Therefore, the resilience of a system depends on the characteristic measured. For example, resilience time periods are likely to be substantially longer than the **re-vegetation** period, that is, the length of time required for closure of the sward.

The Salisbury Plain Training Area (SPTA) in southern England is the largest of the UK military training areas and the only one large enough and with suitable geology to support large-scale tracked vehicle tactical exercises. As an area of around 20,000 ha of SPTA has been designated as a Site of Special Scientific Interest (SSSI) for its quality and contiguity of unimproved chalk grassland (English Nature, 1993), military land managers have a statutory obligation to maintain this resource. Interventionist land restoration techniques across such an extensive area are costly, and difficult to execute without impeding realistic military training. 'Land-rest' and spontaneous restoration are the primary tools available to those responsible for the management of the Salisbury Plain ranges. There is, therefore, particular interest in the response of these grasslands to disturbance.

Many authors have investigated the impacts of tracked vehicles on vegetation, primarily in semi-arid ecosystems where the loss of surface vegetation has serious implications for soil erosion (Milchunas *et al.*, 1998; Severinghaus *et al.*, 1981; Milchunas *et al.*, 1999; Prose, 1985; Diersing *et al.*, 1988; Wilson, 1988; Ayers, 1994; Shaw and Diersing, 1990; McDonagh *et al.*, 1979). However, to date there has been relatively little empirical work on the ecological impacts of military training in the UK, and with the exception of the effects of mowing and grazing, very few workers have investigated the disturbance of chalk grasslands. Therefore the aims of this paper are:

- to compare the resilience of two major vegetation community types found on SPTA using different recovery criteria; and
- to investigate the potential long-term effects of disturbance on chalk grassland communities.

In the absence of long-term monitoring, the aerial photographic record for the Salisbury Plain Training Area was used to investigate the recovery of disturbed grassland over a 50 year period. Although precise dates for disturbance events were not available, it allowed the production of best estimates for succession trajectories over a timeframe otherwise beyond the scope of a 3-year research project.

3.2 METHODS

Selection of study sites

Historical aerial photographs taken on nine dates between 1945 and 1995 were used to select 82 old disturbance sites from six tetrads (2x2 km squares) across the Salisbury Plain Training Area (see Chapter 2, Figure 2.1). These sites covered a variety of CG3 (*Bromus erectus*) and MG1 (*Arrhenatherum elatius*) grassland communities as defined by the National Vegetation Classification (Rodwell, 1992), across the nine dates of the photographs (see Table 3.1). The 2:1 ratio of calcareous grassland sites to mesotrophic grassland sites reflected the relative proportion of CG3 to MG1 in the sample area.

Table 3.1 Number of sampling sites disturbed in each time period on CG3 and MG1 grassland at the Salisbury Plain Training Area.

Date of photograph	Number of sites	
	CG3	MG1
1945	5	2
1955	7	2
1967	6	3
1971	4	-
1981	7	3
1984	6	8
1991	6	4
1994	7	2
1995	6	4
Total	53	29

Vegetation sampling

During July 1998 and 1999, at each of the 82 disturbed sites, 10 sample quadrats were positioned using numbers from a random number table; five were placed in the disturbed area, and five on an immediately adjacent area which from the photographic evidence appeared to have been undisturbed over the time scale of the chronosequence. The vegetation was assessed using quadrats designed to lie along a tank track (50cm wide x 2m long), and vegetation cover was recorded using the Domin scale (Mueller-Dombois and Ellenberg, 1974), including a score for bare ground. Three measurements for sward height were also taken in each quadrat using a drop disk (30cm in diameter, mass 80g) and ruler. Other characteristics recorded at each site included aspect ($-\cos\theta$), slope and grazing intensity (on a subjective scale of 0-3). The quadrats were marked for later collection of soil samples, after a buried ordnance safety check had been carried out.

Soil sample collection

Sample quadrats were marked and revisited for soil sample collection 4-5 months after the vegetation survey. Soil samples measuring 5x5x10cm were collected using a graduated trowel from four random locations per quadrat. These were bulked to make a 1000cm^3 sample.

Chemical analysis of soils

500cm^3 of each soil sample was air-dried and passed through a 2mm sieve. Available phosphorus was extracted using 2.5g of soil with 40ml 0.5M sodium hydrogen carbonate, and analysed using the molybdenum blue method (Allen, 1989). Total organic nitrogen was estimated as a surrogate measure of organic matter content using Nesslers reagent after acid digestion (0.5g of soil with 4.4ml of reagent) (Allen, 1974). Extractable cations (calcium, magnesium, sodium and potassium) were extracted using 10g of soil in 40ml of 1M ammonium acetate (adjusted to pH 9) and subsequently analysed using flame absorption spectrometry (Ca, Mg) and flame emission spectrometry (Na, K). Soil pH was measured using a 1:2.5 slurry of soil and deionised water (Allen, 1974).

Data analysis

Domin values for species cover were first transformed to percentage cover using the method proposed by Currall (1987). Vegetation changes along the time series were analysed using calculated percentage similarity between the species composition of the disturbed site and its adjacent undisturbed reference site, based on Sørensen's similarity index (Sørensen, 1948; Pielou, 1984; Bekker *et al.*, 1997; see Equation 3.1). The percentage similarity between disturbed and undisturbed quadrats was plotted against time since disturbance for each site. The mean percentage similarity between pairs of undisturbed quadrats within the reference plots was also calculated, to indicate target similarity.

$$PS_w = \frac{2 \times \sum Min(A_{iv}, A_{ivref})}{\sum A_{iv} + \sum A_{ivref}}$$

Equation 3.1 PS_w is the percentage similarity between the disturbed and undisturbed sites. A_{iv} is the cover (or presence) of a particular species in the disturbance site, and A_{ivref} is the cover (or presence) of that species in the undisturbed reference site.

Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were carried out on the vegetation and combined vegetation and soils data respectively, using the program CANOCO (Ter Braak, 1988). These multivariate analyses used data from both the disturbed and undisturbed sites. A covariate file was used to identify the pairing of the disturbed plots with their undisturbed reference plot. This focused the analysis on the differences between the disturbance and the reference rather than using absolute values. Where a covariate file is used to identify pairs of samples in a multivariate analysis, we would expect the results to have the following characteristics:

(a) Low eigenvalues

This analysis is investigating differences between sites from the same vegetation community. Compared to between-community analysis, the differences will be comparatively small, and therefore shorter gradients and lower eigenvalues can be expected. As the ordination is focused on the magnitude of the differences between sites rather than absolute values, we would expect the amount of variation in the data to be reduced further, and hence also the eigenvalues.

(b) Convergence on the origin

As the ordination is focused on differences between pairs of sites we would expect a degree of mirror-imaging of sites along gradients. In cases where there is a big difference in a variable between the disturbance and undisturbed plots, for example, the abundance of *Bromopsis erecta* present, then pairs of sites will be plotted further apart. As the difference between the sites moves towards zero there will be a convergence towards the origin.

The species data were log-transformed and Hill's scaling was used.

The difference between the positions of the disturbed and undisturbed sites along axes 1 and 2 of the DCA were correlated against measured environmental variables to identify possible gradients. The difference between the positions of the disturbed and undisturbed sites along axes 1 and 2 of the CCA were correlated against environmental variables either common to both the disturbed and undisturbed sites or only applicable to the disturbed sites, and therefore not suitable for use in the CCA analysis itself (time since disturbance, aspect (-cos θ), slope and grazing intensity). Axes shown to have a significant correlation with the time dimension were used to plot the 'movement' of the disturbance sites through time. ANOVA was used to assess the degree of separation of the samples sites along the primary DCA axes according to time period. This was particularly focused on the later time periods where differences between stands were less easy to identify.

All recorded species were coded according to their 'preference index' for mesotrophic and calcareous grassland communities, as listed in the CEH Biotope Occupancy Database (BOD) (see Griffiths *et al.*, 1999, and Appendix 1). The mean percentage cover of species with a score of 3 (high preference) for each of these communities was calculated for each disturbed and undisturbed site. Species were then classified as being perennial, biennial or annual grasses or forbs. The percentage cover of each of these classes was also calculated for each disturbed and undisturbed site. After testing for normality, paired t-tests were used to assess the difference between the cover of each of these classes of species in disturbed and undisturbed calcareous and mesotrophic grassland sites at different times following disturbance. In doing so, it was possible to separate out the effect of succession following disturbance from successional changes occurring in the undisturbed reference plots.

Data display

Graphs of variables against time were made using LOWESS plots (**LO**cally **WE**ighted **S**catter-plot **S**moothing). This type of plot can be particularly useful for exploring patterns in data (Sparks and Rothery, 1998). Although an attempt was made to fit curves to the data for predictive purposes, the range of values derived for resilience periods was greatly dependent on the type of model fitted to the data (logarithmic, polynomial, exponential, and so on). These models would have given a spurious impression of objectivity, and hence this more subjective method was used to describe general trends.

3.3 RESULTS

Soil analysis

A summary of the soil chemistry data can be found in Tables 3.2 and 3.3. Change in these data over the succession were found to be small, and no post-disturbance flush in nutrients was observed. This may be because such a flush had already occurred prior to the first sample time-period (three years after disturbance), or alternatively, the analysis of soil nutrients on a concentration per unit volume of soil omitted nutrients caught by cut surfaces or in the microbial biomass.

Paired t-tests (Table 3.4) indicate that, with the exception of potassium, disturbed soils have significantly less available major nutrients than the undisturbed soils. In addition, the soils beneath CG3 grasslands generally took longer to re-establish soil nutrients than the soils under the mesotrophic grasslands. In the MG1 grasslands, the soils of disturbed and undisturbed sites are no longer statistically different from each other 27-31 years after disturbance. In the CG3 grasslands, the undisturbed sites continue to have greater amounts of magnesium 27-31 years after disturbance and more nitrogen 43 years after disturbance. The disturbed MG1 grassland sites are more basic than the undisturbed sites, until 27-31 years after disturbance.

Closure of sward

Approximately 17 years after disturbance, both CG3 and MG1 grassland types had achieved 100% cover (Figure 3.1). The mesotrophic communities initially have more rapid colonisation than the calcareous communities, the latter showing a steadier increase in cover over this time period.

Similarity index

The similarity index for disturbed and undisturbed sites revealed different trends for CG3 and MG1 communities (Figure 3.2). Maximum similarity for the MG1 sites was just over 80%, whereas for CG3 sites it was nearer 90%. The MG1 plot rises from about 35% similarity three years after disturbance, reaching a maximum between 75% and 80%; this asymptote occurring approximately 30 years after disturbance. The CG3 sites, however, rise steadily in similarity from just under 50% a few years after disturbance to around 80% after 50 years. There is no asymptote in similarity for the calcareous grassland sites within the time frame sampled in this study, although after 50 years these sites were as near to maximum recorded similarity as the MG1 sites were after 40 years.

Table 3.2 A comparison of the soil properties of CG3 grassland sites on SPTA disturbed at various times and compared with paired undisturbed reference sites. Mean values and standard errors are displayed for disturbed (d) and undisturbed (u) sites.

Years since disturbance		3	4	7	14	17	27	31	43	53
Number of sites		6	8	5	5	8	5	5	7	5
N (µg g^{-1})	d	5960 ± 1032	6834 ± 1014	5647 ± 1258	6507 ± 912	8095 ± 1329	6611 ± 829	6350 ± 1170	3977 ± 441	3725 ± 686
	u	8108 ± 1268	7786 ± 1035	8840 ± 1382	10181 ± 806	9761 ± 1561	7090 ± 1074	6646 ± 1289	2583 ± 463	3281 ± 840
P (µg g^{-1})	d	2.13 ± 0.8	2.62 ± 0.5	1.31 ± 0.5	3.27 ± 0.1	1.92 ± 0.3	1.62 ± 0.5	1.39 ± 0.5	2.12 ± 0.6	1.83 ± 0.1
	u	2.11 ± 0.7	2.90 ± 0.6	1.59 ± 0.6	3.63 ± 0.3	2.23 ± 0.4	1.69 ± 0.3	1.16 ± 0.3	2.04 ± 0.6	1.80 ± 0.2
K (µg g^{-1})	d	99.6 ± 24.2	95.4 ± 9.4	134.9 ± 32.7	122.4 ± 39.1	104.3 ± 9.5	75.1 ± 4.0	91.0 ± 12.8	76.5 ± 4.9	70.7 ± 6.3
	u	116.6 ± 21.3	135.7 ± 23.6	103.1 ± 8.4	123.4 ± 21.0	103.9 ± 11.5	84.8 ± 12.5	106.9 ± 10.7	76.3 ± 5.4	78.1 ± 4.9
Ca (µg g^{-1})	d	4445 ± 497	4365 ± 300	4105 ± 525	3908 ± 591	5507 ± 395	4762 ± 462	5616 ± 526	5410 ± 505	4670 ± 692
	u	4986 ± 252	4620 ± 335	5568 ± 421	5203 ± 263	5824 ± 388	4842 ± 310	5777 ± 289	5263 ± 563	4881 ± 647
Mg (µg g^{-1})	d	101.3 ± 28.7	101.8 ± 19.8	103.6 ± 12.8	77.4 ± 10.1	138.3 ± 17.4	128.8 ± 39.4	117.8 ± 16.2	130.3 ± 29.4	55.0 ± 20.1
	u	146.5 ± 24.0	114.6 ± 13.3	130.9 ± 15.1	120.8 ± 15.2	169.8 ± 11.8	149.2 ± 31.6	135.8 ± 24.4	127.1 ± 25.8	58.3 ± 16.6
Na (µg g^{-1})	d	26.9 ± 7.3	28.9 ± 5.3	46.1 ± 6.6	36.0 ± 6.8	48.8 ± 3.5	40.6 ± 13.5	44.7 ± 4.7	58.6 ± 3.3	44.9 ± 3.1
	u	37.89 ± 5.5	34.4 ± 5.4	58.3 ± 7.3	50.1 ± 6.5	67.0 ± 4.8	42.2 ± 11.2	48.1 ± 8.5	57.9 ± 2.8	44.9 ± 4.5
pH	d	7.53 ± 0.18	7.57 ± 0.09	7.26 ± 0.38	7.49 ± 0.10	7.33 ± 0.16	7.31 ± 0.22	7.36 ± 0.11	7.45 ± 0.32	7.91 ± 0.13
	u	7.44 ± 0.14	7.52 ± 0.07	7.32 ± 0.14	7.37 ± 0.08	7.29 ± 0.12	7.31 ± 0.20	7.32 ± 0.11	7.41 ± 0.35	7.93 ± 0.09

Table 3.3 A comparison of the soil properties of MG1 grassland sites on SPTA disturbed at various times and compared with paired undisturbed reference sites. Mean values and standard errors are displayed for disturbed (d) and undisturbed (u) sites.

Years since disturbance		3	4	7	14	17	31	43	53
Number of sites		5	2	4	7	3	3	2	2
N (µg g^{-1})	d	4622 ± 1099	2562 ± 1410	7288 ± 1117	6137 ± 950	7253 ± 2126	2857 ± 735	1612 ± 530	3253 ± 2140
	u	7234 ± 1049	3188 ± 1907	9165 ± 902	7999 ± 1119	8180 ± 2913	5211 ± 1274	1965 ± 942	4124 ± 1156
P (µg g^{-1})	d	1.55 ± 0.6	1.4 ± 1.4	2.11 ± 0.5	3.33 ± 0.3	1.76 ± 0.9	2.93 ± 0.2	2.12 ± 0.4	1.26 ± 0.0
	u	2.15 ± 0.8	2.74 ± 0.6	2.36 ± 0.7	3.25 ± 0.1	2.78 ± 0.6	2.95 ± 0.6	2.08 ± 0.5	1.66 ± 0.2
K (µg g^{-1})	d	72.7 ± 6.8	45.8 ± 5.9	125.2 ± 27.8	90.4 ± 15.1	94.5 ± 8.2	222.1 ± 8.1	52.5 ± 9.7	64.3 ± 2.2
	u	102.7 ± 22.3	90.7 ± 26.2	115.2 ± 17.9	115.7 ± 24.6	194.4 ± 75.6	214.5 ± 19.4	55.1 ± 13.2	95.9 ± 32.0
Ca (µg g^{-1})	d	3748 ± 673	2464 ± 590	4606 ± 340	3970 ± 397	4600 ± 1135	4111 ± 327	6330 ± 604	5945 ± 277
	u	4934 ± 521	5251 ± 492	5335 ± 275	4697 ± 279	5063 ± 539	4431 ± 141	6219 ± 709	5974 ± 209
Mg (µg g^{-1})	d	68.9 ± 16.2	65.8 ± 7.8	81.9 ± 11.3	69.5 ± 9.3	87.7 ± 31.6	85.5 ± 7.2	102.4 ± 5.7	100.3 ± 38.7
	u	103.0 ± 11.7	124.1 ± 29.3	111.2 ± 11.1	102.3 ± 12.6	106.8 ± 18.7	74.3 ± 1.8	68.1 ± 47.5	102.4 ± 44.9
Na (µg g^{-1})	d	30.3 ± 6.4	18.3 ± 13.0	35.4 ± 7.8	29.6 ± 3.7	46.4 ± 14.2	24.4 ± 12.3	50.3 ± 1.4	49.0 ± 1.5
	u	48.5 ± 7.5	47.0 ± 5.8	43.8 ± 11.5	43.6 ± 4.8	59.6 ± 14.7	29.9 ± 15.0	63.9 ± 14.5	47.7 ± 1.1
pH	d	7.63 ± 0.08	7.76 ± 0.07	7.73 ± 0.07	7.67 ± 0.10	7.70 ± 0.07	7.63 ± 0.08	7.74 ± 0.09	7.79 ± 0.24
	u	7.44 ± 0.07	7.43 ± 0.08	7.65 ± 0.06	7.55 ± 0.11	7.6 ± 0.07	7.58 ± 0.10	7.83 ± 0.04	7.77 ± 0.30

Table 3.4 Significance of soil property differences between disturbed CG3 and MG1 grassland sites on the SPTA, using paired t-tests between sites disturbed at various times, and undisturbed reference sites. u = undisturbed > disturbed, d = disturbed > undisturbed. Number of letters reflect significance, e.g. u = p<0.1, uu = p<0.05, uuu = p<0.01.

Grassland type	Factor	Years since disturbance				
		3-7	14-17	27-31	43	53
CG3	Na	uuu	uuu			
	K					
	Mg	uu	uuu	uu		
	Ca	uu	uu			u
	N	uuu	uuu		uu	
	P		uu			
	pH					
MG1	Na	uuu	uuu			
	K		u			
	Mg	uuu	uuu			
	Ca	uu	uuu			
	N	uuu	uu	u		
	P	uu				
	pH	dd	ddd			

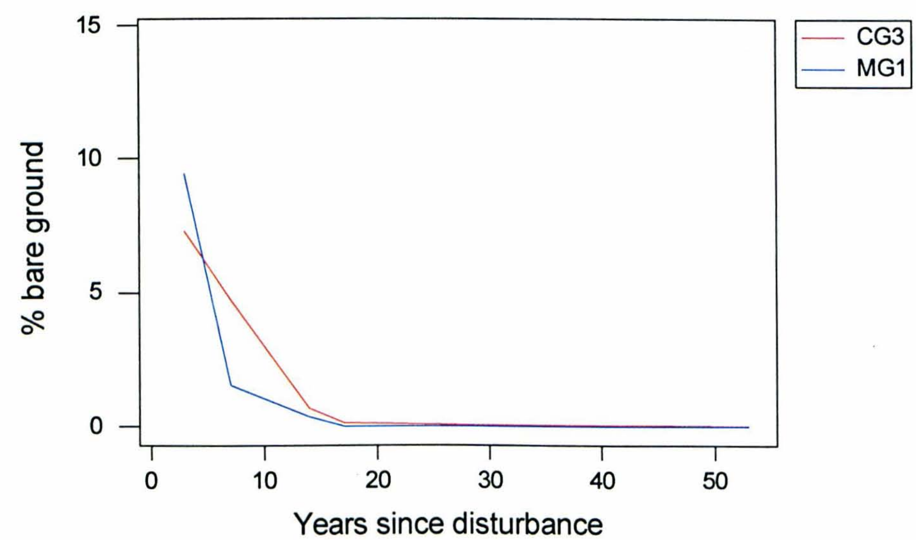


Figure 3.1 Bare ground recorded in old disturbed calcareous and mesotrophic grassland on the SPTA. LOWESS plots are presented; Red = CG3 swards, blue = MG1 swards.

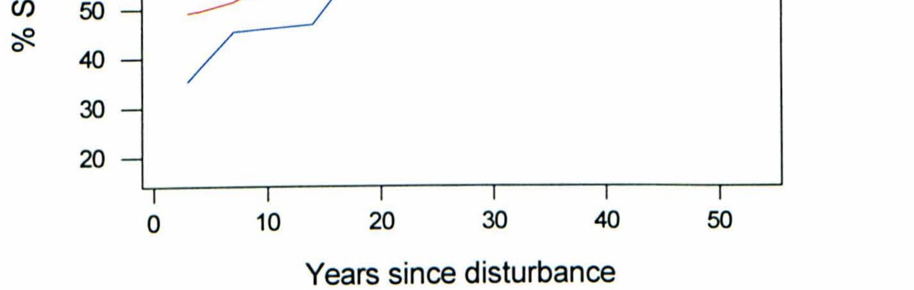
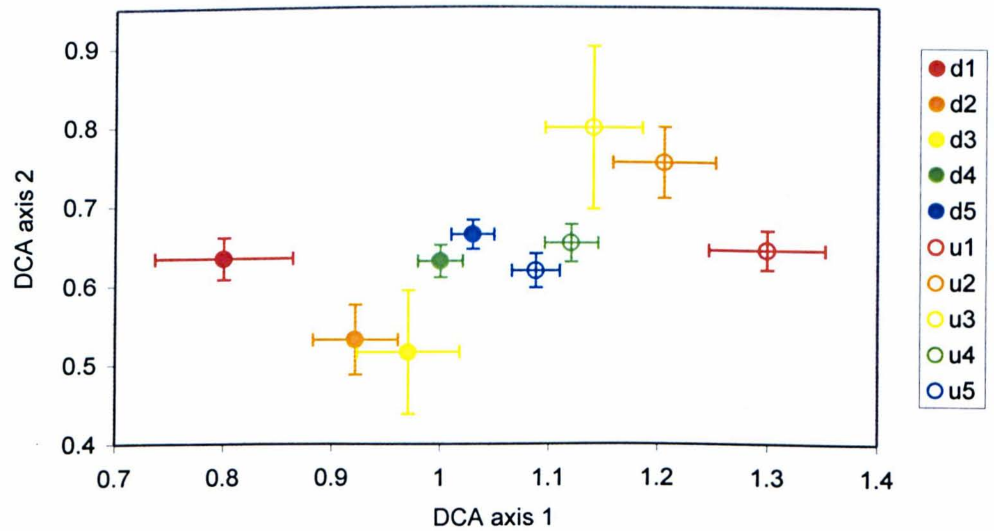
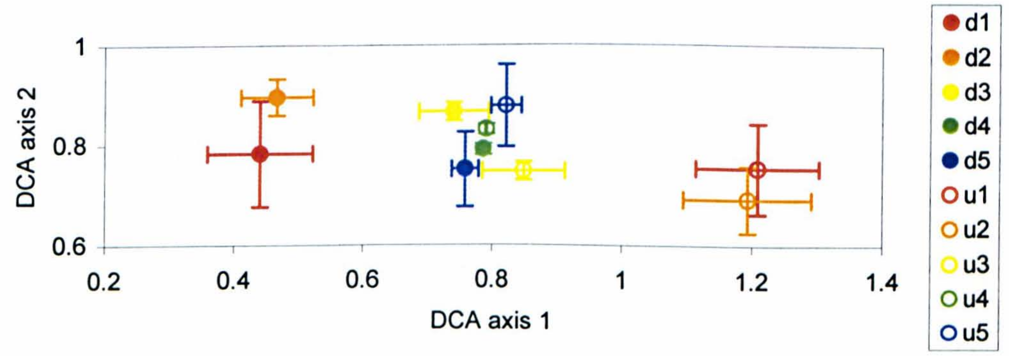


Figure 3.2 Similarity between disturbed and adjacent undisturbed vegetation grassland on SPTA. LOWESS plots are presented; red = CG3 swards, blue = MG1 swards. Solid line = disturbed vegetation, dashed line = maximum similarity within undisturbed stands.



a. CG3 grasslands



b. MG1 grasslands

Figure 3.3 DCA biplots showing relative positions of disturbed and undisturbed (a) CG3 and (b) MG1 grassland sites on SPTA along the first two ordination axes. Closed symbols represent mean position of disturbed sites, open circles represent mean position of undisturbed sites. Time periods coded as: 1 = 3-7 years after disturbance, 2 = 14-17 years, 3 = 27-31 years, 4 = 43 years, 5 = 53 years. Bars show standard error of the mean along the two axes displayed.

Multivariate analysis of plant community changes

The biplots from the DCA analysis (Figure 3.3) display the predicted characteristics noted earlier, with the more recently disturbed sites occupying positions in the far right of the diagram moving through time towards the origin. The significance of correlation coefficients between the position of disturbed sites on axes 1 and 2 and measured environmental variables (Table 3.5) indicate a strong correlation with time and area of bare ground, suggesting that the first axis in both the CG3 and MG1 ordinations represents a successional gradient. Increasing amounts of available calcium and sodium are also associated with this first axis in the CG3 community, and increasing availability of magnesium in the MG1 community. In the CG3 sites, the second DCA axis is not significantly correlated with any of the measured variables, but in the MG1 grasslands is associated with bare ground.

Table 3.5 P-values for correlation coefficients between the position of old disturbance sites along DCA axes 1 and 2 displayed in Figure 3.3, and measured environmental variables (+/- signs represent direction of correlation).

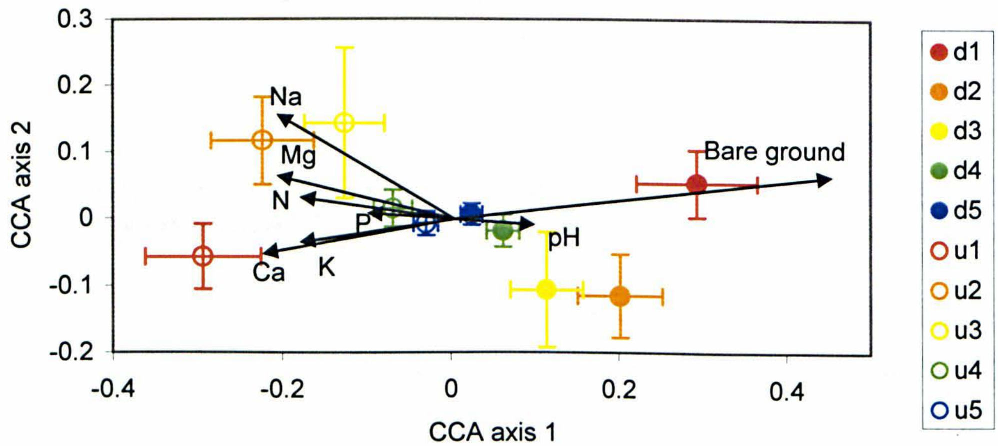
Factor	CG3 DCA axis		MG1 DCA axis	
	1	2	1	2
Time	<0.005+	ns	<0.005+	ns
Bare ground	<0.001-	ns	<0.05-	<0.05-
Aspect	ns	ns	ns	ns
Slope	ns	ns	ns	ns
Grazing intensity	ns	ns	ns	ns
Na	<0.05+	ns	ns	ns
K	ns	ns	ns	ns
Mg	ns	ns	<0.05+	ns
Ca	<0.005+	ns	ns	ns
N	ns	ns	ns	ns
P	ns	ns	ns	ns
pH	<0.05-	ns	ns	ns

There is a significant difference between the position of disturbed and undisturbed CG3 grassland along the first DCA axis (Table 3.6), and hence sward composition, until between 40 and 50 years after the disturbance event. At the 53 year mark, the difference between the disturbed and undisturbed CG3 vegetation is only marginally insignificant at the 95% level (p=0.08). For the MG1 grasslands, however, after 30 years have elapsed since disturbance, there is no statistical difference between the position of disturbed and undisturbed sites along the first DCA axis. These results suggest that a time period of at least 50 years is required for convergence between the species composition of disturbed and undisturbed CG3 grassland, compared to around 30 years for the MG1 grassland.

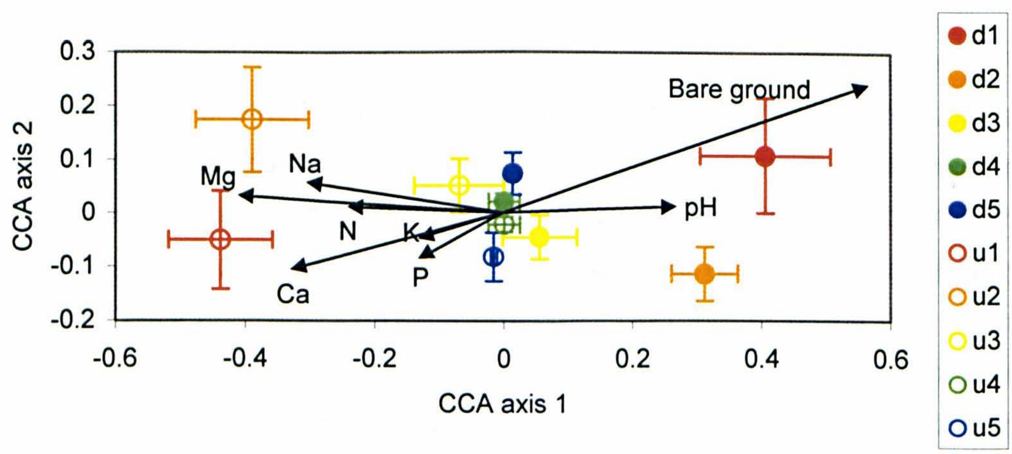
Table 3.6 Significance of one-way ANOVAs between the position of disturbed and undisturbed CG3 and MG1 grasslands, along the first DCA axes in Figure 3.3

Time period	CG3	MG1
1 (3-7 years)	$p<0.001$	$p<0.001$
2 (14-17 years)	$p<0.001$	$p<0.001$
3 (27-31 years)	$p<0.05$	ns ($p=0.263$)
4 (43 years)	$p<0.005$	ns ($p=0.136$)
5 (53 years)	ns ($p=0.08$)	ns ($p=0.179$)

The CCAs for both the CG3 and MG1 grasslands (Figure 3.4) show that both communities have predominantly the same pattern of correlated environmental variables, with area of bare ground explaining most of the variation on the first axes. Negatively correlated with this factor are the measured soil nutrients, most notably calcium (Ca) and potassium (K). The 'movement' of disturbed sites through time can be depicted by plotting the difference between the position of disturbed and undisturbed reference sites along this first axis against time since disturbance (Figure 3.5). As the figures used in Figure 3.5 for CG3 and MG1 sites were derived from separate ordinations, the plot can not be used to assess absolute differences between the community types. However, both communities show an overall decrease over time in the distance between the disturbed site and its undisturbed reference along the first axis of the CCA, although the rate of change varies between the two. The MG1 sites show a rapid decrease followed by a slower rate of change 30 years after disturbance. The CG3 sites undergo a much more gradual change, with no significant break in slope over the 50 year time period investigated.



a. CG3 grassland



b. MG1 grassland

Figure 3.4 CCA biplots showing relative positions of disturbed and undisturbed (a) CG3 and (b) MG1 grassland sites on SPTA along the first two ordination axes. Closed symbols represent mean position of disturbed sites, open circles represent mean position of undisturbed sites. Time periods coded as: 1 = 3-7 years after disturbance, 2 = 14-17 years, 3 = 27-31 years, 4 = 43 years, 5 = 53 years. Bars show standard error of the mean along the two axes displayed. Arrows show relative positions of environmental variables: x3 magnitude.

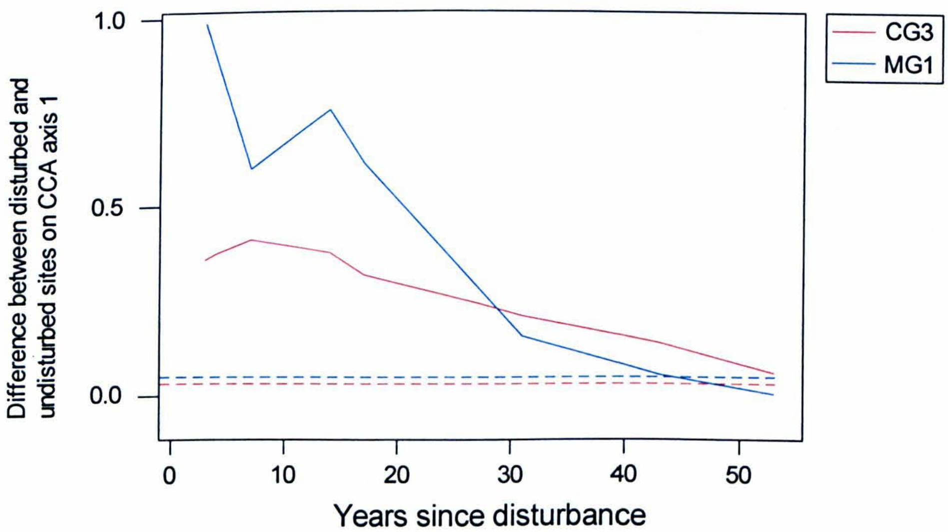


Figure 3.5 The difference over time between the position of disturbed and undisturbed sites on CCA axes 1 for CG3 (solid red line) and MG1 (solid blue line) communities on SPTA. LOWESS plots are displayed. Dashed lines represent mean difference between pairs of undisturbed reference sites across the time series (red = CG3 sites, blue = MG1 sites).

Figure 3.5, as with Figure 3.2, shows no saturation point for the re-establishment of the CG3 grasslands within the 50 year time period sampled. The plot for the mesotrophic grassland sites in Figure 3.5 also implies that when soil chemistry is taken into account, the recovery period for these grasslands is extended beyond the time taken for species re-establishment. The MG1 sites approach the reference line around 40 years after disturbance, although change appears to continue past this date. Both Figure 3.2 and 3.5 imply that mesotrophic grasslands show greater resilience following disturbance than chalk grassland, in that the time period required for MG1 community re-establishment is between 10 and 20 years less.

Community changes along a time series

The significance of paired t-tests between the percentage cover of certain groups of species found at disturbed and undisturbed sites for a series of amalgamated time periods following disturbance shows that disturbance in the calcareous and mesotrophic grasslands initially caused a significant reduction in the cover of calcareous and mesotrophic species respectively (Table 3.8). This was due to a reduction in total cover following disturbance rather than significant increases in other species life forms, although field observations suggest that the early colonisation of mesotrophic grassland sites is characterised by a slight increase in the number and cover of typically calcareous grassland species, such as *Daucus carota* or *Sanguisorba minor*. Forty to fifty years after disturbance the calcareous grassland sites start to show a slight increase in the abundance of typically mesotrophic grassland species in the sward, compared to the undisturbed reference sites ($p<0.1$). This is probably due to increased presence of species such as *Festuca rubra* or *Holcus lanatus*, both of which have a high score in the CEH Biotope Occupancy Database for their prevalence in mesotrophic grasslands but were also typical components of the tall chalk grasslands sampled here. Their cover in old disturbed plots seems to be at the expense of *Bromopsis erecta*. *B. erecta* primarily spreads vegetatively and therefore may find it more difficult to re-establish when in competition with *F. rubra* or *H. lanatus*, which respectively form large transient and persistent seed banks. It is interesting however that the disturbance seems to promote the persistence of these species so long after the disturbance.

In both mesotrophic and calcareous grassland sites, disturbance significantly reduced the cover of perennial grasses, but not perennial forbs. This suggests that the early colonisers of disturbance are forbs rather than grasses. 53 years after disturbance there is a significantly higher cover of perennial grasses in the disturbed calcareous sites than in the undisturbed sites, probably those species responsible for the higher cover of mesotrophic species noted above. Both the mesotrophic and calcareous sites show a small increase in the abundance of perennial forbs in the sward 30-50 years after disturbance. This suggests that disturbance may promote the presence of perennial forbs, possibly representing both the remnants of old disturbance, and providing an innoculum for recolonisation by dispersal or in the seed bank following future disturbances. These include many hemicryptophytic or protohemicryptophytic species such as *Medicago lupulina*, *Trifolium pratense*, *Bellis perennis* or *Centaurea scabiosa*. The early recolonisation of disturbance in both mesotrophic and calcareous grasslands sites is also characterised by a significant increase in the cover of annual and biennial forb species. This effect is more pronounced in the mesotrophic grasslands.

Table 3.8 Significance difference between % cover of certain classes of species found at disturbed CG3 and MG1 grassland sites on SPTA at certain times after disturbance. Results of paired t-tests between disturbed and undisturbed reference sites are displayed. u = undisturbed > disturbed, d = disturbed > undisturbed. Number of letters reflect significance, e.g. u = p<0.1, uu = p<0.05, uuu = p<0.01.

Community	Species type	Years since disturbance				
		3-7	14-17	27-31	43	53
CG3	Typical CG species	uuu	uuu	u		
	Typical MG species				d	d
	Perennial grasses	uuu	uu			dd
	Perennial forbs				d	d
	Annual forbs	dd	d		d	
	Biennial forbs	d				
MG1	Typical CG species					
	Typical MG species	uuu	uu			
	Perennial grasses	uuu	uuu			
	Perennial forbs			dd		d
	Annual forbs	ddd				
	Biennial forbs	d	dd			

3.4 DISCUSSION

Time periods for recovery

It has been demonstrated that the time required for restoration of a grassland's full species compliment and structure following disturbance far exceeds that for the closure of the sward. However, resilience periods are clearly dependent on the number of elements considered (Table 3.9). When soil chemistry variables were included with vegetation re-establishment in Canonical Correspondence Analysis, ecosystem resilience following disturbance was apparently reduced.

Many authors have noted that long time periods are frequently required for full habitat recovery (McDonagh *et al.*, 1979; Prose, 1985; Vorhees *et al.*, 1986; Shaw and Diersing, 1989), and the 30 and 50 year proposed time periods for the re-establishment of mesotrophic and calcareous grasslands respectively indicate the minimum exclusion times if these grasslands are to recover spontaneously (Charman and Pollard, 1995). It is likely that repeated disturbance of the sward prior to full community re-establishment will result in a continuing deterioration of habitat condition. In these situations, it is possible that both the initial resistance of a community to disturbance, and its subsequent resilience will be decreased further, and hence the impact threshold between stable states and irreversible damage will also be lowered (Jones and Bagley, 1998).

Table 3.9 Summary of estimates of resilience to disturbance of calcareous (CG) and mesotrophic (MG) grasslands, according to criteria used: n = cover, v = species assemblage, s = soil properties.

Factor	CG3	MG1
n	<20 years	<20 years
n+v	>50 years	>30 years
n+v+s	>50 years	>40 years

Differences in resilience of calcareous and mesotrophic communities

The results presented here suggest that the mesotrophic grassland communities on Salisbury Plain are more resilient than the chalk grassland communities. Resilience is thought to be a function of a wide range of factors such as species pools and spatial heterogeneity of habitats, nutrient stress, litter loss and accumulation, plant morphology and life strategy, and overall habitat productivity (Leps *et al.*, 1982; MacGillivray *et al.*, 1995; Grace, 1999; Mitchell *et al.* 2000; *inter alia*). For the two communities considered here, resilience is likely to be dependent on a combination of availability of seed for re-establishment, and the recovery of soil nutrient status. The chalk grassland swards tended to be more species-rich than the mesotrophic grasslands and therefore the probability of full re-establishment was lower than that for a more species-poor sward. Additionally, analysis of the soil data showed that the soils in the disturbed CG3 sites were slower than those of the MG1 sites to regain pre-disturbance concentrations of total nitrogen. This may be a controlling factor in the re-establishment of the sward, but would merit further investigation.

Community resilience has been shown to be linked to species strategy and resource allocation (Leps *et al.*, 1982; Levitt, 1978; Grime, 1974). MacGillivray *et al.* (1995) demonstrated that nutrient stress tolerance in a system was positively correlated with resistance to disturbance, but negatively correlated with resilience. Stress tolerators tend to be slow growing, and thus have lower rates of recovery following disturbance (MacGillivray *et al.*, 1995). Chalk grassland systems are more nutrient poor and have more stress-tolerant species than higher productivity mesotrophic grasslands. The difference in recovery periods for these two grassland communities may then be attributed to the particular traits of their component species.

Whilst by no means unimportant, mesotrophic grasslands tend to be assigned a lower conservation priority than chalk grasslands. As the mesotrophic grasslands have here been shown to have greater resilience following disturbance than the chalk grasslands, these areas could be used for military training at times when the habitats are less resistant to disturbance, for example, when soil moisture levels are high. However, the mesotrophic grasslands on SPTA tend to be on the periphery of the training area, traditionally quiet regions that act as 'buffer zones' between military activities and those of local people. In addition, this may increase conflict between military and agricultural interests (see Chapter 7).

Short- and long-term changes in sward composition

It can be difficult to compare disturbed and undisturbed vegetation along a time series, as it is necessary to separate the effects of post-disturbance succession from successional or post-management changes occurring in plots being used as controls. Additionally, it is unknown whether apparently undisturbed control plots had been disturbed during the time-scale of the study. In utilising a comparative approach such as that employed here, rather than investigating absolute changes, it is possible to identify points of convergence between the succession occurring on disturbed and undisturbed sites. A number of authors have noted the early changes in community composition following vehicle disturbance similar to those recorded here, typically involving the initial replacement of larger perennial species by smaller annual species (Shaw and Diersing, 1989; Severinghaus *et al.*, 1981; Milchunas *et al.*, 2000).

That disturbance often leads to a temporary increase in community diversity is well documented (Grime, 1973; Connell, 1978; Huston, 1979; Sousa, 1984), but the plants that commonly colonise disturbed tracks on Salisbury Plain such as *Melilotus altissimus, Echium vulgare* or *Odontites vernus* are not considered typical or desirable components of chalk grassland (Hirst *et al.*, 2000b). English Nature defines damage (as opposed to disturbance) on the SPTA as being '*. . . loss and degradation of habitats and species for which Salisbury Plain was notified as an SSSI*' (Wright, pers. comm.). These changes in sward composition therefore need to be monitored in order to ensure that community re-establishment continues beyond the unstable early stages of succession, and is not interrupted by further disturbance events.

The promotion by disturbance of forbs in disturbed patches has been noted by other authors (see Hillier, 1990). This phenomenon, which occurred in both the mesotrophic and calcareous grassland communities sampled here (Table 3.8), is probably one reason why the grasslands of Salisbury Plain have a particular character that is not easy to characterise using the National Vegetation Classification (Porley, 1986). However, as the grasslands of SPTA were not included in the surveys from which the NVC was derived, it may not be realistic to expect a perfect fit. The persistence of species such as *Melilotus altissimus* or *Pastinaca sativa* at high frequencies in the sward is a consequence of past disturbance events, and will be one of the sources of seed for re-colonisation of future disturbance sites. It is likely therefore that disturbance is forcing long-term changes in these grasslands, and may eventually result in new phytosociological communities.

Wider implications of the study

This investigation has highlighted aspects of habitat disturbance and recovery that are applicable to many other UK military training facilities. The Ministry of Defence is custodian of over 250 SSSIs (MoD, 1999) with many training areas including land that is within National Park boundaries (Otterburn in Northumberland, Castlemartin in Pembrokeshire) or Areas of Outstanding Natural Beauty (AONBs). Training activities in these areas must be carried out within the terms of the designations, and with a view towards sustainable use. Data such as those presented here enable more informed decision-making by those responsible for managing the area, and provide insights into the carrying capacity of these grasslands. However, vehicular disturbance of land is not restricted to military training areas. With the increased popularity of off-road recreational vehicles, these types of disturbance may impact on any part of the countryside with open access (Iverson *et al.*, 1981; Webb *et al.*, 1983). Chapter 5 includes consideration of the impacts that even wheeled vehicles may have on soils and vegetation.

Chalk grasslands remain a rare and fragmented habitat type in NW Europe. Outside Salisbury Plain, the rolling chalk downlands of southern England, many of which enjoy statutory protection, provide a valuable recreational resource for walking, horse-riding and cycling. These activities cannot take place without some localised habitat disturbance, but can be managed more effectively if the ecosystem dynamics are better understood. Appreciation of the length of time that intensively disturbed chalk grassland can take to re-establish may encourage more effective preventative measures at other sites.

Limitations of study

This investigation is based entirely on best estimates of disturbance dates and recovery periods. There is no way of ascertaining whether the disturbance event took place at the beginning or end of a time period determined by the dates of two aerial photographs. This could only be rectified through the establishment of a long-term sampling and monitoring programme, beyond the scope of this study, and outside a workable time frame for conservation policy formulation. Time periods for sampling were determined by the availability of photographic material – these were not at regular intervals, nor was there full coverage of all the randomly selected tetrads.

Habitat stability following disturbance was investigated here using species cover as the measure of vegetation structure. An alternative approach would have been to use biomass harvesting, which would have allowed an estimation of the response of total biomass to disturbance, the relationship with species richness and the contribution of the litter layer. However, given the large number of sampling points, recording of species cover was more practical.

We know very little about the precise source of the disturbance investigated in this study, nor its intensity, and nothing regarding the antecedent ground conditions or sward composition immediately prior to disturbance. The assumption was made that the disturbance depicted on the aerial photographs was as a result of a single event, and that the disturbance intensity was similar for all sampling sites. We have attempted to overcome some of these sampling inefficiencies by recording a large number of sites. Chapters 5 and 6 deal with the early phases of recovery following disturbance, under more controlled conditions.

3.5 CONCLUSIONS

The chronosequence approach adopted in this study has enabled useful insights into the possible variation in habitat regeneration within one study site. Despite this variation, the large sample of sites was sufficient to reveal interesting comparative trends between different grassland communities, and enable estimates of the time periods required for spontaneous habitat recovery. These time periods can vary according to the components of the system investigated.

While the time periods suggested here for habitat resilience are estimates, they have been instrumental in altering the manner in which the grasslands of SPTA have traditionally been viewed. Disturbance on the Salisbury Plain Training Area remains an important management tool in areas where grazing is logistically difficult. However, studies such as this are altering the military perspective of the grasslands as having an inexhaustible capacity for carrying training activities, and a greater appreciation of their complex functioning is being reached. This is essential if the grasslands are to be managed successfully for both military and conservation purposes.

Vegetation survey in the Bulford Ranges

4. INVESTIGATING THE RESPONSE OF THE SOIL SEED BANK TO DISTURBANCE

SUMMARY

Historical aerial photographs were used to identify sites on the Salisbury Plain Training Area (SPTA) which showed a 50-year chronosequence of disturbance. At each site, soils were collected for analysis of their seed bank, and these data compared with the surface vegetation. Sites sampled included both CG3 (*Bromus erectus*) and MG1 (*Arrhenatherum elatius*) grasslands. Significant community differences were identified between the seed populations of sites which had been disturbed, and those undisturbed. Calcareous grassland seed banks were dominated by *Hypericum perforatum* and *Agrostis stolonifera* while the major species in the mesotrophic grassland samples were *Daucus carota* and *Holcus lanatus*. The seed banks from the CG3 sites tended to recover more slowly from the disturbance than the MG1 seed banks. When both seed bank and surface vegetation changes following disturbance were combined, recovery periods were estimated at over 50 years for both the *B. erectus* and *A. elatius* grasslands. These data increase our understanding of the community ecology of the Salisbury Plain grasslands, and will aid management of military training and disturbance in the future.

4.1 INTRODUCTION

The potential importance of buried seed populations in the functioning of plant communities has long been acknowledged (Brenchley, 1918; Chippindale and Milton, 1934; Champness and Morris, 1948). Seed banks[1] have the selective advantage of devices of seed dormancy and germination that enable seedlings to germinate in conditions otherwise dominated by established plants (Thompson and Grime, 1979). Consequently, seed banks are one method by which plant communities survive periodic disturbance, through the buffering buried seed populations can provide against the disturbance effect (Donelan and Thompson, 1980). Disturbance in a system favours species with high seed fecundity (Thompson, 1978). In addition, habitats which experience a high frequency of

[1] The terms *'seed'* and *'seed bank'* are all used in this study in a very broad sense. We have used the term *seed* to include both seeds and fruit, and *seed bank* as reference to all the unattached viable seeds of a species at a specific time. This encompasses all seeds found above and below the soil surface (Thompson and Grime, 1979), and in this study incorporates both persistent and transient seed bank components.

disturbance tend to become characterised by species with mechanisms that delay the germination of seeds until the conditions are optimal for establishment (Pons, 1991). The selective advantage of regeneration from a dormant seed bank means that disturbed habitats should therefore be characterised by a higher incidence of regeneration from the seed bank (Roberts, 1970; Olmsted and Curtis, 1947).

Changes in seed banks during succession have been studied by a number of authors (Donelan and Thompson, 1980; Davies and Waite, 1998; Dutoit and Allard, 1995; Falińska, 1999; Bekker *et al.*, 2000). With the exception of Falińska (1999), these studies have looked at long successional gradients, for example from an abandoned arable field to a woodland, rather than succession following individual disturbance events. Bekker *et al.* (1998) compared the seed banks of restoration sites and their target communities in order to include the soil seed bank in the quantitative assessment of habitat re-establishment. They concluded that a greater appreciation of community response to disturbance was possible by comparing the content of the seed bank to the composition of the surface vegetation.

The study area

Salisbury Plain Training Area (SPTA) in southern England is the largest of the UK military training areas covering some 38,000 ha of the English chalk. Around 20,000 ha of the area have been designated as a Site of Special Scientific Interest, containing the largest known expanse of unimproved chalk grassland in north-west Europe (English Nature, 1993). Although protected by the military presence from many of the landscape changes of the past century, such as urban expansion, industrial development and agricultural improvement, the grasslands of Salisbury Plain are continually exposed to disturbance from other sources such as shelling, burning and the passage of heavy armoured vehicles.

The recovery of the chalk grasslands of Salisbury Plain from this military disturbance is almost entirely dependent on ecosystem resilience. Interventionist forms of habitat restoration on the SPTA are logistically difficult, due to limited time and financial resources for such a vast area, and the inconvenience this would cause to military training programmes. There is, therefore, great interest in the current density and species composition of the soil seed bank, and the contribution it can make to habitat re-establishment. Consequently, this chapter seeks to answer the following questions:

- What is the size and composition of seed banks on SPTA?
- How do the buried seed populations of grassland communities on SPTA differ?
- How do the seed banks of old disturbance sites change along a vegetation chronosequence?
- How can changes in seed banks influence community resilience following disturbance?

The number of studies that combine the analysis of above-ground vegetation and seed banks is limited (Hutchings and Booth, 1996; Davies and Waite, 1998). The investigation of old disturbance sites enables the use of a space-for-time chronosequence of both vegetation and seed bank sampling. This allows estimation of the nature and timing of the response of the seed bank following physical disturbance, and the potential implications for habitat-scale regeneration.

4.2 METHODS

Selection of study sites

Aerial photographs taken at nine dates between 1945 and 1995 were used to select 82 sites from six tetrads (2x2 km squares) across the Salisbury Plain Training Area (see Chapter 2, Figure 2.1), which showed a time series of military disturbance. These sites covered a variety of CG3 (*Bromus erectus*) and MG1 (*Arrhenatherum elatius*) grassland communities as defined by the National Vegetation Classification (Rodwell, 1992) (see Table 4.1). The 2:1 ratio of calcareous grassland sites to mesotrophic grassland sites reflects the relative proportion of CG3 to MG1 in the sample area.

Vegetation sampling

During July 1998 and 1999, at each of the 82 disturbed sites, 10 sample quadrats were positioned using numbers from a random number table; five were placed in the disturbed area, and five on an immediately adjacent area which from the photographic evidence appeared to have been undisturbed over the time scale of the chronosequence. The vegetation was assessed using quadrats designed to lie along a tank track (50cm wide x 2m long), and vegetation cover was recorded using the Domin scale (Mueller-Dombois and Ellenberg, 1974), including a score for bare ground. Three measurements for sward height were also taken in each quadrat using a drop disk (30cm in diameter, mass 80g) and ruler. Other characteristics recorded at each site included aspect ($-\cos\theta$), slope and grazing intensity (on a subjective scale of 0-3). The quadrats were marked for later collection of soil samples, after a buried ordnance safety check had been carried out.

Table 4.1 Number of sampling sites disturbed in each time period on CG3 and MG1 grassland at the Salisbury plain Training Area.

Date of photograph	Number of sites	
	CG3	MG1
1945	5	2
1955	7	2
1967	6	3
1971	4	-
1981	7	3
1984	6	8
1991	6	4
1994	7	2
1995	6	4
Total	54	28

Soil sample collection

Sample quadrats were marked and revisited for soil sample collection 4-5 months after the vegetation survey. Soil samples measuring 5x5x10cm were collected using a graduated trowel from four random locations per quadrat. These were bulked to make a 1000cm^3 sample.

Chemical analysis of soils

Each soil sample was halved, and one half (500cm^3) was air dried and passed through a 2mm sieve. Available phosphorus was extracted using 2.5g of soil with 40ml 0.5M sodium hydrogen carbonate, and analysed using the molybdenum blue method (Allen, 1989). Total organic nitrogen was estimated as a surrogate measure of organic matter content, using Nesslers reagent after acid digestion (0.5g of soil with 4.4ml of reagent) (Allen, 1974). Extractable cations (calcium, magnesium, sodium and potassium) were extracted using 10g of soil in 40ml of 1M ammonium acetate (adjusted to pH 9), and analysed using flame absorption spectrometry (Ca, Mg) and flame emission spectrometry (Na, K). Soil pH was measured using a 1:2.5 slurry of soil and deionised water (Allen, 1974).

Soil seed bank collection and recording

The remaining soil fraction was mixed, air-dried and chilled in a cold room at 4°C for eight weeks. Seed trays (10 x 15cm) were filled with 600cm^3 of sterile sand and 300cm^3 of each composite sample was spread on top of the sand. The trays were placed in a glasshouse with automatic watering from below. Emerging seedlings were identified and removed over a 12 month period. The seed trays were stirred after each clearance of seedlings to promote further germination.

Data analysis

The soil samples analysed represented both persistent and transient seed bank components, due to their autumn collection. Species recorded were classified in two ways: (a) those typical of mesotrophic or calcareous grassland communities as listed in CEH Biotope Occupancy Database (BOD) (see Griffiths *et al.*, 1999 and Appendix 1), and (b) the proportions of annual, biennial and perennial forb, and perennial grass species.

Relative differences between the seed bank samples taken from MG1 and CG3 grassland communities were identified using Detrended Correspondence Analysis (DCA) within the program CANOCO (Ter Braak, 1988). Prior to analysis, the mean number of seeds per species per sample at each site was calculated and logarithmically transformed. Absolute differences in the species content of these two broad grassland communities were analysed using ANOVA.

Significant trends over time in the seed banks from disturbed sites were analysed using linear regression. Species variation between seed bank samples from disturbed sites of different ages was modelled using Canonical Correspondence Analysis (CCA), using Forward Selection to choose significant environmental variables at $p<0.05$.

The species data for both surface vegetation and seed bank used were expressed as mean percentages of the total recorded for each site, and a correlation coefficient matrix was used to calculate the degree of similarity between the seed bank and surface vegetation at difference times after the disturbance event. This enabled equal weighting of all species occurring in the seed bank and surface vegetation samples. Percentage similarity between the disturbed and reference seed banks, was assessed using Sørensen's index (Sørensen, 1948). The Regeneration Index for each disturbance site was also calculated (Bekker *et al.*, 1997, Equation 4.1), combining both surface vegetation and seed bank data. The regeneration index returns a value between 0 and 100% for the degree of association between the species composition of a disturbed community and that of its undisturbed target community. The lower the value of the index, the greater the 'distance' between the disturbed and undisturbed community.

$$PS_{sv} = \frac{2 \times \sum Min(A_{isvdis}, A_{isvref})}{\sum A_{isvdis} + \sum A_{isvref}} x100 \qquad PS_{sb} = \frac{2 \times \sum Min(A_{isbdis}, A_{isbref})}{\sum A_{isbdis} + \sum A_{isbref}} x100$$

$$RI = \frac{PS_{sv} + PS_{sb}}{2}$$

Equation 4.1 PS_{sv} is the percentage similarity between disturbed and undisturbed surface vegetation recorded at a site. A_{isvdis} is the cover (or presence) of a particular species in the disturbance site, and A_{isvref} is the cover (or presence) of that species in the undisturbed reference site. PS_{sb} is the percentage similarity between disturbed and undisturbed seed bank recorded at a site. A_{isbdis} is the amount of a species (or presence) in the disturbance site sample, and A_{isbref} is the amount of a species (or presence) in the undisturbed reference site sample. RI is the Regeneration Index.

Time series plots were made using the LOWESS (**LO**cally **WE**ighted **S**catter-plot **S**moothing) function in Minitab. This type of plot can be particularly useful for exploring patterns in time series data (Sparks and Rothery, 1998).

4.3 RESULTS

Overview of species recorded

A total of 191 species were recorded in the experiment, with just over half (55%) occurring in both the seed bank samples and the vegetation (Figure 4.1 and Table 4.2). Species that occurred solely in the seed banks samples were dominated by annuals and biennials, including a number of notable uncommon arable weeds such as *Kickxia spuria* and *Minuartia hybrida*. A large proportion (56%) of typical calcareous grassland species occurring in the surface vegetation were absent from the seed bank including *Asperula cynanchica*, *Hippocrepis comosa* and *Polygala* *calcarea*. Species classified as occurring in both the surface vegetation and the seed bank, were not necessarily spread equally between the two. *Bromopsis erectus*, *Arrhenatherum elatius* and *Lotus corniculatus* occurred predominantly in the surface vegetation, with only negligible seed banks, whereas *Reseda lutea* and *Helictotrichon pratensis* were significantly more abundant in the seed bank samples.

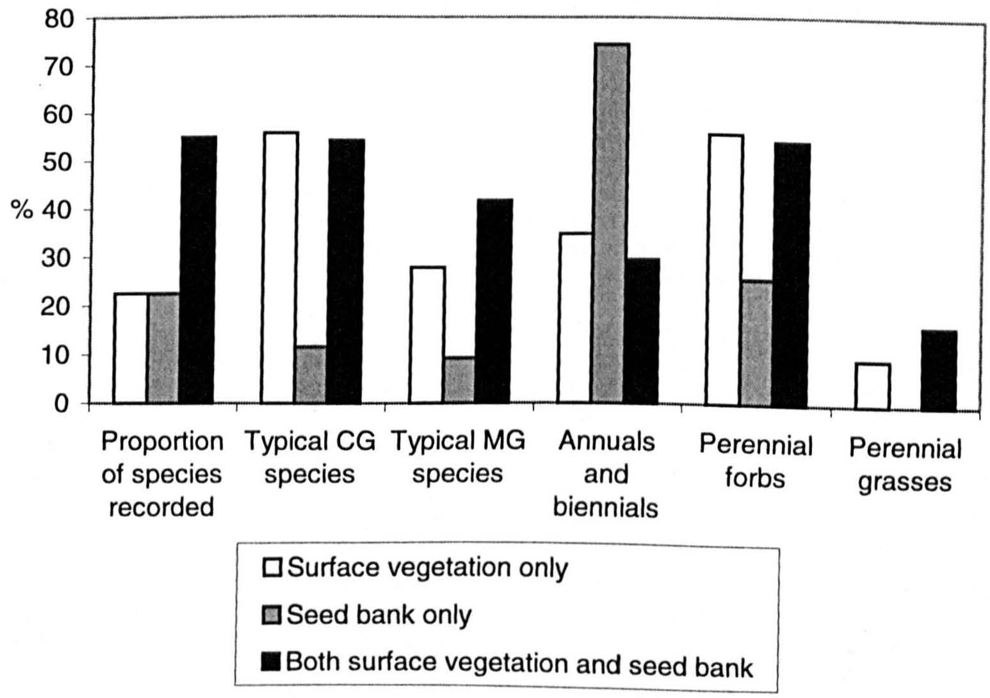


Figure 4.1 Proportion of species types recorded in the surface vegetation and seed banks across CG3 and MG1 grassland communities on the SPTA.

Table 4.2 List of species recorded in the experiment solely in the surface vegetation or seed banks, and species occurring in both the surface vegetation and seed banks, in CG3 and MG1 communities on the SPTA.

Only in surface vegetation	Only in seed banks	In both surface vegetation and seed banks	
Anacamptis pyramidalis	Aethusa cynapium	Achillea millefolium	Lathyris nissolia
Asperula cynanchica	Anisantha sterilis	Agrimonia eupatoria	Lathyris pratensis
Blackstonia perfoliata	Aphanes arvensis	Agrostis stolonifera	Leontodon autumnalis
Briza media	Atriplex patula	Anagallis arvensis	Leontodon hispidus
Carduus nutans	Barbarea vulgaris	Anthoxanthum odoratum	Leucanthemum vulgare
Cerastium arvense	Capsella bursa pastoris	Anthriscus sylvestris	Linaria vulgaris
Cirsium eriophorum	Cardamine hirsuta	Anthyllis vulneraria	Linum catharticum
Clinopodium acscendens	Carex caryophyllea	Arenaria serpyllifolia	Lolium perenne
Clinopodium vulgare	Catapodium rigidum	Arrhenatherum elatius	Lotus corniculatus
Crepis biennis	Chaenorhinum minus	Artemesia vulgaris	Medicago lupulina
Crepis vesicaria	Chenopodium album	Bellis perennis	Melilotus altissimus
Festuca ovina	Erophila verna	Bromopsis erecta	Odontites vernus
Festuca pratensis	Erucastrum gallicum	Bromus hordaeceus	Pastinaca sativa
Gentianella amarella	Euphorbia peplus	Campanula glomerata	Phleum bertolonii
Geranium columbinum	Fallopia convolvulus	Campanula rotundifolia	Picris echioides
Geranium pratense	Fumaria officinalis	Carex flacca	Picris hieracioides
Heracleum sphondylium	Galium aparine	Centaurea nigra	Pimpinella saxifraga
Hieracium pilosella	Juncus bufonius	Centaurea scabiosa	Plantago lanceolata
Hippocrepis comosa	Kickxia spuria	Centaurium erythraea	Plantago major
Knautia arvensis	Luzula campestris	Cerastium fontanum	Plantago media
Linum bienne	Matricaria discoidea	Cerastium glomeratum	Poa annua
Malva moschata	Minuartia hybrida	Cirsium acaule	Poa pratensis
Onobrychis viciifolia	Myosotis arvensis	Cirsium arvense	Poa trivialis
Ononis repens	Orobanche minor	Cirsium vulgare	Polygonum aviculare
Origanum vulgare	Papaver dubium	Clinopodium acinos	Potentilla anserina
Orobanche elatior	Papaver rhoeas	Convolvulus arvensis	Potentilla erecta
Phleum pratense	Polygala vulgaris	Crataegus monogyna	Potentilla reptans
Polygala calcarea	Polygonum arenastrum	Crepis capillaris	Primula veris
Ranunculus acris	Potentilla sterilis	Cynosurus cristatus	Prunella vulgaris
Ranunculus bulbosus	Rumex obtusifolia	Dactylis glomerata	Ranunculus repens
Reseda luteola	Sagina apetala	Daucus carota	Reseda lutea
Rubus fructiosus	Sagina procumbens	Deschampsia caespitosa	Rhinanthus minor
Serratula tinctoria	Scrophularia nodosa	Echium vulgare	Rumex acetosa
Sherardia arvensis	Silene vulgaris	Elytrigia repens	Rumex crispus
Sonchus arvensis	Solanum dolcamara	Euphrasia nemorosa	Sanguisorba minor
Stachys officinalis	Sonchus oleraceus	Festuca arundinacea	Scabiosa columbaria
Stellaria media	Ulex europaea	Festuca rubra	Senecio jacobaea
Thesium humifusum	Verbascum thapsus	Filipendula vulgaris	Senecio vulgaris
Tragopogon pratensis	Veronica arvensis	Galium mollugo	Silene latifolia
Trifolium medium	Veronica persica	Galium verum	Sinapis arvensis
Trisetum flavescens	Veronica serpyllifolia	Genista tinctoria	Sonchus asper
Ulex europaeus	Vicia hirsuta	Geranium dissectum	Stellaria graminea
Vicia tetrasperma	Viola arvensis	Geranium molle	Succisa pratensis
		Glechoma hederacea	Taraxacum sp.
		Helianthemum nummularium	Thymus polytrichus
		Helictotrichon pratensis	Trifolium campestre
		Helictotrichon pubescens	Trifolium pratense
		Holcus lanatus	Trifolium repens
		Hypericum perforatum	Tripleurospermum inodorum
		Hypochoeris radicata	Urtica dioica
		Koeleria macrantha	Veronica chameadrys
			Vicia cracca
			Vicia sativa agg.
			Viola hirta

A comparison of species recorded in undisturbed calcareous and mesotrophic grassland seed banks

Detrended Correspondence Analysis (DCA) of the undisturbed reference seed bank samples (Figure 4.2) indicated that there were subtle but significant differences between the species found in the CG3 and MG1 grassland seed banks on Salisbury Plain. Significant separation between samples from CG3 and MG1 grasslands occurred along the first axis ($F=30.52$, $p<0.001$). Five out of the 10 most frequently recorded species in the seed banks of these two communities when undisturbed were common to both communities (Table 4.3). Over 20% of the seed banks from the CG3 grasslands were composed of *Hypericum perforatum* and *Agrostis stolonifera*, and over 18% of the MG1 seed bank was either *Daucus carota* or *Holcus lanatus*.

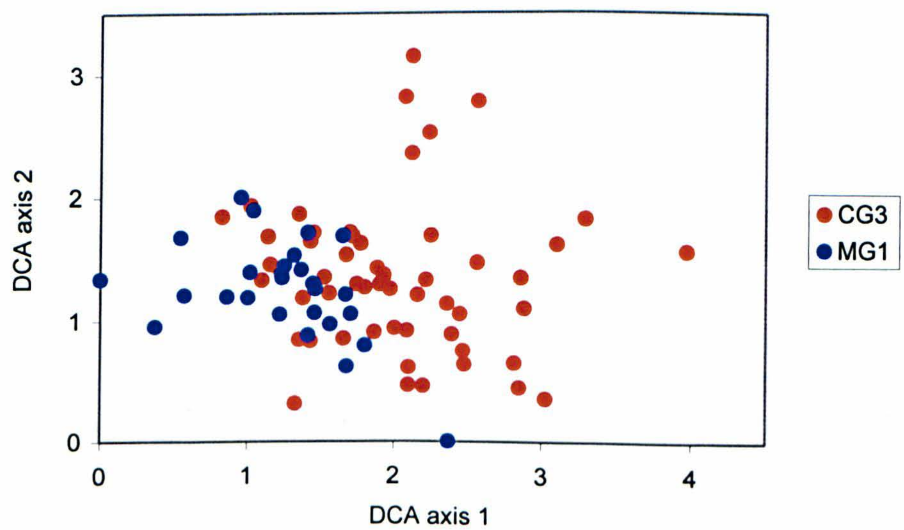


Figure 4.2 DCA biplot of undisturbed CG3 and MG1 grassland seed bank samples taken from the SPTA, showing relative positions along first two ordination axes. Based on presence/absence data. Red: CG3 grasslands, blue: MG1 grasslands. Eigenvalue of axis 1 = 0.52 and axis 2 = 0.41.

Analysis of variance showed significant between-community differences in recorded densities of certain species (Table 4.4). Expected results included the higher number of typical MG1 grassland species recorded in the mesotrophic seed banks, such as *Dactylis glomerata* and *Arrhenatherum elatius*, and the chalk grassland specialist *Helianthemum nummularium* being exclusive to the calcareous grassland seed banks. However, other differences were more intriguing, such as the prevalence in the MG1 grassland seed banks of *Melilotus altissimus* (by an order of magnitude) and *D. carota* (twice as common), when neither of these species have a high preference index score for mesotrophic grasslands. Differential community responses to disturbance are therefore likely to be a product of both below- and above-ground variation in species composition.

There was no difference between the overall seed population densities recorded in the CG3 and MG1 seed banks, although the mesotrophic grassland seed banks were more species-rich ($p<0.05$) (Figure 4.3). This species richness seems to comprise a greater number of annual and biennial species ($p<0.05$) and to an even greater degree, perennial grass species ($p<0.001$).

Table 4.3 The ten most common species in seed banks from undisturbed CG3 and MG1 communities on the SPTA, according to proportion of total number of seeds recorded in each community.

CG3 seed bank samples		MG1 seed bank samples	
Species	**%**	**Species**	**%**
Hypericum perforatum	10.4	*Daucus carota*	9.28
Agrostis stolonifera	9.98	*Holcus lanatus*	9.03
Carex flacca	6.91	*Agrostis stolonifera*	7.75
Holcus lanatus	6.29	*Dactylis glomerata*	6.02
Arenaria serpyllifolia	5.22	*Lolium perenne*	4.44
Centaurium erythraea	5.09	*Hypericum perforatum*	3.93
Daucus carota	4.94	*Festuca rubra*	3.67
Plantago lanceolata	2.81	*Helictotrichon pratensis*	2.80
Cerastium fontanum	2.74	*Medicago lupulina*	2.80
Senecio jacobaea	2.53	*Plantago lanceolata*	2.80

Table 4.4 A selection of significant ANOVA p- and F-values for seed population densities of certain species recorded in undisturbed mesotrophic (MG1) and calcareous (CG3) grasslands on the SPTA.

Species	CG3 mean	MG1 mean	F-value	P-value
Arenaria serpyllifolia	[redacted]	0.93	5.15	<0.05
Arrhenatherum elatius	0.13	[redacted]	4.23	<0.05
Carex flacca	[redacted]	0.75	8.30	<0.005
Dactylis glomerata	0.69	[redacted]	17.49	<0.001
Daucus carota	3.57	[redacted]	5.12	<0.05
Festuca rubra	1.06	[redacted]	4.16	<0.05
Helianthemum nummularium	[redacted]	0.00	6.63	<0.05
Lolium perenne	0.69	[redacted]	10.25	<0.005
Melilotus altissimus	0.13	[redacted]	9.19	<0.005

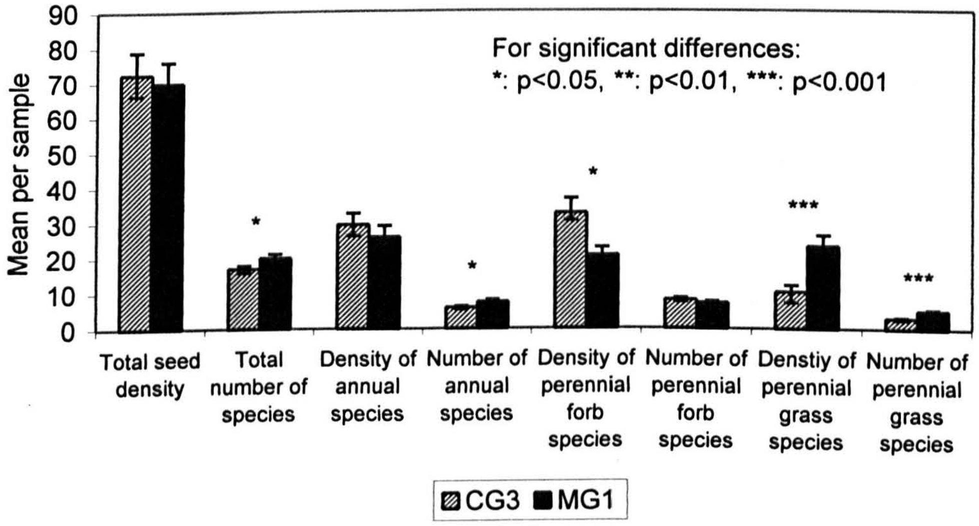


Figure 4.3 Differences between seed population density and species richness of certain classes of species found in undisturbed CG3 and MG1 seed banks on the SPTA. Significant differences from ANOVA are identified. Bars shown are standard error of the mean.

Changes in grassland seed banks following disturbance

The percentage composition of perennial species in the seed banks of both CG3 and MG1 disturbed grasslands showed similar patterns along the successional chronosequence (Figure 4.4). In both communities, the proportion of perennial forbs in the seed bank fluctuates between 30 and 40%, with no significant increase or decrease over time. Perennial grasses make up a small percentage of the seed banks until around 20 years after disturbance, after which they increase as more grasses colonise the disturbed area. This was a significant increase over time for both communities. The pattern for annual and biennial species, however, is very different for the two communities studied. Soon after disturbance ruderal annual and biennial species comprise the greatest proportion of the seed banks of both communities (around half), and in the MG1 grasslands tend to decline along the time sequence. In the CG3 grasslands however, following disturbance there is an increase in the proportion of annuals and biennials in the seed bank, peaking at around 60% after 15 years, and subsequently falling back to around 35%. This peak can almost entirely be attributed to the influx of seeds from *Arenaria serpyllifolia* regenerating in disturbed areas, before this species loses its competitive advantage and thereafter is much reduced in the sward and seed bank.

(a) (b)

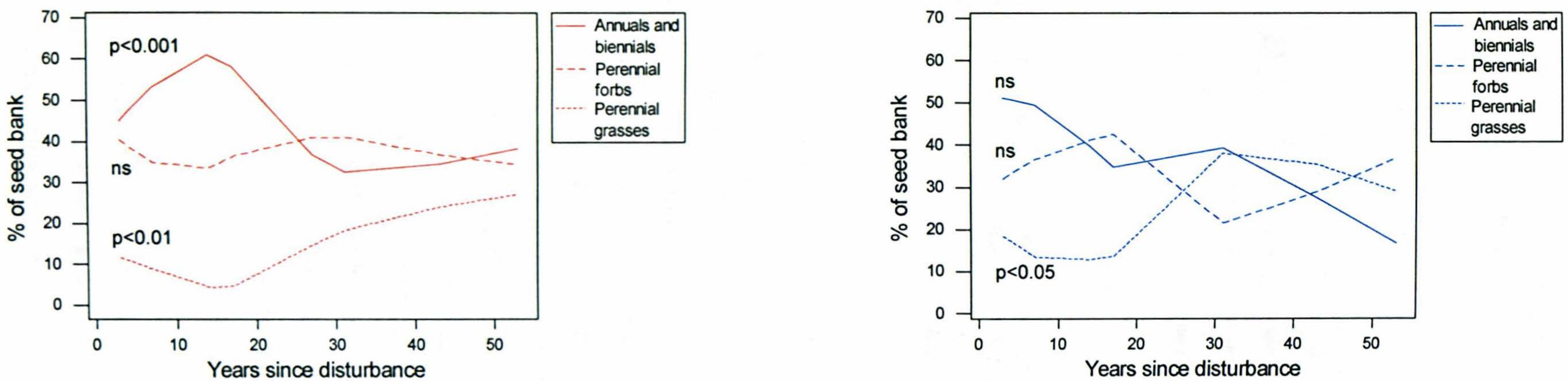
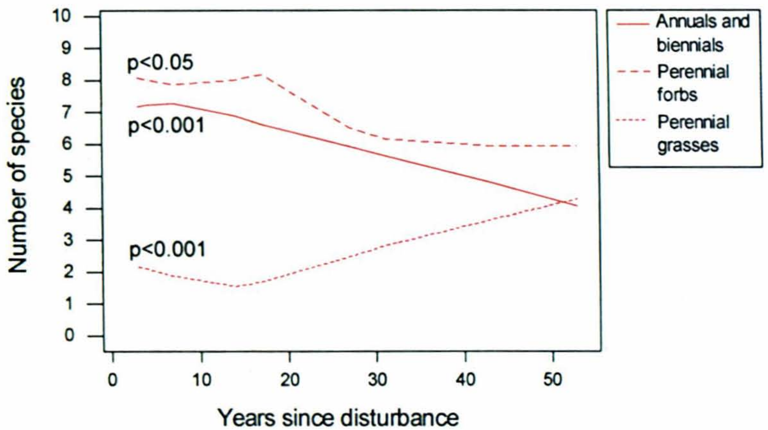


Figure 4.4 Composition of annual, biennial and perennial species in seed banks from the SPTA, from previously disturbed (a) CG3 and (b) MG1 communities. LOWESS plots of percentage cover are presented. Significance of linear regressions over time are indicated for each line (ns = not significant).

(a)



(b)

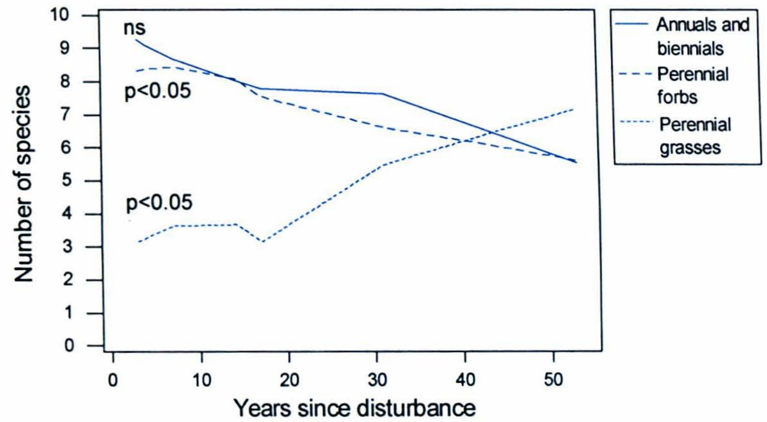


Figure 4.5 Composition of annual, biennial and perennial species in seed banks from the SPTA, from previously disturbed (a) CG3 and (b) MG1 communities. LOWESS plots of number of recorded species are presented. Significance of linear regressions over time are indicated for each line (ns = not significant).

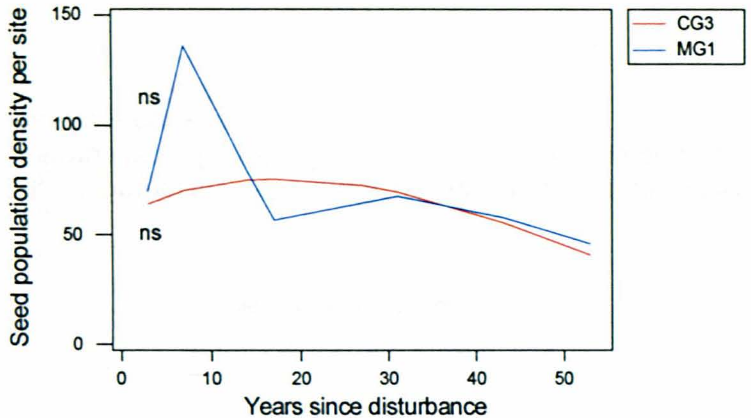


Figure 4.6 Change over time in seed population density of CG3 and MG1 seed banks from previously disturbed sites on the SPTA. LOWESS plots are presented. Significance of linear regressions over time are indicated for each line (ns = not significant).

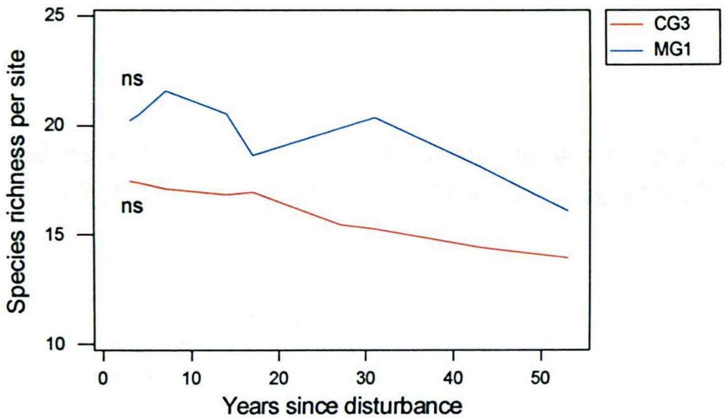


Figure 4.7 Change over time in species richness of CG3 and MG1 seed banks from previously disturbed sites on the SPTA. LOWESS plots are presented. Significance of linear regressions over time are indicated for each line (ns = not significant).

During the 50 year chronosequence, the seed bank components recorded in both the CG3 and MG1 experienced a decrease in the number of annual and biennial, and perennial forb species, and an increase in the number of perennial grass species (Figure 4.5). With the exception of the observed decrease in perennial forb species in the mesotrophic grassland seed banks, these changes over time were all significant ($p<0.05$), and were similar to trends reported in Chapter 3 for changes in functional groups of species along the surface vegetation chronosequence. Although species richness and seed population density decreased over time in both CG3 and MG1 grassland seed banks, no significant linear regressions were reported (Figures 4.6 and 4.7). This may be due to a tendency towards a humped back response, most notably in seed density in the CG3 seed banks (Figure 4.6).

From the Canonical Correspondence Analysis (CCA), Forward Selection of environmental variables identified time elapsed since disturbance to be a significant factor explaining the variation in both CG3 and MG1 seed banks (Figures 4.8 and 4.9). In both cases, the height of the surrounding vegetation was the most significant variable along the first axis. This may be because the structure of the surrounding vegetation is an important controlling factor of seed bank composition. Time since disturbance was correlated in both communities with the second CCA axis (Table 4.5). The association was stronger in the calcareous grassland seed banks, although this may be a function of sample size. More recently disturbed sites have lower values on the second CCA axis, and older sites have higher values.

Table 4.5 Correlation coefficients (r) between environmental variables included in final CCA models and the first two ordination axes.

Environmental variable	CG3 seed banks		MG1 seed banks	
	Axis 1	Axis 2	Axis 1	Axis 2
Sward height	0.747	0.395	0.727	0.432
Time since disturbance	0.127	0.625	0.574	0.640
pH	-0.494	0.507		
Mg	0.522	-0.512		
P	0.254	-0.254		
N			-0.498	-0.016
Na			-0.325	0.798

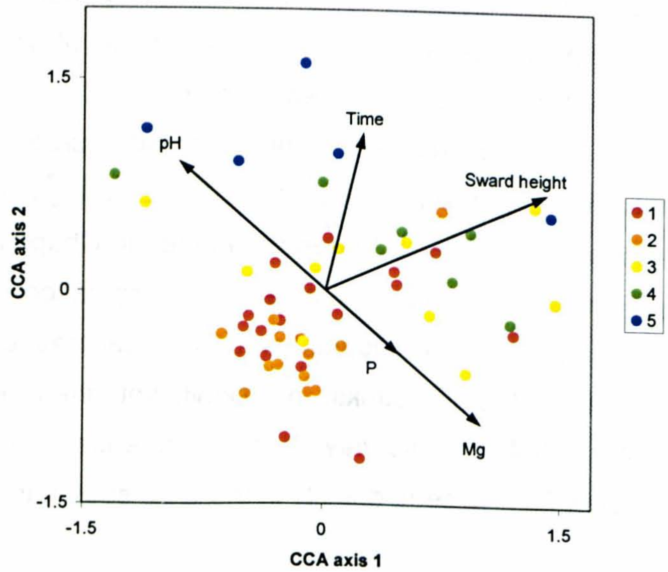


Figure 4.8 CCA biplot showing relative positions of CG3 seed bank samples from disturbed sites of different ages on the SPTA. Disturbance time periods are coded as: 1 = 3-7 years after disturbance, 2 = 14-17 years, 3 = 27-31 years, 4 = 43 years, 5 = 53 years. Arrows show relative positions of environmental variables at x4 magnitude. Eigenvalue of CCA axis 1 = 0.24 and CCA axis 2 = 0.20.

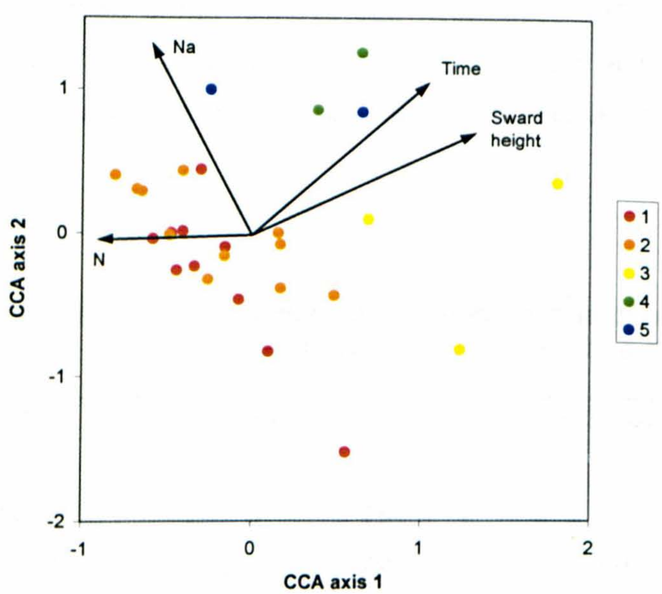


Figure 4.9 CCA biplot showing relative positions of MG1 seed bank samples from disturbed sites of different ages on the SPTA. Disturbance time periods are coded as: 1 = 3-7 years after disturbance, 2 = 14-17 years, 3 = 27-31 years, 4 = 43 years, 5 = 53 years. Arrows show relative positions of environmental variables at x4 magnitude. Eigenvalues of CCA axis 1 = 0.23 and CCA axis 2 = 0.18.

Association between seed banks and surface vegetation along a chronosequence
In both CG3 and MG1 communities, association between the recorded vegetation and composition of the seed banks samples at a site decreases along the chronosequence (Table 4.6, shaded diagonal). This is more pronounced in the CG3 grasslands where there is no significant correlation between the species recorded in the seed bank samples and those in the surface vegetation 14 years after the disturbance event. In contrast, species in the seed banks and the surface vegetation in the MG1 grasslands continue to be significantly correlated until 53 years after disturbance. This is likely to be due to the greater persistence in the MG1 sward of species germinating from the seed bank as a result of the disturbance, or MG1 communities having a higher proportion of species that were recorded in the seed banks sampling.

Seed banks of old disturbed sites tended to contain species elements of all previous vegetation states in both calcareous and mesotrophic grassland communities (Table 4.6, above shaded diagonal). In the CG3 grasslands, this association was stronger the older the seed bank. This is likely to be due to depletion of the seed bank following disturbance and subsequent recovery due to seed inputs from surrounding regenerating vegetation.

Similarity between the seed bank and the surface vegetation along the vegetation chronosequence (Table 4.6, below shaded diagonal) implies that elements of seed banks of earlier successional stages may be maintained in the sward only in the short term. For the calcareous grassland community, where there was a significant decrease in the number of annual species in both the recorded seed bank components and surface vegetation, the association with the seed bank ends 14-17 years after disturbance. Mesotrophic grassland swards follow a less distinct but similar pattern, where significant association with earlier seed bank composition seemingly ceases 17-31 years after disturbance.

Table 4.6 Significance of correlations between species composition of seed bank samples and surface vegetation on the SPTA, at different times after disturbance. Results are displayed for (a) CG3 sites and (b) MG1 sites. Significance represented as: ***: p<0.001, **: p<0.01, *: p<0.05, ns: not significant. Shaded values on the diagonal represent within-year correlations. Data above the shaded diagonal represent cases where an element of past surface vegetation is represented in the seed bank. Data below the shaded diagonal represent cases where an element of past seed banks is represented in the surface vegetation.

(a) CG3 sites

Years since		Seed bank								
disturbance		3	4	7	14	17	27	31	43	53
Surface vegetation	3	***	***	***	**	***	**	***	***	***
	4	*	**	*	ns	**	*	*	***	***
	7	**	***	***	*	*	***	***	***	***
	14	*	*	ns	ns	*	ns	ns	***	***
	17	ns	ns	ns	ns	ns	*	ns	**	***
	27	ns	ns	ns	ns	ns	ns	ns	ns	**
	31	ns	ns	ns	ns	ns	ns	ns	***	***
	43	ns	ns	ns	ns	ns	ns	ns	ns	***
	53	ns	ns	ns	ns	ns	ns	ns	ns	ns

(b) MG1 sites

Years since		Seed bank							
disturbance		3	4	7	14	17	31	43	53
Surface vegetation	3	***	**	***	***	***	***	***	**
	4	***	***	***	***	***	***	***	***
	7	***	**	***	***	***	**	***	**
	14	***	ns	***	***	ns	***	**	*
	17	***	**	***	***	***	***	***	***
	31	ns	ns	ns	ns	ns	***	***	*
	43	**	ns	*	ns	ns	*	***	ns
	53	ns	ns	ns	ns	ns	ns	*	ns

Similarity between disturbed and undisturbed seed bank populations

Changes over time in the similarity between disturbed and undisturbed seed bank populations of the calcareous and mesotrophic grassland sites show a similar pattern to each other. There is a rapid increase in similarity soon after disturbance, followed by a decrease and another rise (Figure 4.8). This happens sooner and to a greater degree in the mesotrophic grassland sites, suggesting greater resilience of these seed banks than those of calcareous grasslands. Similarity between the disturbed and undisturbed CG3 seed bank populations lies around 35% soon after disturbance, rising to around 50% after 50 years. The MG1 seed bank samples also have a similarity of around 35% soon after disturbance, but rise to over 60% similarity after 50 years. Neither community displays an asymptote during the chronosequence time period investigated.

Estimating habitat resilience incorporating surface vegetation and seed bank components

The regeneration indices show that initially the chalk grassland recovered faster than the mesotrophic grassland (Figure 4.9). A slowing in the rate of change in the CG3 sites 15-25 years after disturbance allows the mesotrophic grassland sites to draw level, and 50 years after disturbance both communities have reached a regeneration index of nearly 70%. However, neither community reaches an asymptote within the 50 year period sampled, and neither community has approached target regeneration. The resilience periods suggested in Chapter 3 for these two grassland communities can now be extended to incorporate recovery of the seed bank following disturbance. Using these data, a minimum of 50 years is needed for full habitat recovery of both CG3 and MG1 communities. As these estimates are limited by the availability of photographic records, it is likely that substantially longer time periods may be required (Table 4.7).

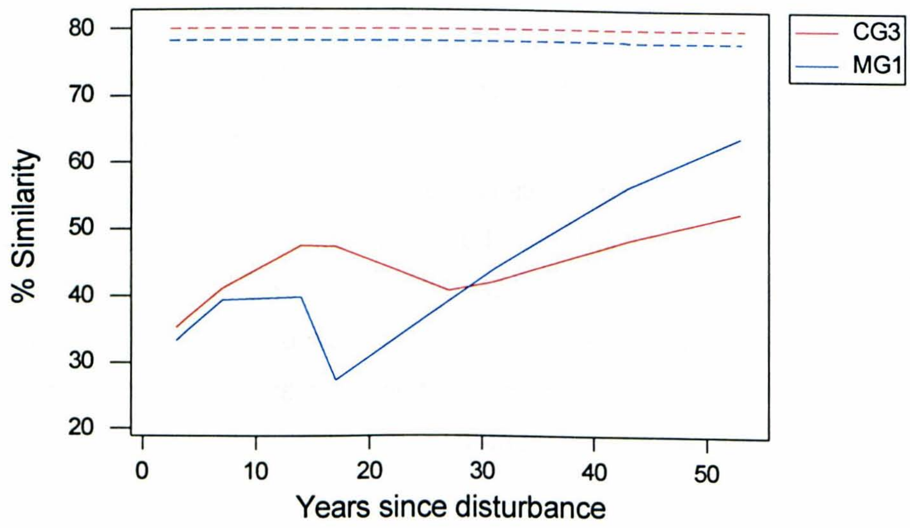


Figure 4.8 Similarity between disturbed and undisturbed seed bank populations of grassland communities on the SPTA. LOWESS plots are presented; solid lines = similarity between disturbed and undisturbed seed banks, dashed lines = maximum similarity within undisturbed seed bank samples. Red = CG3 grasslands, blue = MG1 grasslands.

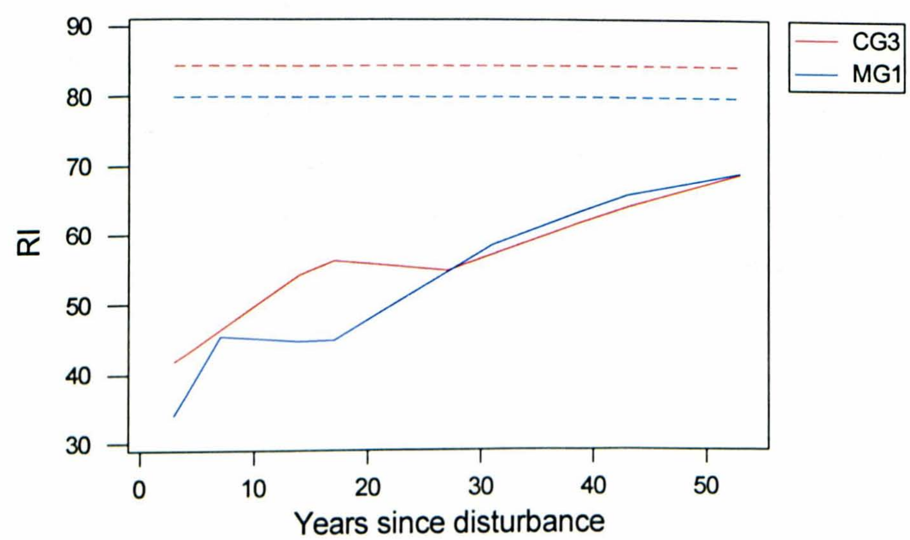


Figure 4.9 Calculated regeneration indices (RI) for disturbed CG3 and MG1 grasslands on the SPTA. LOWESS plots are presented; solid lines = calculated RI, dashed lines = maximum RI within undisturbed stands. Red = CG3 grasslands, blue = MG1 grasslands.

Table 4.7 Summary of estimates of resilience following disturbance of calcareous (CG3) and mesotrophic (MG1) grasslands on the SPTA, according to criteria used: n = cover, v = surface vegetation species assemblage, s = soil properties, b = seed bank species assemblage.

Factor	CG3	MG1
n	<20 years	<20 years
n+v	>50 years	>30 years
n+v+s	>50 years	>40 years
n+v+b	>50 years	>50 years

4.4 DISCUSSION

Comparing seed banks of different grassland communities

It has been suggested that due to the occurrence of similar species in seed banks from a variety of grassland vegetation communities, the seed banks found within grasslands should be relatively uniform in their content (Williams, 1984; Bekker, 1998). Bekker (1998) proposes that '*Only investigations on a spatially large scale could reveal significant differences between buried seed pools of grassland systems.*' (p.152). However, differences found between the composition of MG1 and CG3 seed banks on Salisbury Plain, in some cases from parcels of land immediately adjacent to each other, demonstrate that there can be significant variation between grassland community seed banks even within the relatively small spatial scales considered here.

These differences can help to explain the response of two grassland communities to disturbance. For example, the seed banks of MG1 grasslands had a greater content of *Daucus carota* and *Melilotus altissimus* than CG3 samples, even though neither of these species are characteristic of mesotrophic grassland. This accounts for field observations of how the passage of a tank through MG1 grassland on the SPTA frequently results in 'stripes' of yellow and white flowers through an otherwise grass-dominated sward, where *D. carota* and *M. altissimus* respectively have established following the disturbance. The more constant loss rate from the seed bank of early-successional ruderal species characteristic of disturbed MG1 grasslands, may be one reason why this community is more resilient to disturbance than the CG3 grasslands. It would seem that even at this spatial scale, community seed bank variation may be important in explaining or predicting spontaneous habitat recovery following disturbance.

Seed bank changes along a chronosequence

Many studies of successional changes in soil seed banks report a decline in species richness and seed density over time (Donelan and Thompson, 1980; Pickett and McDonnell, 1989; Akinola *et al.*, 1998; Jensen, 1998). Neither of these phenomena were found in the Salisbury Plain grassland seed banks, where fluctuations were more prone to a humped-back response to disturbance. This is accordance with the findings of Falińska (1999) who suggests that investigation of sections of long successional series can reveal subtle short-term post-disturbance changes in the seed bank, particularly where the extremes of the series belong to the same habitat class. Indeed, where a studied successional series begins and ends with a grassland community, it affords investigation of community processes rather than large-scale successional changes that, on the whole, are well described in the literature (Bekker *et al.*, 1997). Less well understood is how particular communities respond to disturbance, and the role the seed bank might play in regeneration.

It is known that while most grassland species form transient or short-term persistent rather than persistent seed banks (Bakker, 1989), pioneer species tend to lie dormant and thus are able to initiate new succession following disturbance (Harper, 1977). The speed at which a disturbed community returns to its pre-disturbance condition will therefore partly depend on the amount of regeneration of pioneers and ruderal species from the seed bank, their persistence in the sward, and the period of time before they are out-competed by later successional grassland species that re-establish through seed rain or vegetative spread mechanisms.

The seed bank sampling strategy adopted here allowed an estimation of the populations of both transient and persistent seed bank forming species. The calcareous grasslands sampled provide an example of how regeneration of pioneer species from the seed bank can have a negative impact on the resilience of a community to disturbance (Bekker, 1998). The rapid occupation of space by pioneers, their reciprocal return of seeds to the seed bank and their competitive ability at the expense of target species will all slow community recovery (Graham and Hutchings, 1988b; Strykstra *et al.*, 1998). These are all characteristics of *Arenaria serpyllifola*, which forms a prolific persistent seed bank and may be a causal factor in the slower recovery of the chalk grassland sites compared with the MG1 grasslands.

The incorporation of the seed bank into an estimation of habitat resilience following disturbance significantly increases the time periods for full community recovery. Although the disturbance dates used in this study were estimates, the use of the regeneration index (Figure 4.9) showed that the mesotrophic and calcareous grassland communities sampled were 12.5 and 17% respectively below target values for complete regeneration even 50 years after disturbance. Changes in the seed bank are likely to lag behind successional changes in the surface vegetation, and therefore a slower response of the seed bank is to be expected (Donelan and Thompson, 1980). Given the contribution of the seed bank to the regeneration process, these revised regeneration periods may therefore better represent the minimum exclusion times required for full habitat recovery from disturbance if a spontaneous restoration strategy is used as a management approach. Subsequent habitat disturbance prior to full recovery of the seed bank is likely to result in a continued degradation of this source of propagules, and decrease the habitat's resistance and resilience to further disturbance events. Repeated disturbance prior to 'full' recovery may result in a threshold being crossed after which the return of the ecosystem to its pre-disturbance target condition may not be achievable simply by allowing sufficient time for undisturbed recovery (Milchunas *et al.*, 1999). Allowing this type of land degradation will necessitate more interventionist and often costly forms of ecological restoration.

Conservation interest of the SPTA seed banks

Studies of viable seed populations are often carried out to assess the potential contribution of this source of propagules to the restoration of degraded habitats, given the palimpsest nature of earlier vegetational states. On the SPTA, the majority of the grasslands are already of high nature conservation interest, and the focus here has instead been on their contribution to the re-establishment of these desirable communities following disturbance. Nevertheless, Salisbury Plain has not always been used as a military training area and evidence of past cultivation has been provided by the rich arable weed flora of the soil seed bank. In the seed banks studied here, a record was made for *Minuartia hybrida* (Nationally Scarce in the UK, Stewart *et al.*, 1994), as well as a number of other declining arable weeds such as *Kickxia spuria* and *Lathyris nissolia* (see Sutcliffe and Kay, 2000). The creation of bare, stony plots to encourage the nesting of Stone Curlew on SPTA has inadvertently resulted in the re-establishment of many rare arable weeds, some in large numbers including *Legousia hybrida, Fumaria densiflora and Valerianella dentata*, and even a handful of plants of *Adonis annua*. The potential contribution of these sites to the conservation of declining weed species has now been recognised, and arable weed plots are being created and managed accordingly (Walker and Ash, pers. comm.). In addition, however, low intensity disturbance events may be helping to maintain this arable weed flora across the whole training area.

4.5 CONCLUSIONS

The estimates presented here for recovery periods of the SPTA grasslands following disturbance are likely to alter perceptions of their carrying capacity for military training. Although it is accepted that military disturbance is an integral part of the community functioning of these grasslands, and can bring some ecological benefits, very little was previously known about the processes of recovery. The Army's priority continues to be a strategy to manage the soils and vegetation communities on the SPTA in a sustainable fashion, combining the requirements of tactical exercises and supporting the carrying capacity of the land for future use (Jones and Bagley, 1998). Therefore, data such as those presented here regarding the sensitivity of ecosystems to human disturbances, can assist defence estate managers in making more informed decisions regarding training schedules, and in implementing integrated land management plans.

Seed banks in glasshouse: before germination (above) and after (right).

5. INVESTIGATING HABITAT RESISTANCE TO MILITARY VEHICLE DISTURBANCE

SUMMARY

The effects of different types of military vehicle disturbance on the soil and vegetation of a chalk grassland were compared on the Salisbury Plain Training Area (SPTA). Permanent quadrats were established on experimentally disturbed sites and changes in the vegetation and soils were recorded. The tall chalk grassland community sampled proved to be relatively resistant to wheeled vehicle disturbance, but significantly less resistant to tracked vehicles, with post-disturbance changes in vegetation composition being primarily related to the area of bare soil exposed. Indeed, multiple passes of tracked vehicles and tracked vehicle slews exceeded a disturbance threshold from which chalk grassland recovery may be less predictable. In addition, wheeled vehicles had significant soil compaction and sward height effects which may have implications for the management of off-road vehicles. The characterisation of communities and recovery following disturbance by different vehicles will assist the formulation of a sustainable management plan for SPTA, incorporating both military and conservation objectives.

5.1 INTRODUCTION

Effective management of military training areas requires knowledge of the impacts of the various kinds of training activity (Jones and Bagley, 1998), such as the frequency of use and the type of equipment, and necessary land rest periods. The most intensive use of military training areas is by tracked vehicles (Shaw and Diersing, 1990), and previous studies have focused primarily on the impacts of these vehicles in semi-arid regions (Prose, 1985; Braunack and Williams, 1993; Milchunas *et al.*, 1999, *inter alia*). Milchunas *et al.* (2000), for example, describe how tracked vehicles alter competitive relationships between higher plants in a system, as well as causing soil compaction and changes in the vertical and horizontal structure of plant communities. Some authors have also investigated the impact of tracked vehicles on faunal groups, including birds (Severinghaus and Severinghaus, 1982) and ground squirrels (van Horne and Sharpe, 1998). There has to date, however, been little empirical work on the impacts of heavy armoured vehicles on UK military training areas, and the semi-natural habitats contained therein.

The Salisbury Plain Training Area (SPTA) is the largest of the UK military training areas, covering some 38,000 ha of the Wiltshire chalk (Brown, 1995). It is the only UK training area large enough and with suitable geology for large-scale tactical armoured vehicle exercises. It is also the largest Site of Special Scientific Interest (SSSI) in the UK, containing the greatest extent of unimproved chalk grassland in NW Europe (English Nature, 1993).

Changing European politics and the recent Strategic Defence Review have resulted in the displacement of many British regiments from continental military establishments, increasing the pressure on all the UK training areas, and in particular the SPTA. Intensive military use of the SPTA inevitably results in disturbance to the grasslands, primarily by tracked vehicles, but also through shelling and burning. This disturbance creates a mosaic of grassland types, providing a diversity of habitats for various flora and fauna. However, increased use has heightened the extent and intensity of habitat disturbance on the area (Hirst *et al.*, 2000a), and it is becoming progressively more important for defence land managers to understand the disturbance ecology of Salisbury Plain in order to manage the predicted growth in military usage within statutory conservation objectives.

The response of vegetation communities to disturbance is usually separated into two components: **resistance** and **resilience** (Westman, 1978; Grimm *et al.*, 1992; Holling, 1973; Milchunas *et al.*, 2000). Resilience, considered in Chapters 3 and 4, refers to the time period required for a vegetation community to return to its pre-disturbance state. Resistance, in comparison, refers to the magnitude of the initial change in community structure and composition immediately following a disturbance event. It is possible, for example, for a community to have low resistance, but high resilience following disturbance, or *vice versa*. The chronosequence approach presented in Chapters 3 and 4 gave an insight into the recovery of the grasslands of Salisbury Plain over a 50 year period. However, these data lacked precise information regarding pre-disturbance site characteristics and the specific disturbance event, and there was no data from very recently disturbed sites. Accordingly, here an experiment was designed to:

- investigate chalk grassland resistance to disturbance by different military vehicles, and

- investigate the early phases of plant community dynamics following disturbance of a chalk grassland.

It is thought that many ecosystems may show both resistance to and resilience following disturbance, until a threshold has been surpassed (Jones and Bagley, 1998). Although opportunities for rigorous experimentation on military training areas are rare, it was possible to set up a replicated randomised experimental design enabling the direct investigation of such thresholds of disturbance intensity on the SPTA. Post-disturbance changes in vegetation were monitored for two years after treatment application in permanent plots, thus overcoming the constraints of the earlier chronosequence approach.

5.2 METHODS

Site selection and experimental design

The area of Salisbury Plain Training Area designated for this experiment is classified under the National Vegetation Classification (Rodwell, 1992) as CG3d (a *Bromus erectus* grassland, *Festuca rubra - Festuca arundinacea* sub-community). CG3d is common on Salisbury Plain; 28% of the training area contains a component of this vegetation type (Pywell, 1998), and it is one of the communities for which it has been designated as an SSSI. There is, therefore, particular interest in the ability of this vegetation community to withstand vehicular disturbance.

Following consultation with the Army, three commonly used military vehicles differing in mass and traction, were selected for the experiment: a Land Rover (1t, wheeled), a Bedford truck (4t, wheeled) and a Challenger tank (64t, tracked). The experimental design comprised six replicate blocks each containing eight lanes 25m in length to which difference disturbance treatments were randomly allocated (Figure 5.1). Treatments included a control (no vehicle pass), single and multiple passes of each vehicle, and a tracked vehicle slew[1]. Lanes allocated to wheeled vehicles were 5m wide, and for the tracked vehicle 10m. Additional lanes 15m in width were used for the tracked vehicle slew. Immediately before the treatments were applied in October 1998, the site was surveyed in order to identify any significant inter- and intra-block variation in species cover. Three 50cm x 50cm vegetation quadrats were

[1] Slew – a sharp turn made by a tracked vehicle.

randomly placed in each lane and the vegetation recorded using the Domin scale (Mueller-Dombois and Ellenberg, 1974).

Recording vehicular disturbance

Immediately after the disturbance was applied, three permanent quadrats (0.5 x 2.0m) were marked with stakes at distances of 6, 12 and 18m along the length of each disturbed lane, and paired with parallel similar, but undisturbed, quadrats nearby. Following an ordnance check, soil penetrative resistance measurements were taken in each quadrat in each lane using a manual penetrometer, from which values for soil compaction were inferred.

Soil samples were also taken during the two days following the disturbance treatments. A 10x10x10cm divot of soil was removed from the centre of each of the three disturbed quadrats using a graduated trowel, and separated into 0-5cm and 5-10cm depth fractions. 500cm^3 of each soil sample was air dried and passed through a 2mm sieve. Available phosphorus was extracted using 2.5g of soil with 40ml 0.5M sodium hydrogen carbonate, and analysed using the molybdenum blue method (Allen, 1989). Total organic nitrogen was estimated as a surrogate measure of organic matter content using Nesslers reagent after acid digestion (0.5g of soil with 4.4ml of reagent) (Allen, 1974). Extractable cations (calcium, magnesium, sodium and potassium) were extracted using 10g of soil in 40ml of 1M ammonium acetate (adjusted to pH 9) and subsequently analysed using flame absorption spectrometry (Ca, Mg) and flame emission spectrometry (Na, K). Soil pH was measured using a 1:2.5 slurry of soil and deionised water (Allen, 1974).

In July 1999 and 2000, vegetation was surveyed in the three permanent quadrats and adjacent undisturbed quadrats in each lane. Species cover was recorded using the Domin scale, including a score for bare ground. Three random vegetation height measurements were also taken in each quadrat using a drop disc (30cm in diameter, mass 80g) and ruler.

Data analysis

Prior to analysis mean vegetation cover values were derived for each lane using the transformation of the Domin scale proposed by Currall (1987).

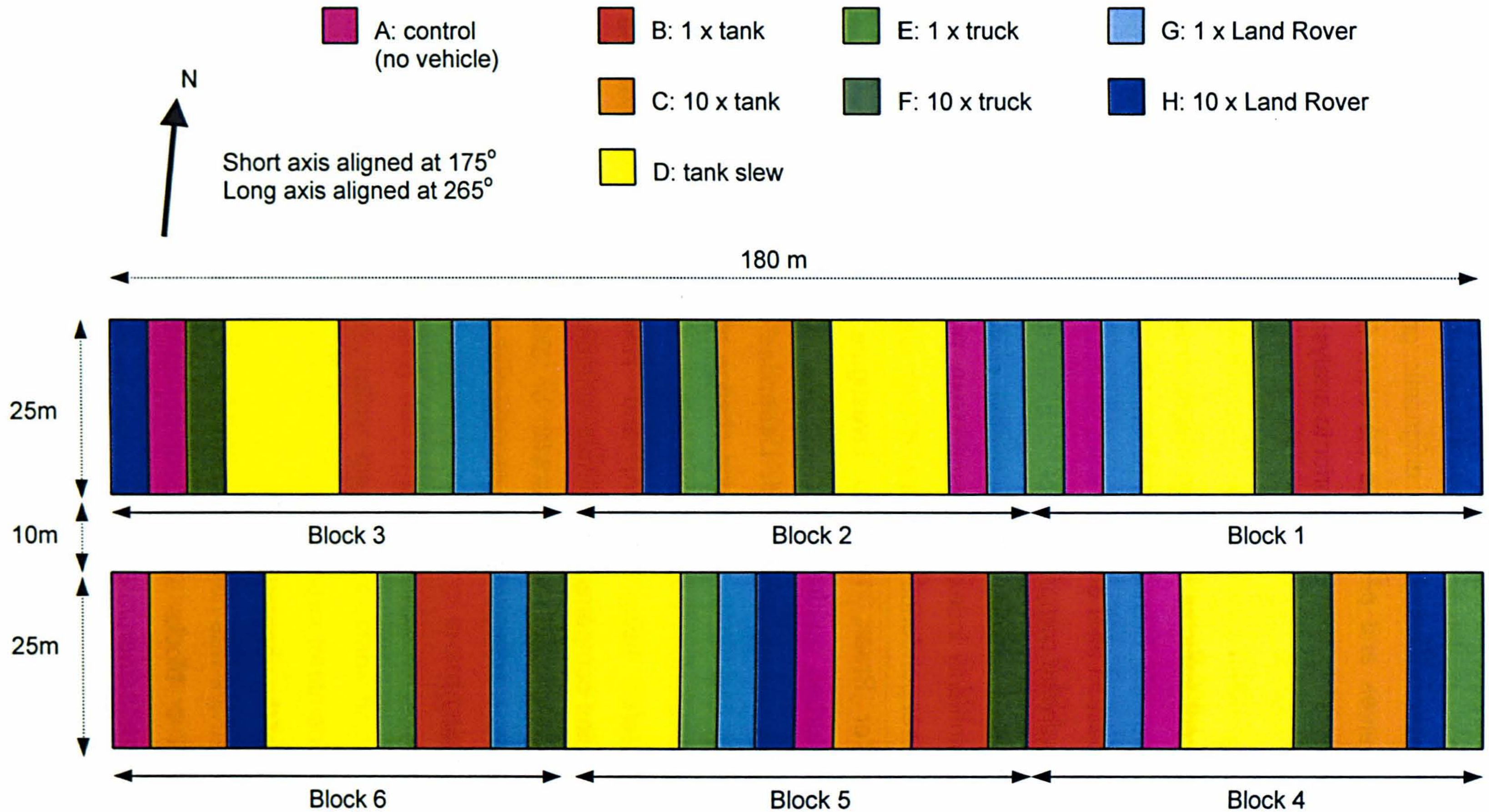


Figure 5.1 Design and treatment allocation of the Salisbury Plain Training Area habitat disturbance and recovery experiment, SPTA West (ST980458)

(i) Pre-treatment site survey

Following the pre-treatment site survey, TABLEFIT (Hill, 1996) was used to allocate a percentage fit of the treatment lanes to a CG3d community. Two-way analysis of variance (ANOVA) was used to detect between-treatment and between-block variation in these percentage fits, and also in the percentage cover of *Bromopsis erecta* and *Arrhenatherum elatius*, the two diagnostic grasses of CG3 and MG1 respectively. Cover values and percentage fits were found not to be normally distributed and hence were log-transformed prior to analysis.

(ii) Disturbance effects

The effects of the different vehicles on sward height, creation of bare ground, and sward composition of annuals, biennials and perennials after one and two years of recovery, and soil compaction after one year were assessed using ANOVA. Tukey's tests provided *a priori* pairwise comparisons of the treatments. Percentage similarity between the disturbed and undisturbed vegetation in each lane was calculated based on Sørensen's similarity index (Sørensen, 1948; Pielou, 1984; Bekker *et al.*, 1997). Canonical Correspondence Analysis (CCA) was carried out using the program CANOCO (Ter Braak, 1987) to investigate trends in the species composition of the disturbed quadrats after one year of recovery, as related to underlying measured environmental variables. Detrended Correspondence Analysis (DCA) was then used to investigate vegetation change after one and two years of recovery. Significant differences between treatments and time periods within the ordinations were detected using ANOVA, and Tukey's tests for pairwise comparisons. The species component of the multivariate analyses was investigated by classifying species as being characteristic of calcareous or mesotrophic grassland (using the CEH Biotope Occupancy database, see Appendix 1) or of disturbed ground (manually).

5.3 RESULTS

Pre-disturbance status of the vegetation

Prior to the experiment, there was no significant variation between the percentage fit of the treatment lanes or blocks to a CG3d, nor in the percentage cover of *Bromopsis erecta* or *Arrhenatherum elatius* (Table 5.1). The experimental site was therefore considered to be sufficiently homogenous in its community cover for experimental treatments to be applied.

Table 5.1 Analysis of variance table for between-treatment and between-block variation in pre-experiment vegetation cover.

Factor	Source	DF	SS	MS	F	P
% fit to CG3d	Block	5	0.01	0.0025	1.39	ns
	Treatment	7	0.01	0.0016	0.88	ns
	Error	35	0.06	0.0018		
	Total	47	0.09			
Bromopsis erecta cover (%)	Block	5	0.04	0.0073	1.06	ns
	Treatment	7	0.07	0.0097	1.42	ns
	Error	35	0.24	0.0069		
	Total	47	0.35			
Arrhenatherum elatius cover (%)	Block	5	0.61	0.122	0.80	ns
	Treatment	7	0.49	0.070	0.45	ns
	Error	35	5.39	0.154		
	Total	47	6.49			

Post-disturbance changes in soil compaction, sward height and major species groups

ANOVA models identified a number of significant differences between certain treatments and the controls one and two years after disturbance, as well as some significant between-year changes (Table 5.2). One year after disturbance, with the exception of the single Land Rover pass, sward heights in all remained significantly reduced. By Year 2, this difference in sward height was only detectable in the tank slew lane ($p<0.01$). The substantial recovery of sward height in the two other tank treatment lanes was primarily due to the high abundance of *Melilotus altissimus*, a fast growing biennial forb, rather than the re-establishment of the tall perennial grasses responsible for sward height in most other treatment lanes.

Only the multiple tank pass and tank slew treatments resulted in significant areas of bare ground after one year of recovery. Although the disturbance caused by the single tank pass did create bare ground, sward closure after one year was sufficient for there to be no difference between the area of bare ground in these lanes and the control. After the second year of recovery, there was a significant decrease in the amount of bare ground in the multiple tank pass and tank slew lanes ($p<0.001$), and in Year 2 only the tank slew lanes still had significantly more bare ground than the control. During Year 2, bare ground in the tank slew lanes halved (from a mean of 43% in 1999 to 21% in 2000) while in the multiple tank pass lane it fell by two-thirds, from 24% in 1999 to 8% in 2000.

The results of the ANOVA show that multiple tank passes and tank slews increased community species richness. This effect was present both one and two years after disturbance, and had possibly increased further by the second year. Interestingly, a single tank pass did not have a significant effect on species diversity after one year of recovery, but after the second year, a significantly higher number of species was recorded in this treatment. The number of species in the control and wheeled vehicle disturbance lanes ranged from 12 to 27 species per m^2, whereas in the tank disturbed lanes the range was 21 to 33 species per m^2.

Disturbance by wheeled vehicles caused no significant change in the species composition of the sward. In contrast, the disturbance caused by tracked vehicles resulted in significant changes in the cover of annuals and biennials, and perennial forbs and grasses. All tracked vehicle disturbance treatments promoted the establishment of annual and biennial species in the sward, and one year after the disturbance this was maintained, especially where the disturbance was more intense (single tank pass: $p<0.01$; multiple tank pass and tank slew: $p<0.001$).

Tracked vehicle disturbance also promoted the establishment of perennial forb species, particularly in the multiple tank pass lane. After two years of recovery, this effect had been lost from the single tank pass treatment, but persisted in the tank slew and multiple tank pass. These effects were mirrored by the slower establishment of perennial grass species which were significantly reduced by the tracked vehicle disturbance ($p<0.001$ for tank disturbance treatments both one and two years after disturbance). Although the percentage cover of perennial grasses increased over the two years of recovery in these treatment lanes, the increase was not significantly different from the increase that occurred in the control lanes.

Table 5.2 Significance of Tukey's pairwise comparison tests of ANOVAs showing differences between treatment lanes and controls in Year 1 and 2, and magnitude of between-year changes. ns: not significant, ***: p<0.001; **: p<0.005; *: p<0.05. +: greater than control, -: less than control.

Factor	ANOVA	Treatment						
		Tank			Truck		Land Rover	
		x1	x10	slew	x1	x10	x1	x10
Soil compaction	Year 1	***(+)	***(+)	***(+)	***(+)	***(+)	*(+)	***(+)
Sward height	Year 1	***(-)	***(-)	***(-)	**(-)	***(-)	ns	***(-)
	Year 2	ns	ns	***(-)	ns	ns	ns	ns
	Change	***(+)	***(+)	*(+)	ns	*(+)	ns	ns
Bare ground	Year 1	ns	***(+)	***(+)	ns	ns	ns	ns
	Year 2	ns	***(+)	***(+)	ns	ns	ns	ns
	Change	ns	***(-)	***(-)	ns	ns	ns	ns
Number of species	Year 1	ns	*(+)	*(+)	ns	ns	ns	ns
	Year 2	*(+)	***(+)	***(+)	ns	ns	ns	ns
	Change	ns	ns	ns	ns	ns	ns	ns
% cover annuals and biennials	Year 1	***(+)	***(+)	***(+)	ns	ns	ns	ns
	Year 2	**(+)	***(+)	***(+)	ns	ns	ns	ns
	Change	ns	ns	*(+)	ns	ns	ns	ns
% cover perennial forbs	Year 1	**(+)	***(+)	**(+)	ns	ns	ns	ns
	Year 2	ns	***(-)	**(-)	ns	ns	ns	ns
	Change	ns	ns	ns	ns	ns	ns	ns
% cover perennial grasses	Year 1	***(-)	***(-)	***(-)	ns	ns	ns	ns
	Year 2	***(-)	***(-)	***(-)	ns	ns	ns	ns
	Change	ns	ns	ns	ns	ns	ns	ns

Post-disturbance changes in plant communities

(i) Composition after 1 year of recovery

Canonical Correspondence Analysis (CCA) models using vegetation data recorded one year after disturbance, with Forward Selection of environmental variables tested by Monte Carlo permutations, encompassed bare ground, available calcium (Ca), phosphorus (P) and magnesium (Mg) ($p<0.05$), and disregarded all other measured soil characteristics, including soil compaction ($p>0.05$). The biplot (Figure 5.2) shows good separation of the tracked vehicle treatments along the first axis, related to a gradient of increasing disturbance intensity. The tracked vehicle treatments have higher positive values along this axis, with the wheeled vehicle treatments and controls placed in the left of the diagram. The separation of sites along the second axis is related to the availability of nitrogen and phosphorus. Although no statistical between-block difference in community cover was identified during the pre-experiment survey, some blocks appeared to be slightly more mesotrophic (less calcareous) in character, and this is illustrated on the second axis. All treatments are more variable along this second axis than the control.

The tracked vehicle treatments were the only treatments to be significantly different from the control along the first axis (Table 5.3), the wheeled vehicle treatments showing no significant separation from the untreated lanes. There was, however, no difference between the multiple tank pass and a tank slew treatment along this disturbance intensity gradient.

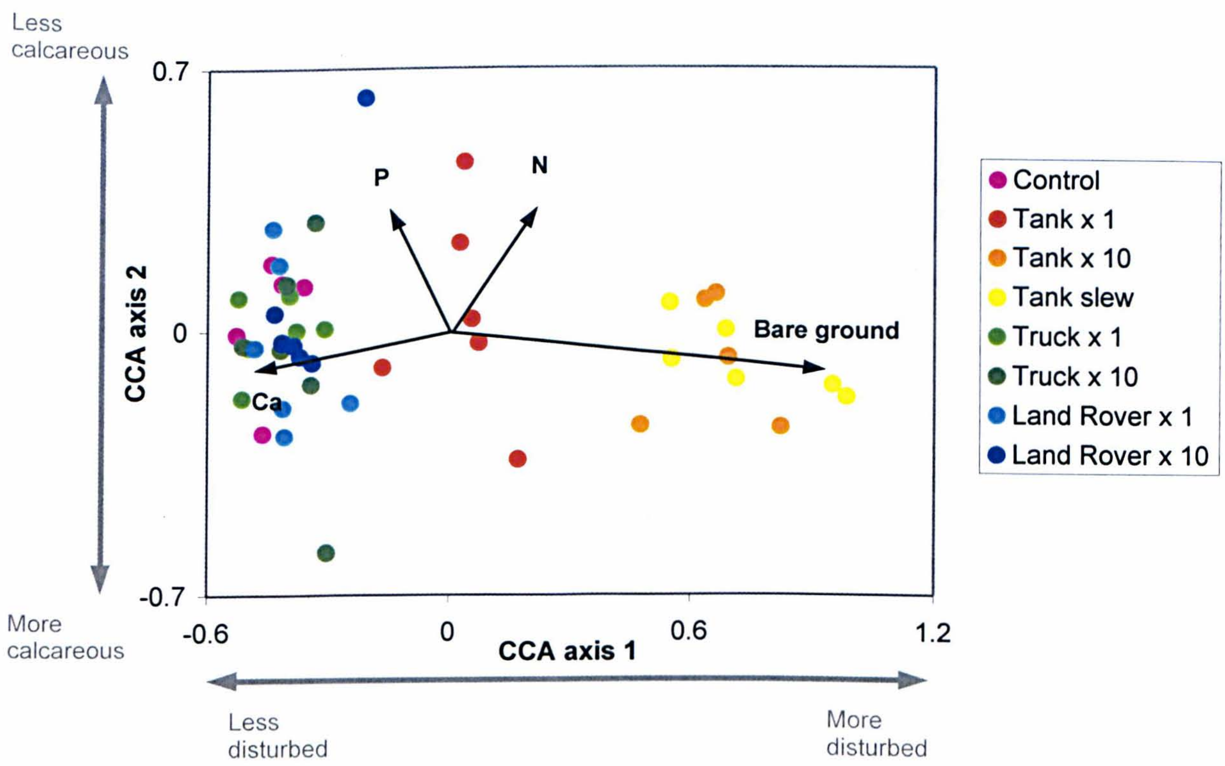


Figure 5.2 CCA biplot showing relative positions of treatments one year after application, with selected correlated environmental variables. Symbols are colour-coded according to treatment. Environmental variable scores are shown at x2.5 magnification of true values. Proposed gradients for axes 1 and 2 are displayed. Eigenvalue for axis 1 = 0.18, axis 2 = 0.04.

Table 5.3 Statistical significance of Tukey's pairwise comparison tests of ANOVAs on position of disturbance treatments along CCA axis 1 in Figure 5.2. *** : p<0.001, ** : p<0.01, * : p<0.05

	Control	Tank x 1	Tank x 10	Tank slew	Truck x 1	Truck x 10	Land Rover x 1
Tank x 1	***						
Tank x 10	***	***					
Tank slew	***	***	ns				
Truck x 1	ns	***	***	***			
Truck x 10	ns	***	***	***	ns		
Land Rover x 1	ns	***	***	***	ns	ns	
Land Rover x 10	ns	***	***	***	ns	ns	ns

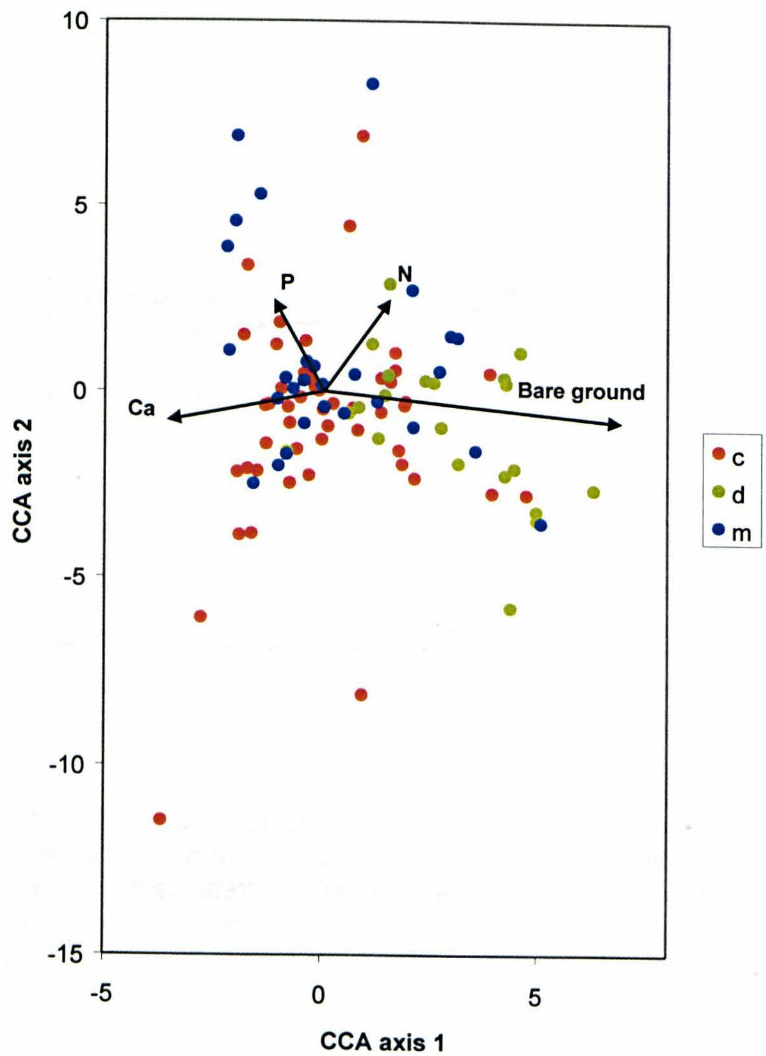


Figure 5.3 CCA biplot showing relative position of species along first two ordination axis, coded according to their preference for calcareous (c) or mesotrophic (m) grassland communities, or being characteristic of disturbed grassland (d). Environmental variable scores are shown at x19 magnification of true values.

A trend of increasing frequency of ruderal species along the first CCA axis can also be identified from the distribution of species within the CCA biplot (Figure 5.3). Typical colonists of severe disturbance, species with positive scores on axis 1, include ruderal species such as *Arenaria serpyllifolia* and *Anagallis arvensis*, and early successional species associated with short chalk turf, such as *Festuca ovina* and *Euphrasia nemorosa*. Species with negative scores on axis 1 are unable to tolerate heavy disturbance such as *Anacamptis pyramidalis*, and those characteristic of more established rank chalk grasslands, such as *Bromopsis erecta, Crataegus monogyna* and *Stachys officinalis*.

Use of ANOVA showed that typical early colonists of disturbed ground occupy significantly different positions along the first CCA axis, from those of more established calcareous and mesotrophic grassland swards (Tables 5.4 and 5.5). On the second axis, there is significant separation between the species associated with the calcareous and more mesotrophic swards, with typical MG species higher up this axis. This separation connects with the gradient of measured N and P identified in Figure 5.3.

Table 5.4 Analysis of variance table for separation of disturbance species and species typical of calcareous and mesotrophic grasslands along CCA axes 1 and 2.

	Source	DF	SS	MS	F	P
CCA axis 1	Species type	2	138.5	69.2	21.4	<0.001
	Error	97	313.6	3.23		
	Total	99				
CCA axis 2	Species type	2	68.9	34.5	4.89	<0.01
	Error	97	683.4	7.05		
	Total	99				

Table 5.5 P-values for the statistical significance of Tukey's pairwise comparison tests of distribution of species groups along CCA axes 1 and 2. ***: p<0.001; ***: p<0.01; *: p<0.05

	CCA axis 1		CCA axis 2	
Species group	Disturbance species	CG species	Disturbance species	CG species
Typical CG species	***		ns	
Typical MG species	***	ns	*	*

(ii) Community composition after 1 and 2 years of recovery

Detrended Correspondence Analysis (DCA) of the vegetation data from both one and two years after disturbance showed high similarity between the species composition of the four wheeled vehicle treatments and the controls. In addition, the between-year change in these treatments was similar in direction and magnitude. This movement of the controls/less intensively disturbed treatments could represent between-year ranges of sampling error, or continuing succession in the absence of management. After two years of recovery, the species assemblage of the single tank treatment was significantly different to that of the controls, but the direction and magnitude of change remained similar to that taking place in the controls and wheeled vehicle treatments. The change recorded in these less intensively disturbed lanes was predominantly along the first ordination axis. In contrast, the year-on-year changes observed for the multiple tank pass and tank slew were not only much larger than the changes observed in the control and wheeled vehicle treatments, but were predominantly along the second axis.

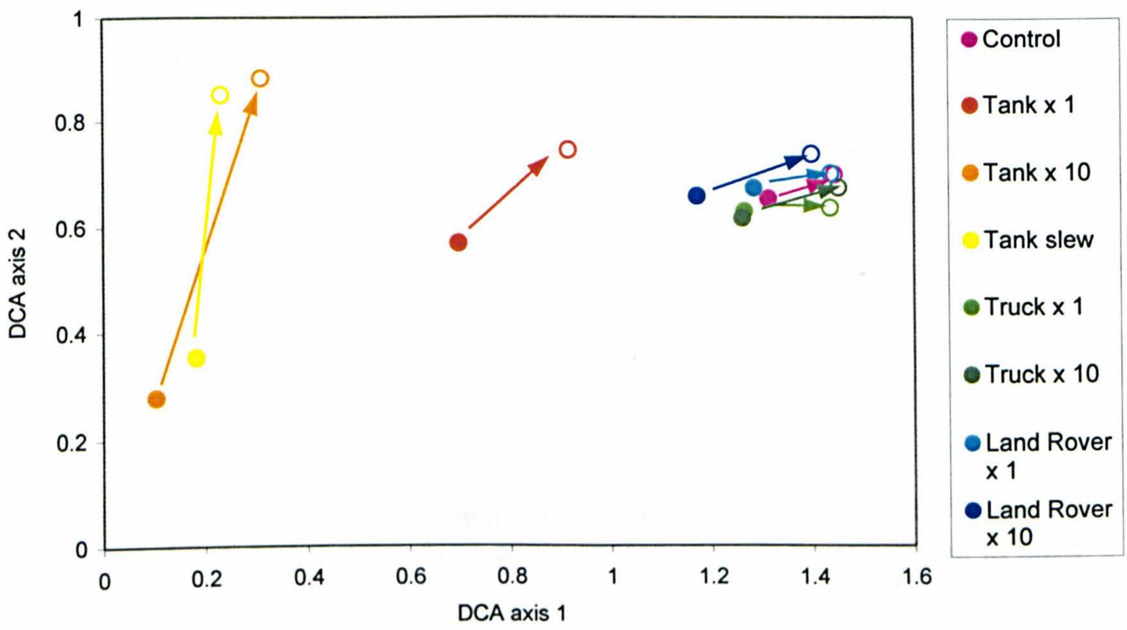


Figure 5.4 DCA biplot showing mean position of treatment lanes one and two years after disturbance. Closed circles = Year 1, open circles = Year 2. Symbols colour-coded according to treatment. Arrows signify between-year movement of treatments in the ordination space.

ANOVA showed that there was no difference between the distance moved by any of the disturbance treatments along the first DCA axis and the distance moved by the controls (Table 5.6). However, on the second axis, the multiple tank pass and tank slew treatments moved significantly more than the control (Table 5.8), while the shift for the single tank pass treatment was not significant.

Table 5.6 Analysis of variance table for difference between treatments one and two years after disturbance, along DCA axes 1 and 2.

	Source	DF	SS	MS	F	P
DCA axis 1	Treatment	7	0.141	0.020	0.83	ns
	Error	40	0.975	0.024		
	Total	47	1.116			
DCA axis 2	Treatment	7	2.26	0.32	9.05	<0.001
	Error	40	1.43	0.04		
	Total	47	3.68			

Table 5.7 Significance of the distance moved by controls and disturbance treatment along the second DCA axis, between one and two years after disturbance. Derived from Tukey's pairwise comparison tests. ***: p<0.001; **: p<0.01; *: p<0.05.

	Tank x 1	Tank x 10	Tank slew	Truck x 1	Truck x 10	Land Rover x 1	Land Rover x 10
P-value	ns	***	**	ns	ns	ns	ns

5.4 DISCUSSION

Physical impacts of military vehicles

The aim of this experiment was to investigate the resistance of a chalk grassland community to disturbance by different military vehicles, and the factors important in the early phase of vegetation community re-establishment. An initial comparison of vehicle compaction effects and reductions in sward height one year after treatment application indicates that the impact of tracked vehicles is much greater than that of wheeled vehicles. However, the smaller but significant compaction effects of the wheeled vehicles confirm the observations of Milchunas *et al.* (1998), that even light vehicles can have an impact off-road. Such compaction can alter local hydrology, soil nutrient status and decomposition of litter (Voorhees *et al.*, 1989; Alakukku and Elonen, 1995), in addition to restricting root penetration and growth (Agnew and Carrow, 1985, Braunack and Williams, 1993). Modified site conditions caused by soil compaction, altered hydrology and the availability of propagules all affect grassland re-establishment (Jones and Bagley, 1998; Shaw and Diersing, 1990).

The remediation of soil compaction occurs through the action of soil fauna and frost heave. Estimates for the recovery of soils from compaction in desert systems range between 80 and 140 years (Knapp, 1992; Webb and Wilshire, 1980). It is likely that in less dry environments, where microbial populations are higher, recovery rates will be faster (Belnap, 1995). However, for chalk grasslands this remains an area that would merit further investigation.

The sward height measurements suggest that where community composition is not significantly altered by wheeled vehicle disturbance, structural recovery may still be retarded, at least until the second year of recovery. Small-scale structural diversity such as this is important for certain faunal groups, especially invertebrates (Kirby, 1992), and a certain amount of disturbance from these sources may usefully mimic the effects of traditional grazing. Soil compaction and sward height reduction effects have wider implications than just those relevant to the SPTA, due to the increased used of off-road 4x4 vehicles in both recreational and agricultural contexts. These data suggest that the use of such vehicles could potentially result in changes in the soils and vegetation across a range of vegetation types, as suggested by Iverson *et al.* (1981).

In this experiment, the most intense disturbance was caused by a tracked vehicle slew and a multiple tank pass. The action of a tracked vehicle causes stripping of the original vegetation and exposure of mineral soil, thus creating a more severe perturbation of the soil than wheeled vehicles. The separation of treatments along the first axis of the CCA (Figure 5.3), the 'disturbance gradient', indicates that the availability of a site for seedling establishment (i.e. the amount of bare ground) is the primary determinant of species composition during the early phase of recovery. Tracked vehicles clearly create a significant amount of bare ground.

In terms of the species composition of the re-establishing vegetation community, there was little to differentiate between the slew and the multiple tank pass. However, the major difference between a slew and a multiple track pass, not recorded during the course of this experiment, is the physical area of top-soil displaced during a tank turn. This creates a large area of bare ground in the region of the slew, as well as potential establishment sites on the displaced soil. Ayers (1994) demonstrated that sharper turns create wider ruts, depending on the operating characteristics of the vehicle in question. It is also likely that soil displacement is less severe at slower turning speeds, although Horn *et al.* (1989) showed that slower speeds result in greater soil compaction.

The physical disturbance of land has important management implications in addition to changes in species assemblages (which will be considered in Chapter 6). Farmers are less inclined to cut hay on parcels of grassland that have been disturbed by tracked vehicles in case of damage to their vehicles or equipment. Equally, uneven surfaces can hinder the erection of fencing for stock, and the checking of animals out on the range (see Chapter 7). Limiting options for management in this way imposes constraints on the attainment of conservation objectives.

Early succession trajectories following vehicle disturbance

The results of the multivariate analysis using both Year 1 and 2 data give an indication of the magnitude and direction of early succession trajectories following disturbance. While the single tank pass treatment lanes appear to be 'on course' to returning to their original composition, the multiple tank pass and the tank slew treatments are moving in a different direction, and not, at this time, towards the undisturbed controls. These data suggest that somewhere between the intensity of a single tank pass and a multiple tank pass/slew, a threshold has been passed beyond which the system moves into a different mode of community functioning. Leininger and Payne (1980) indicated that increased numbers of tracked vehicle passes increases what they refer to as 'damage', and here this disturbance threshold seems to be associated with the amount of bare ground created and the amount of soil compaction, as indicated by the first ordination axis.

It is uncertain as to the direction that the vegetation in these more intensively disturbed treatment lanes will now move, and future monitoring is needed in order to establish this. In work on sagebrush steppe in the US, a number of authors have proposed that vegetation communities will not necessarily return to their original state once they have transgressed an ecological threshold to a new, altered state (Westoby *et al.*, 1989; Laycock, 1991). Possible scenarios for this tall chalk grassland include eventual return to pre-disturbance state, either through an equilibrium approach, or a less direct route (Figures 5.5a and b), or the establishment of a 'new' community type (Figure 5.5c). The results presented in Chapter 3 suggest that complete re-establishment of this community type is possible, but can take a longer time to achieve than the two years investigated here.

Additionally, the biplots produced from the ordinations in Chapter 3 do not suggest a simple linear successional trajectory, but an arc-shaped movement (see Figures 3.3 and 3.4). The sites sampled in Chapter 3 were old high-intensity disturbance events and it is possible that the movement along the second ordination axis of the multiple tank pass and tank slews observed in Figure 5.4 is the early stage of this same successional trajectory.

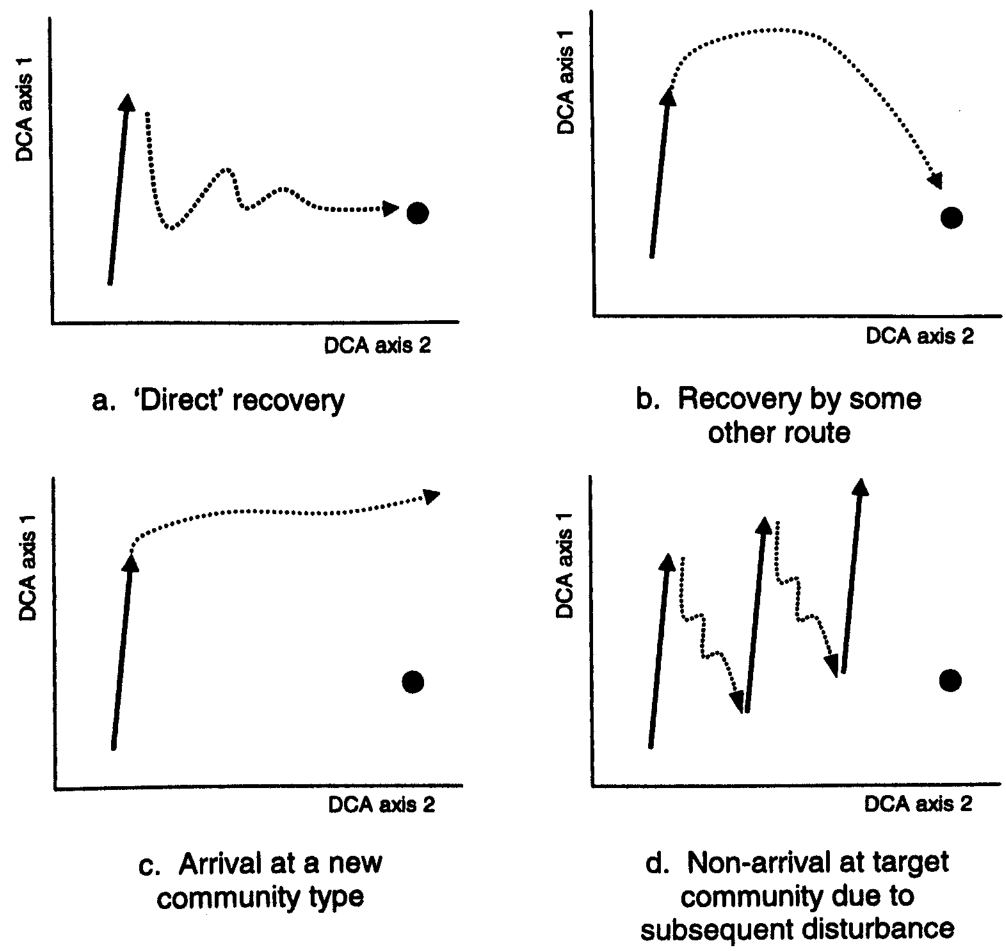


Figure 5.5 Possible future scenarios for extreme disturbance sites, depicted on hypothetical ordination axes. a: 'direct' recovery; b: indirect recovery; c: establishment of a new community type; d: non-arrival at the target community due to subsequent disturbance. The circle represents the relative position in the ordination space of the target community.

Attainment of a new community type following disturbance may be a possibility. It is generally accepted that the grasslands of SPTA do not fit exactly with the communities described in the National Vegetation Classification (Rodwell, 1992), resulting in the variants described by Porley (1986). This mismatch is usually ascribed to two factors: first that the SPTA chalk grasslands were omitted from the sample quadrats used to compile the NVC, and secondly the disturbance on the SPTA is fundamentally changing the character of these particular chalk grassland communities. For example, *Melilotus altissimus* is a 'constant' species on the SPTA, recorded at DAFOR score of Occasional or Frequent across the area, yet is absent from the NVC chalk grassland community types. *M. altissimus* is particularly associated with disturbance communities on SPTA.

Ecological resistance to disturbance

In addition to physical characteristics of the habitat prior to disturbance and the nature of the disturbance event, resistance to disturbance is likely to depend on a number of ecological factors, including breadth of ecological tolerance of preferential species of the habitat in question, and susceptibility to invasion of low-preference species (Jones and Bagley, 1998). The species component of re-vegetating chalk grassland, and its intrinsic ecological value, will be considered in more detail in Chapter 6. However, many preferential chalk grassland species are specialists of this habitat type, or have a low tolerance of disturbance, such as *Anacamptis pyramidalis*, and *Succisa pratensis*. It is species such as these that are more likely to be lost from the sward as a result of continual background disturbance. The initial re-establishment of vegetation cover on the tracked vehicle disturbance sites after one year was rapid (between 66 and 75%), due to the high availability of propagules, yet these pioneer species, such as *Arenaria serpyllifolia* and *Agrostis stolonifera,* are not normal components of the chalk grassland communities for which SPTA was designated an SSSI.

5.5 CONCLUSIONS

Measuring habitat resistance and resilience remains an inexact science, and most experimentation is dependent on a within-habitat comparative approach (Jones and Bagley, 1998; Wilson, 1988). However, it has been suggested that grasslands demonstrate a greater response to disturbance than other habitats such as scrubland (Milchunas *et al.*, 1998). The tall chalk grassland sampled here showed high resistance to disturbance by wheeled vehicle, including a 4 tonne truck, but was substantially less resistant to tracked vehicle disturbance, with relatively large changes in both species assemblage and soil properties. A single tracked vehicle pass may cause significant change to community composition, but the subsequent succession is likely to return the community to its original state. Community changes as a result of disturbance by large numbers of tracked vehicles are likely to be longer-term.

Disturbance events, such as the passage of tracked vehicles, are useful in maintaining heterogeneity in the grasslands of Salisbury Plain, but should not occur at the expense of other forms of more controlled management, such grazing or hay production. Balancing the positive ecological effects of disturbance with the threat of habitat fragmentation remains the challenge for defence land managers on Salisbury Plain. Information regarding the mechanisms, direction and timing of habitat recovery are necessary if the environmental impacts of military training are to be assessed and managed effectively.

POSTSCRIPT

Includes preliminary work published in: **Hirst, R.A., Pywell, R.F., Putwain, P.D. and Marrs, R.H. (2000).** Ecological impacts of military vehicles on chalk grassland. In Aspects of Applied Biology **58**, *Vegetation management in changing landscapes*. pp293-298. Association of Applied Biologists, Warwick.

Tracked vehicle slew in a CG3d community

6. INVESTIGATING MECHANISMS OF HABITAT RE-ESTABLISHMENT FOLLOWING MILITARY DISTURBANCE: THE ROLE OF THE SEED BANK AND THE SEED RAIN

SUMMARY

An experiment was set up to investigate the relative contributions of the seed bank and the seed rain to the re-establishment of a tall chalk grassland community following disturbance by military vehicles. It was shown that the composition of the regenerating sward had little in common with recorded species in the seed bank, as the majority of propagules originated from the surrounding vegetation. However, a high number of desirable chalk grassland species present in the surface vegetation were not represented in either the sampled seed bank, or the seed rain. These results suggest that large swathes of undisturbed grassland are needed for successful spontaneous recovery following disturbance. The vulnerability of these high nature conservation interest grasslands to incremental degradation as a result of unchecked disturbance has not been appreciated before.

6.1 INTRODUCTION

The soil seed bank and seed rain

The soil seed bank and seed rain are part of the fundamental ecosystem processes that contribute to successional changes in ecological communities (Jefferson and Usher, 1989). Seed bank studies (referring to all the detached viable seeds of a species at a specific time, including both seeds and fruits, above and below the soil surface, see Thompson and Grime, 1979, which here will include both persistent and transient seed bank components) have long been acknowledged as being valuable for the understanding of community structure and function (Brenchley, 1918; Chippindale and Milton, 1934; Milton, 1943; Champness and Morris, 1948). Investigation of the role of seed rain, that is, propagules dispersed by the wind, water or biotic mechanisms to a potential germination site (Harper, 1977; Jefferson and Usher, 1989), has been less intense (Figure 6.1).

Most systematic grassland seed bank and seed rain studies have taken place on abandoned sites *apropos* restoration potential (Hutchings and Booth, 1996; Willems and Bik, 1998; Davies and Waite, 1998; Graham and Hutchings, 1988; Dutoit and Alard, 1995; Falińska, 1999; Jensen, 1998). However, an understanding of the relative contributions of the seed bank and seed rain to the natural colonisation and succession of sites with high nature conservation value is important for managers; it enables prediction of the response of a habitat following management intervention or less controlled disturbance events (Jefferson and Usher, 1989).

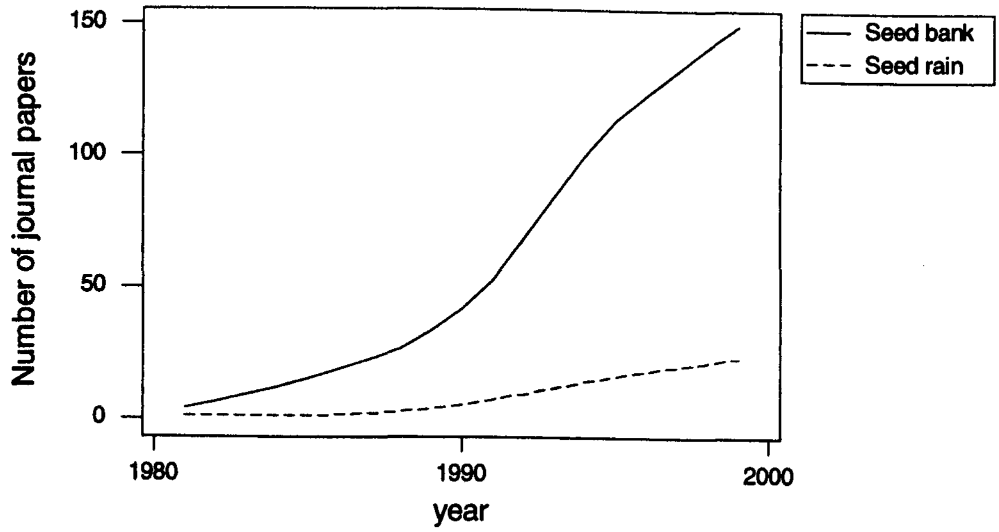


Figure 6.1 Number of scientific journal papers on seed banks and seed rain, using Web of Science records (http://wos.mimas.ac.uk), 1981-1999.

The study area

The Salisbury Plain Training Area (SPTA) is the largest military training area in the UK, covering some 38,000 ha of southern Wiltshire (Brown, 1995). Around 20,000 ha of the site have been designated as a Site of Special Scientific Interest (SSSI) for their contiguity and quality of chalk grassland (English Nature, 1993), a habitat much reduced across north west Europe by agricultural expansion and urban and industrial development. The most intensive military use of the SPTA is for tactical tracked vehicle training, and hence heavy armoured vehicles represent the primary source of grassland disturbance, in addition to shelling and burning. Although the Ministry of Defence (MoD) is statutorily required to manage these grasslands for their conservation interest, active restoration of degraded land is logistically difficult and costly over such an extensive area, and would impede realistic military training. Therefore, defence land managers have a particular interest in the ability of the Salisbury Plain grasslands to recover spontaneously from disturbance events.

Disturbance and re-colonisation

Tracked vehicles are known to have intense disturbance effects on habitats, both directly through the mortality of individual plants, and through more indirect and long-term effects including soil compaction and altered nutrient cycling (Milchunas *et al.* 1999). After disturbance, vegetation re-establishment is dependent on the availability of both propagules and favourable germination conditions (Willems and Bik, 1998), with the seed bank and seed rain providing the majority of seeds for re-vegetation (Graham and Hutchings, 1988). However, little is known about the biological mechanisms by which re-colonisation is achieved on the SPTA, and hence the likely outcomes of continual unchecked disturbance. Therefore, this study uses a controlled disturbance experiment to investigate:

- the respective potential contributions of the seed rain and seed bank to spontaneous habitat recovery following vehicle disturbance of chalk grassland.
- management implications for grasslands with high conservation interest that are subject to unavoidable disturbance.

Detailed investigation of the natural colonisation and succession of disturbed ground may then give insights into a habitat's ability to re-vegetate.

6.2 METHODS

Site selection and experimental design

The area of Salisbury Plain Training Area designated for this experiment is classified under the National Vegetation Classification (Rodwell, 1992) as CG3d (a *Bromus erectus* grassland, *Festuca rubra - Festuca arundinacea* sub-community). This vegetation type is common on Salisbury Plain; 28% of the training area contains a component of CG3d (Pywell, 1998), and it is one of the communities for which it has been designated as a SSSI. There is, therefore, particular interest in the ability of this vegetation community to withstand and recover from vehicular disturbance.

Following consultation with the Army, three commonly used military vehicles differing in mass and traction were selected for the experiment: a Land Rover (1t, wheeled), a Bedford truck (4t, wheeled) and a Challenger tank (64t, tracked). The experimental design comprised six replicate blocks each containing eight lanes 25m in length to which difference disturbance treatments were allocated randomly (see Chapter 5, Figure 5.1). Treatments included a control (no vehicle pass), single and multiple passes of each vehicle, and a tracked vehicle 'slew'. Lanes were 5m (wheeled vehicles), 10m (tracked vehicle) and 15m (tracked vehicle slew) wide. Immediately before the treatments were applied in October 1998, the site was surveyed to identify any significant inter- and intra-block variation in vegetation cover. Three 50cm x 50cm vegetation quadrats were randomly placed in each lane and the vegetation recorded using the Domin scale (Mueller-Dombois and Ellenberg, 1974).

Sampling post-disturbance surface vegetation, seed banks and seed rain

(i) Surface vegetation

Immediately after the disturbance was applied, three permanent quadrats (0.5 x 2.0m) were marked with stakes at distances of 6, 12 and 18m along the length of each disturbed lane, and paired with parallel undisturbed quadrats nearby. In July 1999 and 2000, the vegetation was surveyed in the six quadrats in each lane. Vegetation cover was recorded using the Domin scale, including a score for bare ground.

(ii) Soil seed banks

Following an ordnance check, soil samples were taken during the two days following the disturbance. A block of soil measuring 10x10x10cm was removed from the centre of each of the three disturbed quadrats using a graduated trowel, and separated into 0-5cm and 5-10cm depth fractions. These were mixed, air-dried and chilled in a cold room at 4°C for eight weeks. Seed trays (10 x 15cm) were filled with 600ml of sterile sand and 300ml of each composite sample spread on top of the sand - one tray for each of the eight treatments in each block, at each of the two depths, giving 96 seed banks in total. The trays were placed in a greenhouse with automatic watering from below. Emerging seedlings were identified and recorded for 12 months. The seed banks were re-disturbed after each clearance of seedlings to promote further germination. This technique enabled sampling of both persistent and transient seed bank components.

(iii) Seed rain

Two out of the six experimental blocks (blocks 1 and 3) were chosen randomly for seed rain analysis. Seed trays (10 x 15cm) were filled with sterile compost (see Archibold, 1980) and following an ordnance check, were fixed to the ground with nails at the 6, 12 and 18m quadrat locations along each disturbance treatment lane. Trays were put out for two consecutive periods: July-August and September-October 1999, giving 96 trays in total. After each two month period, the trays were collected in and placed in the glasshouse. Emerging seedlings were identified and removed. Germination ceased after about a month in the glasshouse, and trays were then placed in the cold room at 4°C for six weeks. Subsequent to this chilling, the trays were returned to the glasshouse for three months and additional germinating seeds were identified and removed. When in the field, the seed traps were not protected from herbivory. The aim was to record seeds that would have been available for germination following a disturbance event, when herbivory could also have occurred.

Data analysis

Species identified in each of the surface vegetation, soil seed bank and seed rain samples were classified as being an annual or biennial, perennial forb or perennial grass species. The percentage composition of each of these groups was calculated for individual treatment lanes. Percentage composition of preferential calcareous and mesotrophic grassland species was also calculated, using the CEH Biotope Occupancy Database (see Appendix 1).

Detrended Correspondence Analysis was conducted on the presence/absence species data for the recorded surface vegetation, seed bank and seed rain to assess the degree of association between the stands. Data was amalgamated for the two seed bank soil depths and the two seed rain recording periods.

Percentage similarity between stands of surface vegetation and the soil seed bank and seed rain were investigated using Sørensen's similarity index (see Sørensen, 1948; Pielou, 1984; Bekker *et al.*, 1997), based on presence/absence data.

Split-plot ANOVA with time as a subplot factor was used to distinguish between treatment and time period differences in the composition of the seed rain trays.

6.3 RESULTS

Sources of propagules for re-establishment

The largest group of species recorded in this experiment was of those found solely in the sampled surface vegetation (Tables 6.1 and 6.2). Indeed, 60 out of the 119 species recorded in the surface vegetation (50.4%) were recorded neither in the seed rain, nor in the seed bank samples. Of these 60 species, 29 (48.3%) were desirable species of chalk grassland. It is these species, such as *Anacamptis pyramidalis*, *Centaurea scabiosa* or *Hippocrepis comosa*, that have a higher probability of being permanently lost from the sward as a result of disturbance.

Table 6.1 Proportions of species recorded in the surface vegetation, seed rain and seed bank samples, from a CG3d community on the Salisbury Plain Training Area.

Source	Number of species		CG grassland species	
	n	% of total	n	% of total
Surface vegetation only	60	45.8	29	22.1
Seed bank only	4	3.1	1	0.8
Seed rain only	6	4.6	1	0.8
Surface vegetation and seed bank samples	14	10.7	10	7.6
Surface vegetation and seed rain	16	12.2	7	5.3
Seed bank and seed rain samples	2	1.5	0	0.0
Surface vegetation, seed bank and seed rain samples	29	22.1	17	13.0
Total	131	100.0	65	49.6

Similarity between surface vegetation, seed bank and seed rain

A Detrended Correspondence Analysis (DCA) based on qualitative data for species recorded in the surface vegetation, seed bank and seed rain indicated a greater correspondence between surface vegetation and seed rain samples, than between the seed bank and surface vegetation (Figure 6.2). The surface vegetation and seed rain trays were relatively constant in their composition, whereas the seed bank samples were highly variable. The separation of the three sources of species data primarily occurs along the first of the two DCA axes shown. Greater association between the seed rain and seed bank samples was expected, due to the potential overlap between species recorded in the seed rain traps, and those known to form transient seed banks.

Table 6.2 List of species recorded in seed bank and seed rain study on the SPTA, according to source of propagules. SV = undisturbed surface vegetation, SB = seed bank, SR = seed rain. Total number of species recorded in experiment = 131.

Only SV		Only SB	Only SR	SV and SB	SV and SR	SB and SR	SV, SB and SR
Allium vineale	*Luzula campestris*	*Erucastrum gallicum*	*Cardamine hirsuta*	*Achillea millefolium*	*Anthoxanthum odoratum*	*Capsella bursa pastoris*	*Agrostis stolonifera*
Anacamptis pyramidalis	*Onobrychis viciifolia*	*Galium mollugo*	*Chenopodium album*	*Agrimonia eupatoria*	*Arrhenatherum elatius*	*Cardamine flexuosa*	*Bromopsis erecta*
Anagallis arvensis	*Phleum pratense*	*Rumex crispus*	*Cynosurus cristatus*	*Aphanes arvensis*	*Bromus hordaceus*		*Carex flacca*
Anisantha sterilis	*Picris echioides*	*Verbascum thapsus*	*Sagina apetala*	*Arenaria serpyllifolia*	*Dactylis glomerata*		*Cerastium fontanum*
Anthyllis vulneraria	*Pilosella officinarum*		*Sagina procumbens*	*Centaurium erythraea*	*Festuca ovina*		*Cirsium arvense*
Briza media	*Pimpinella saxifraga*		*Stellaria media*	*Cirsium acaule*	*Knautia arvensis*		*Cirsium vulgare*
Centaurea nigra	*Poa humilis*			*Hypericum perforatum*	*Leontodon autumnalis*		*Daucus carota*
Centaurea scabiosa	*Poa trivialis*			*Lathyris pratensis*	*Leontodon hispidus*		*Festuca rubra*
Chaenorhinum minus	*Polygonum aviculare*			*Leucanthemum vulgare*	*Lolium perenne*		*Helictotrichon pratensis*
Cirsium eriophorum	*Potentilla anserina*			*Linaria vulgaris*	*Odontites vernus*		*Helictotrichon pubescens*
Convolvulus arvensis	*Potentilla reptans*			*Medicago lupulina*	*Poa annua*		*Holcus lanatus*
Crataegus monogyna	*Primula veris*			*Plantago major*	*Poa pratensis*		*Hypochoeris radicata*
Crepis capillaris	*Ranunculus acris*			*Senecio vulgaris*	*Ranunculus bulbosus*		*Linum catharticum*
Elytrigia repens	*Rhinanthus minor*			*Vicia cracca*	*Scabiosa columbaria*		*Lotus corniculatus*
Euphrasia nemorosa	*Rumex acetosa*				*Sonchus asper*		*Melilotus altissimus*
Fallopia convolvulus	*Serratula tinctoria*				*Tragopogon pratensis*		*Pastinaca sativa*
Festuca arundinacea	*Sherardia arvensis*						*Phleum bertolonii*
Filipendula vulgaris	*Sinapis arvensis*						*Plantago lanceolata*
Fumaria officinalis	*Sonchus arvensis*						*Plantago media*
Galium verum	*Stachys officinalis*						*Prunella vulgaris*
Gentianella amarella	*Succisa pratensis*						*Ranunculus repens*
Geranium columbinum	*Trifolium dubium*						*Reseda lutea*
Geranium dissectum	*Trifolium pratense*						*Sanguisorba minor*
Geranium molle	*Trisetum flavescens*						*Senecio jacobaea*
Glechoma hederacea	*Urtica dioica*						*Sonchus oleraceus*
Helianthemum nummularium	*Veronica chameadrys*						*Taraxacum sp.*
Hippocrepis comosa	*Veronica hederifolia*						*Trifolium campestre*
Koeleria macrantha	*Vicia hirsuta*						*Trifolium repens*
Lamuim purpureum	*Vicia tetrasperma*						*Vicia sativa agg.*
Leontodon saxatilis	*Viola hirta*						

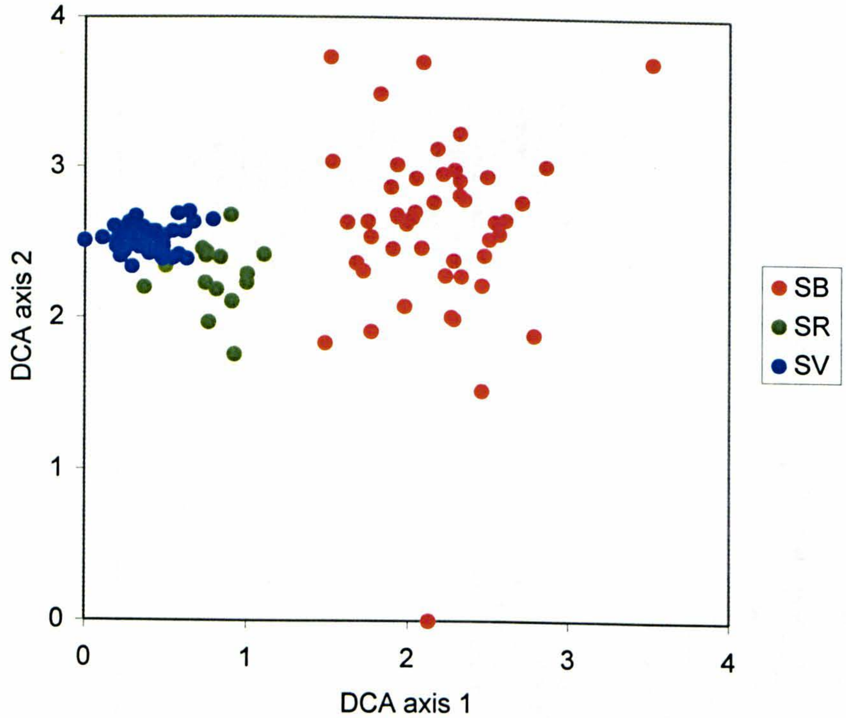


Figure 6.2 DCA biplot showing the relative positions of the surface vegetation (SV), seed bank (SB) and seed rain (SR) samples from a CG3d community on the SPTA, based on presence/absence data. Eigenvalue for axis 1 = 0.36, axis 2 = 0.22.

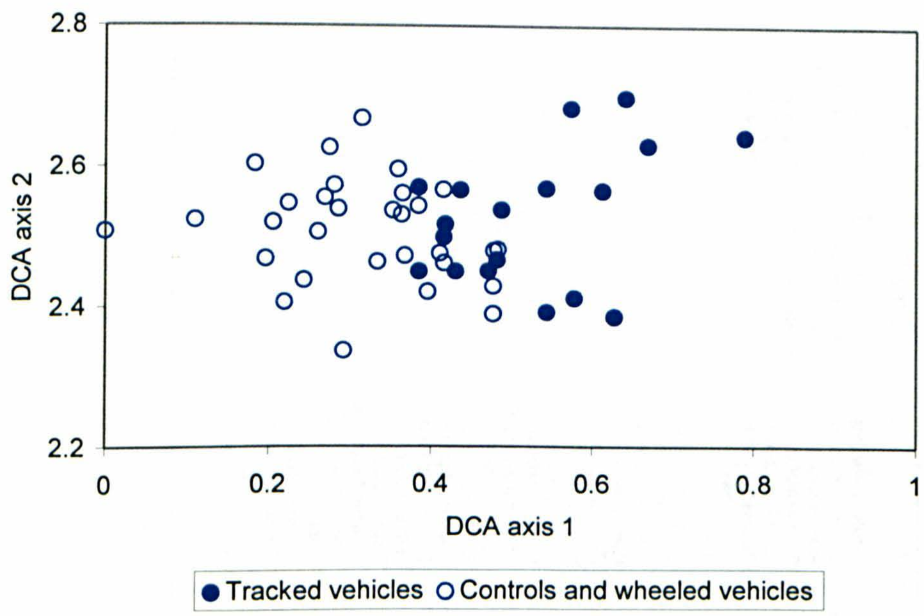


Figure 6.3 Close-up of the DCA biplot in Figure 6.2 showing just the position of the surface vegetation (SV) samples, coded according to source of disturbance. Lanes disturbed by tracked vehicles are located nearer to the seed bank samples.

Closer investigation of the positions of the surface vegetation samples (Figure 6.3) showed that the quadrats recorded in the lanes disturbed by the tank displayed a greater similarity to the seed bank along the first axis, than the controls or vegetation disturbed by wheeled vehicles ($F = 39.6$, $p<0.001$).

The similarity between the seed bank samples and surface vegetation in the control plots ranged between 0 and 38%, with a mean of 15.7% similarity (Table 6.3). The higher values recorded were those for the tracked vehicle disturbance plots, where the soil was disturbed sufficiently for there to be regeneration from the seed bank. In comparison, the seed rain samples showed a much higher degree of similarity with the surface vegetation recorded one year after disturbance, ranging between 33 and 54%, with a mean of 41.4% similarity. However, ANOVAs showed no significant difference in recorded similarity between any of the treatment lanes, neither between the surface vegetation and the seed bank samples, nor the surface vegetation and the seed rain samples.

Table 6.3 Association between recorded vegetation and seed bank and seed rain samples, using Sorensen's similarity index.

Factor	Similarity with surface vegetation (%)			
	Min	Max	Mean	SE
Seed bank	0	37.5	15.7	1.13
Seed rain	32.7	53.7	41.4	1.31

Table 6.4 The 10 most common species occurring in the surface vegetation, seed rain and seed bank samples of undisturbed CG3d grassland on the SPTA, according to percentage composition.

Surface vegetation	%	Seed bank	%	Seed rain	%
Bromopsis erecta	70.4	*Carex flacca*	16.2	*Holcus lanatus*	30.4
Festuca rubra	13.3	*Helictotrichon pratensis*	10.5	*Festuca rubra*	15.6
Arrhenatherum elatius	7.5	*Sonchus oleraceus*	10.0	*Arrhenatherum elatius*	14.8
Dactylis glomerata	2.4	*Daucus carota*	8.4	*Bromopsis erecta*	9.7
Holcus lanatus	2.3	*Agrostis stolonifera*	7.8	*Bromus hordaceus*	7.0
Helictotrichon pubescens	1.7	*Medicago lupulina*	5.9	*Dactylis glomerata*	2.5
Carex flacca	1.7	*Cerastium fontanum*	4.3	*Stellaria media*	1.9
Leontodon hispidus	1.1	*Senecio jacobaea*	3.8	*Helictotrichon pubescens*	1.8
Helictotrichon pratensis	1.0	*Arenaria serpyllifolia*	2.9	*Sonchus oleraceus*	1.6
Galium verum	0.7	*Ranunculus repens*	2.9	*Helictotrichon pratensis*	1.5

Species composition of surface vegetation, seed bank and seed rain samples

The cover of annuals and biennials, perennial forbs and perennial grasses in the surface vegetation showed the greatest degree of similarity to the composition of the seed rain samples (Figure 6.4). However, the percentage composition of typical calcareous and mesotrophic grassland species of the surface vegetation had more in common with the seed bank samples (Figure 6.5).

Certain species make a greater contribution to these similarities than others (Table 6.4). The high cover of perennial grass species in the surface vegetation is dominated by the presence of *Bromopsis erecta*. *B. erecta* does not form a persistent seed bank and was absent from the soil seed bank samples, but did occur in the seed rain samples. A high proportion of the seed rain samples was accounted for by *Holcus lanatus* rather than *B. erecta*. *H. lanatus* is also responsible for the dominance of typically mesotrophic grassland species in the seed rain samples (Figure 6.6). The high proportion of typical calcareous grassland species in the seed bank samples can also be attributed to large numbers of *Carex flacca, Daucus carota* and *Medicago lupulina*, with only low numbers recorded for other typical calcareous grassland species (see Appendix 1).

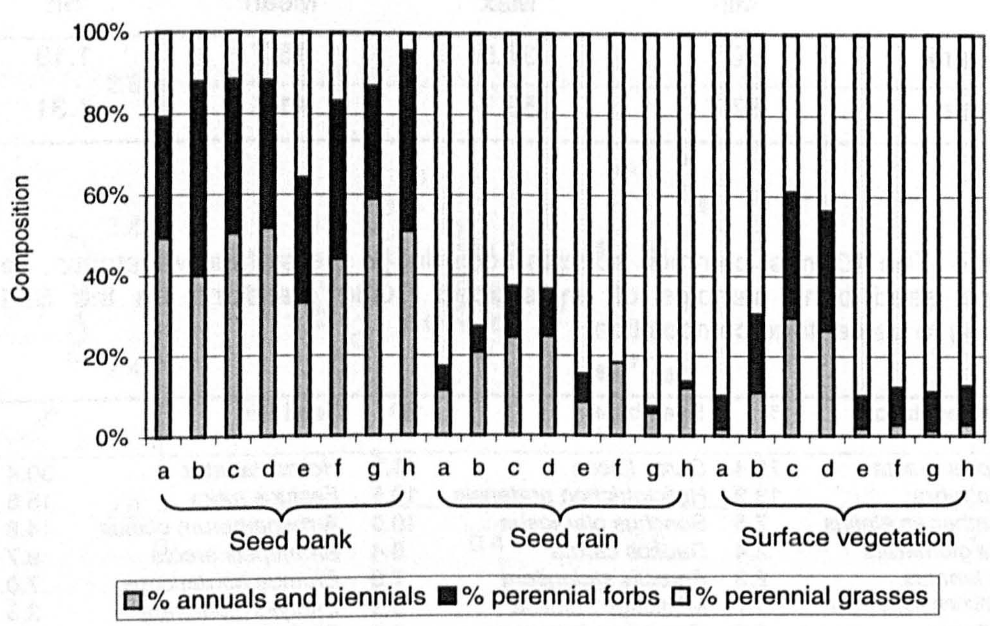


Figure 6.4 Composition of surface vegetation, seed bank and seed rain samples recorded on a disturbed CG3d community on the SPTA, by annuals and biennials, perennial forbs and perennial grasses. Disturbance treatments coded as: a = control, b = tank x1, c = tank x 10, d = tank slew, e = truck x 1, f = truck x 10, g = Land Rover x 1, h = Land Rover x 10.

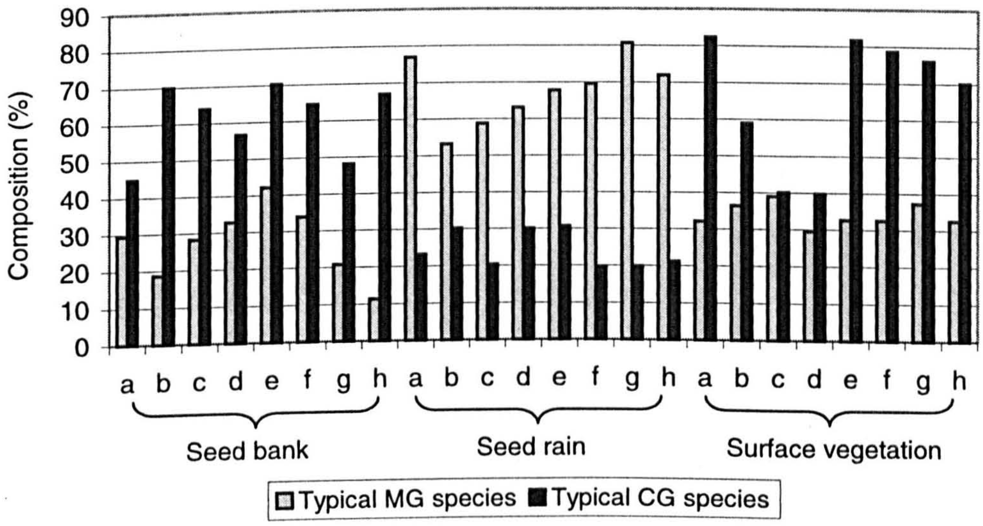


Figure 6.5 Composition of surface vegetation, seed bank and seed rain samples recorded on a disturbed CG3d community on the SPTA, by typical calcareous (CG) and mesotrophic (MG) grassland species, using the CEH Biotope Occupancy Database. Species can have high preference score for both CG and MG grasslands, and therefore the sum of these two groups can exceed 100%. Disturbance treatments coded as: a = control, b = tank x 1, c = tank x 10, d = tank slew, e = truck x 1, f = truck x 10, g = Land Rover x 1, h = Land Rover x 10.

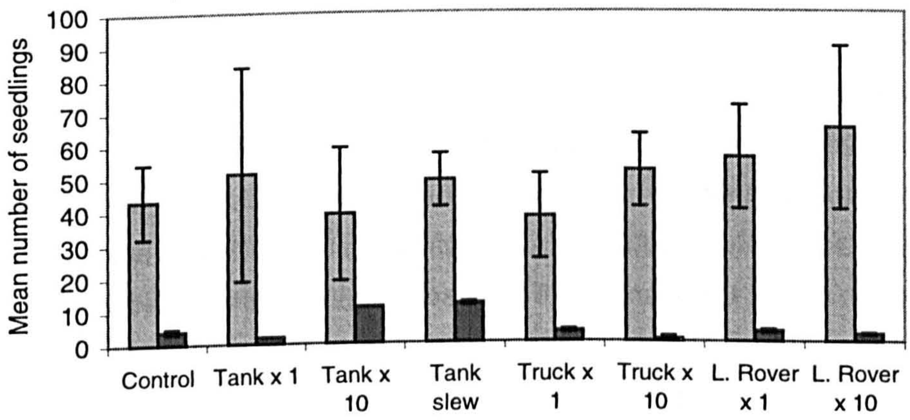
Time period differences in seed rain

Recorded number of seedlings germinating from seed traps placed in August and July far exceeded those from the September and October traps, the main source of seeds in this earlier period being perennial grasses (Table 6.5, Figure 6.6c). Although no significant between-treatment variation was recorded, the number of perennial forb seedlings seemed to show a slight increase in the seed traps from treatments disturbed by the tank (Figure 6.6b).

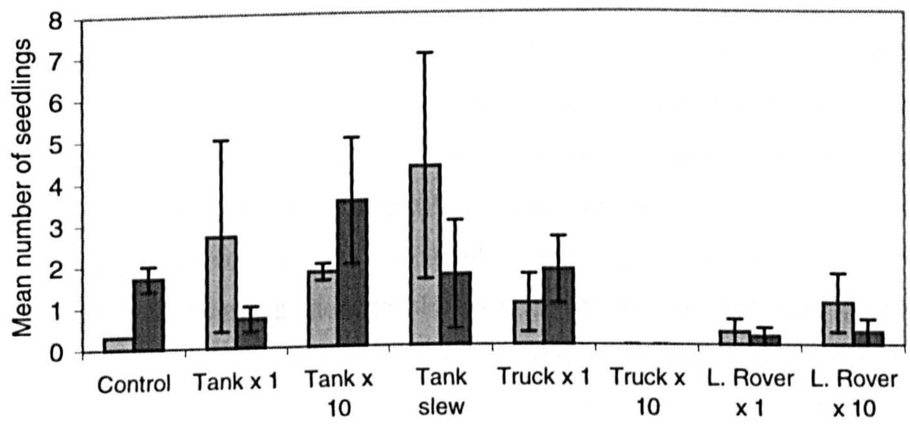
Table 6.5 Split plot for time ANOVA table, for seedling density in seed rain traps placed in a CG3d grassland on the SPTA in July-August and September-October.

	Source	DF	SS	MS	F	P
Total seedling density	Block	1	1387	1387		
	Treatment	7	473.2	67.6	0.34	ns
	Error a	7	1404	200.6		
	Time	1	15665	15665	44.5	<0.001
	Treatment * Time	7	896.2	128.0	0.36	ns
	Error b	8	2814	351.8		
	Total	31				
Density of perennial forb seedlings recorded	Block	1	0.22	0.22		
	Treatment	7	32.7	4.68	0.88	ns
	Error a	7	37.4	5.34		
	Time	1	0.35	0.35	0.22	ns
	Treatment * Time	7	16.5	2.36	1.52	ns
	Error b	8	12.4	1.55		
	Total	31				
Density of perennial grass seedlings recorded	Block	1	928.1	928.1		
	Treatment	7	533.0	76.1	0.33	ns
	Error a	7	801.0	114.4		
	Time	1	12155	12155	53.3	<0.001
	Treatment * Time	7	640.0	91.4	0.40	ns
	Error b	8	1825.0	228.1		
	Total	31				

a.



b.



c.

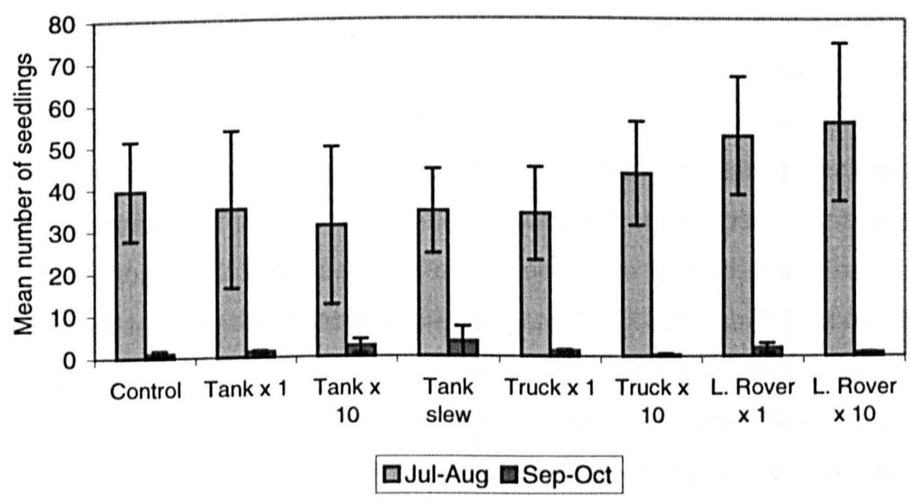


Figure 6.6 Mean number of (a) all types of seedlings, (b) perennial forb seedlings and (c) perennial grass seedlings recorded in seed rain traps placed in a CG3d grassland on the SPTA between July-August and September-October. Bars shown are standard error of the mean.

6.4 DISCUSSION

Potential contributions of the seed bank and seed rain to spontaneous restoration

The results presented here confirm the findings of other authors that the seed bank has limited potential value in the restoration of calcareous grasslands (Davies and Waite, 1998; Graham and Hutchings, 1988; Dutoit and Alard, 1995). This is attributed to the inability of most desirable chalk grassland species to form a persistent seed bank, and if they do, it usually is not in large numbers (Thompson and Grime, 1979; Donelan and Thompson, 1980; Graham and Hutchings, 1988; Thompson, 1993). The seed banks recorded in this experiment (persistent and transient components combined) had a similarity index of around 15% with the vegetation recorded one year after disturbance. Although the seed banks had a high content of calcareous grassland species, this comprised a large number of individuals from only a few species. The majority of the desirable chalk grassland species were indeed either absent or present only in very low numbers. The low similarity recorded between the surface vegetation and seed bank for even the undisturbed control plots is contrary to the findings of Willems (1995), who recorded 77% similarity in an old isolated chalk grassland site. This is likely to be because the SPTA community sampled is a taller, more rank chalk grassland than that sampled by Willems, and dominated by *Bromopsis erecta*. Although *B. erecta* is known to form a transient seed bank (Thompson *et al.*, 1997), it is generally absent from the seed banks sampled here.

Re-colonisation from the seed bank did seemingly occur following disturbance events that caused significant perturbation of the soil surface. Although this re-establishment tended to be by ruderal species of early successional stages (such as *Reseda lutea, Capsella bursa-pastoris or Agrostis stolonifera*), rather than by desirable chalk grassland species, the colonisation of bare ground by these species may be essential for the modification of site conditions for the establishment of later successional, and hence more desirable species (see the 'facilitation model' of Connell and Slatyer, 1977). Many authors acknowledge that seed banks are palimpsests of previous vegetational states (Thompson and Grime, 1979; Davies and Waite, 1998), and therefore the higher similarity between early re-colonising vegetation and the seed bank in vegetation disturbed by tracked vehicles is to be expected.

The absence of certain species from the seed banks recorded here may be a product of the sampling methodology adopted. The soil removed from the quadrat represented just 1% of the potential sampling volume, as number and size of samples were limited by glasshouse space. Under these conditions, rare species or those with patchy distributions are likely to be under-estimated. Seed concentration methods such as those proposed by Ter Heerdt *et al.* (1996) and Thompson *et al.* (1997) could be adopted to economise on glasshouse space. Additionally, the method adopted allowed no separation of the transient and persistent components, and thus an appreciation of the potential overlaps between the former and the seed rain.

Nonetheless, the potential value of the seed bank for regeneration following disturbance would appear limited, compared to the contribution of the seed rain (Figure 6.3), and other possible methods of community re-establishment not investigated in this experiment, such as vegetative spread. Seed rain samples reached a similarity index of around 40% with the re-establishing vegetation one year after disturbance, and this is indicative of the potential importance of seed rain on progressive secondary succession (Jefferson and Usher, 1989; Jensen, 1998). However, seed rain can also have a regressive role in the re-vegetation of habitats. If the bulk of re-colonisation occurs from the seed rain, then this will also include dispersed seeds from already re-colonised species. These species, such as *Senecio jacobaea* or *Sonchus oleraceous,* may not be desirable or typical components of chalk grassland swards, but have effective seed rain dispersal strategies. There is, for example, some evidence to suggest that the perennial forb content of the seed rain traps collected here was highest in the lanes disturbed by the tracked vehicle. These were treatment lanes with a higher proportion of perennial forbs in the seed rain, due to the sward compositional changes as a result of the disturbance. This may be the mechanism by which species characteristic of disturbance (e.g. *Melilotus altissimus*) persist in the sward long after the disturbance event has taken place.

The success of seed rain as a regeneration mechanism for bare ground is dependent on a number of factors, including distance from parent plant, concentration of parent plants, the ease with which seeds are dispersed and the amount of activity by distributing agents. In the majority of plant species, seeds shed from an individual reach the ground very close to the parent plant (Jefferson and Usher, 1989). Verkaar *et al.* (1983) demonstrated that many short-lived chalk grassland forbs have restricted dispersal distances of between 0.3 and 3.5m from the parent plant. Poole and Cairns (1940) found that 60% of seed shed from

Senecio jacobaea was recorded at the base of the source plant. Given the spatial heterogeneity of chalk grasslands, the absence from the seed rain samples of many species recorded at the site should therefore be expected. It is also possible that herbivory by small mammals may have reduced the number of occurrences of some species. However, there were no field signs of high herbivore activity, and any loss of seeds as a result of such activity would reflect the real-time post disturbance reduction in germinable seeds. In addition, the sampling technique for seed rain employed here is limited to the readily germinable component of the seed rain and probably underestimates the contribution from families such as Orchidaceae. It is likely that the number of seed traps used in this experiment was below the minimum sampling area for 95% probability of full species representation. Further experimentation with compost traps is needed to establish this.

Data presented here suggests a substantial number of species were found in all three of the surface vegetation, the seed bank and the seed rain (Table 6.1), and it is not uncommon for a species to be reliant on more than one mechanism for regeneration (Pakeman *et al.*, 1998). It is likely that the mechanisms of grassland development following disturbance are related to the size of the gap created by the disturbance event. Pakeman *et al.* (1998) suggest that on an acid grassland, gaps less than $5cm^2$ are more likely to re-establish from clonal expansion, and those greater than $7cm^2$ have a higher likelihood of regeneration from seed. Burke and Grime (1996) found that while the amount of bare ground created during a disturbance event greatly influenced the probability of successful establishment of 'introduced' species, in nutrient-limited calcareous grasslands even high disturbance rates did not release sufficient mineral nutrients for most invading species to develop past the seedling stage. As the relationships between size, frequency of creation and spatial distribution of gaps are likely to be important in determining patterns of recolonisation, further work is needed on how these aspects affect regeneration of bare ground on the Salisbury Plain Training Area.

Timing of disturbance

Seed dispersal is usually considered as a spatial phenomenon, but temporal factors also play an important role (Harper, 1977). Different species have different ripening times, and vary in the length of time seeds are retained before dehiscence. Peaks in germination rarely coincide with peaks in dehiscence (Thompson and Grime, 1979), and longevity of seed persistence and viability following release from the plant will be important in determining whether disturbance results in a suitable site for successful reproduction. Additionally, antecedent soil moisture conditions, one of the main precursors of disturbance intensity, are dependent on fluctuations in local meteorological conditions (Thurow *et al.*, 1995). This means that the timing of disturbance will affect the speed of sward closure and the character of post-disturbance vegetation. In a tracking experiment on Prairie grasslands, Wilson (1988) found that alien species were more likely to invade bare areas created by spring disturbance, and that spring tracking created more bare ground.

The greater part of wind-blown seed dispersal occurred on this site between July and August. Germination peaks are likely in early autumn and spring (Thompson and Grime, 1979). Replication of this experiment at other times of the year would be useful in order to increase further the understanding of the relationship between time of disturbance and community characteristics of regeneration.

Implications for management

Small-scale localised disturbances such as those investigated here are important for conservation management in a habitat where more traditional forms of intervention are restricted. Maintaining structural variation in a sward through a range of successional stages is one of the most important needs of invertebrates (Kirby, 1992). Bare ground and early successional patches in a tall grassland community provide valuable micro-habitats with warmer surfaces and a variety of food plants and types of shelter. For example, many threatened butterfly species of calcareous grasslands require vegetation in early stages of succession, including the Adonis blue (*Lysandra bellargus*) and the Silver-spotted skipper (*Hesperia comma*) (Thomas, 1983; Thomas *et al.*, 1986; Morris *et al.*, 1994). During a survey of disturbed areas on SPTA, a number of note-worthy carabid species were found to be associated with tall ruderal vegetation and bare ground, including *Harpalus schaubergerianus*, *Harpalus puncticeps*, *Harpalus cordatus* and *Amara curta* (Telfer, pers. comm.). A record was also made of the Red List species of tortoise beetle *Cassida nobilis* in such an area. The disturbance of these tall chalk grasslands by military vehicles therefore has wider benefits than purely mimicking grazing or mowing in order to prevent succession to scrub, but should not be at the expense of the conservation of 'intact' chalk grassland.

The large contribution of seed rain to habitat regeneration following disturbance, however, has important implications for the management of these grasslands at a local landscape scale. Chalk grasslands, especially those sampled here, are inherently spatially heterogeneous, with adjacent vegetation stands potentially only reaching 80 or 90% similarity (see the similarity coefficients recorded for undisturbed chalk grassland in Chapter 3, Figure 3.2). Species-area relationships are well documented, and in order to maximise the chances of full species recovery following disturbance, there will be a critical minimum size of grassland parcel from which seed rain can supply propagules for regeneration. It has already been demonstrated that the landscape of the Salisbury Plain Training Area is becoming increasingly fragmented (Chapter 2, Figure 2.8), and that the average size of grassland parcels is diminishing. This, and the associated edge effect of grassland fragmentation will decrease the probability of full species re-assembly of patches of bare ground if disturbance is left uncontrolled and unchecked.

6.5 CONCLUSIONS

This study has provided an unique opportunity to investigate the responses to disturbance of a high conservation interest grassland. Most seed bank and seed rain studies are carried out in order to assess the restoration potential of degraded sites, and equally, much restoration ecology research is based on event observation without understanding fully the functioning of a target community. This type of study provides invaluable insights into the functioning of a tall chalk grassland, giving those responsible for the management of the Salisbury Plain Training Area a more sophisticated appreciation of the likely outcomes of disturbance. Although the small-scale heterogeneity created by localised disturbance on Salisbury Plain encourages invertebrates and halts scrub encroachment, the long-term detrimental changes that may occur in the habitat as a result of unchecked disturbance may not have been fully appreciated. The extension of such studies to further habitats across other military training areas with conservation designations is imperative if defence land managers are to be successful in their implementation of integrated and sustainable land management plans and in meeting statutory conservation requirements.

7. HOW DOES MILITARY DISTURBANCE AFFECT TENANT FARMING ACTIVITIES? QUESTIONNAIRE AND INTERVIEW SURVEYS.

SUMMARY

Increases in the intensity of military training on the Salisbury Plain Training Area (SPTA) in Wiltshire, southern England, is necessitating a review of its management in order to meet statutory conservation obligations as well as military training requirements. This study investigates the impact of increased training activity on tenant farmers, a previously neglected group. Questionnaire and interview surveys were used to examine the attitudes of farmers who lease land on an active Ministry of Defence (MoD) army training area towards military disturbance. Responses suggest farmers are experiencing heightened levels of disturbance, and although systems for damage assessment and compensation are currently satisfactory on Schedule I land, there is increasing discontent among farmers about disturbance on Schedule III land. In order to secure both successful future management of the Plain and farming livelihoods, it may be necessary for the discourse between MoD and its tenant farmers to be reassessed.

7.1 INTRODUCTION

Post Cold War changes in the armed forces and UK military training

The end of the Cold War and the demise of the Warsaw pact in the early 1990s have led to many changes in the British military forces. A decreased threat of conflict saw the reduction of the UK armed forces and a partial withdrawal of troops from Germany. This lessening of international tension was coined the 'Peace Dividend' by many commentators who predicted a consequential down-scaling of economic inputs to the armed forces and the release of assets, including training areas, for other uses (Farrington, 1995; Woodward, 1996; Doxford and Hill, 1998). The 'Options for Change' programme (MoD, 1990) saw the reduction of the British Army by around 24%, the return of US military personnel to America, and the closure of many USAF[1] bases in Britain (Doxford and Savege, 1995). The release of parts of the defence estate was therefore primarily limited to the disposal of redundant RAF and USAF bases (Farrington, 1995). Troops previously stationed across continental Europe, numbering around 32,000, mainly comprised of

[1] USAF: United States Air Force.

armoured and mechanised infantry and artillery units. This put additional demands on the existing defence estate designated for army training purposes.

The intensity of use of the major UK military training areas such as Salisbury Plain, Castlemartin (Pembrokeshire) and Otterburn (Northumberland) has therefore been increasing since the early 1990s. Given the finite nature of training lands and the need of the armed forces to train realistically and safely with weapons of increased mobility, range and lethality, these UK training areas are under great pressure. Particular difficulty has arisen through decreased access to training areas in Germany that were designated for tracked vehicle training (Doxford and Hill, 1998). The impacts of this increased use of British military training areas have sparked debate as to the consequences for the economy and social structure of local communities, nature conservation, public access and archaeology. However, an additional but previously neglected interest group is that of MoD tenants farming land on military training areas.

The study area: The Salisbury Plain Training Area

The Salisbury Plain Training Area (SPTA) is the largest military training area in the UK, covering approximately 38,000 ha of southern central Wiltshire. Exclusive use of the area by the military since the end of the 19th century has protected much of the grassland from the kinds of changes in the countryside seen elsewhere during the 20th century, such as agricultural improvement, industrial development and urban expansion. As a result the training area is exceptionally rich in ancient monuments, and contains the largest known expanse of chalk grassland in north-west Europe. In 1993 around 20,000 ha of the SPTA were designated as a Site of Special Scientific Interest (SSSI) (English Nature, 1993).

Farming on SPTA

Despite its restricted public access land on the periphery of the training area is leased to 42 tenant farmers. This land falls into two categories:

Schedule I: This land is normally located adjacent to farms and villages on the extreme edges of the training area. Its value is annually assessed, and rented out to farmers at a nationally comparable rent. It is normally used for arable cultivation. Farmers are compensated by the MoD for damage that occurs on this land as a result of military disturbance.

Schedule III: This land is leased to farmers at low rents (an average of £8 an acre) and, extending far into the ranges, is used predominantly for rough grazing. Schedule III can also be used, under agreement, for ploughing consents. Compensation is *not* available for military disturbance on Schedule III land. Schedule III land falling within the boundaries of the SSSIs is also subject to conservation management agreements.

Grazing consents may also be allocated to farmers on the ranges. These are temporary licences issued as and when grazing management is required in that part of the training area.

In order to receive compensation for disturbance, farmers must first contact Defence Estates in order to have the incident assessed by a Land Agent. The Land Agent will then make a report to the MoD enabling the training area HQ to establish whether or not there were military units in the vicinity at the time of the disturbance. Once the disturbance has been shown to have originated from a military source, a payment can be made. The amount of compensation depends on the type of crop involved, and payment on the timing of the incident. Assessment of crop disturbance is often left until harvest when losses to the entire crop can be calculated.

Under the Schedule I and III system, the farming on and around SPTA is characterised by a combination of intensive arable production on Schedule I, and extensive cattle and sheep grazing on Schedule III. Crops grown include winter- and spring-sown oilseed rape, winter wheat, barley and occasionally oats. Cattle and sheep can be kept in permanent pennings by arrangement but are more commonly penned using temporary electric fences. Stock are usually housed during the winter and put out on the ranges during the spring and summer. Silage production is not allowed under the terms of the SSSI agreements. Some farmers cut grass for hay, and some make a hybrid known as 'haylage'[2]. This is an atypical farming regime in the normally intensive arable belt of the Wiltshire downs.

[2] Haylage: A cross between hay and silage. Cut at the same time as the hay it is not left to dry in the fields for so long, and bagged as if silage. This produces a wetter feed than normal hay.

Farming and the Peace Dividend

It is accepted that the so called 'Peace Dividend' has not resulted in decreased pressure on SPTA. Indeed, the reverse is true. Since the early 1990s, the training area has been used more intensively, especially for tracked vehicle training. Not only have numbers using the training area increased, but traditionally quiet and more peripheral parts of the area are being drawn into more regular usage. As a consequence of these changes, we would expect:

- increased interaction between the Army, farmers and local communities during active training exercises;
- increased disturbance on leased farmland;
- the issue of disturbance and compensation to be increasingly contentious.

Qualitative research involving the farming community has primarily focussed on attitudes towards environmental policy and conservation practice (e.g. Newby *et al.*, 1977; MacDonald, 1984; Carr and Tait, 1991, Battershill and Gilg, 1996; McHenry, 1996, among others). Few studies have investigated tenant-landlord relations, and formal structured surveys on the UK defence estate have been scarce. In addition, farming has until now been a relatively neglected aspect of the post Cold War management of SPTA. However recent structural reorganisation in the defence sector is likely to precipitate an increased interest in issues surrounding the management of military lands (Woodward, 2000). The objective of this study was to use a combination of questionnaire and interview surveys to test the validity of the above assertions and to establish the general feeling of SPTA tenant farmers towards military disturbance. This would indicate whether current or potential conflict in this sector should also be included in the already intriguing land use problem of how to manage SPTA for both military training and conservation purposes.

7.2 METHODS

Questionnaire survey

A postal questionnaire provided the most effective means of producing a baseline census of the opinions of all 42 SPTA farmers. An anonymous questionnaire was designed containing 26 primarily closed-answer questions contained in 5 sections (see Appendix 2). The questions aimed to establish:

(i) Facts and figures about the farm - acreage, length of tenancy and general location on SPTA;

(ii) Frequency and type of disturbance - types of disturbance on Schedule I and III; times when disturbance is more commonplace;

(iii) Investigating compensation on Schedule I - experiences of monetary claims for damage;

(iv) Disturbance and decision-making - does military disturbance affect decisions about land or the general running of the farm?

(v) Changes in disturbance - reactions to proposed increases in disturbance.

The questionnaires were accompanied by a letter detailing the purpose of the work and institutional affiliations, and a FREEPOST envelope for return. Subsequently, a reminder and a second FREEPOST envelope were sent out to encourage further returns. Responses were coded according to whether they represented the views of farmers from the West, Centre or East of SPTA. A second classification was used for acreage under Schedule I and III to differentiate between the experience of larger and smaller farms. The classifications used are detailed in Table 7.1.

Table 7.1 Classification of farms responding to SPTA disturbance questionnaire by acreage of Schedule I and Schedule III.

Land Class	Acreage	Code	Number of farms in class
Schedule I	0-249	1	7
	250-499	2	10
	500+	3	5
	No response	*	4
Schedule III	0-499	1	8
	500-999	2	6
	1000+	3	9
	No response	*	3

Closed answer questions in the questionnaire were integer coded for different classes of response. Open answer questions were collated under re-occurring themes used by respondents (see Weber (1985) for further explanation of content analysis). Chi-squared tests were used to assess differences in responses by location and farm size. Pie-charts and bar-charts were used to summarise responses.

Interview surveys

There are a number of advantages and disadvantages of interviews for the collection of qualitative data (Table 7.2). Primarily, they allow deeper exploration of an issue than questionnaire surveys and can be much more rewarding. Although time-consuming, both on the part of the interviewer and respondent, and often costly in terms of travel and subsistence, response rates are high and survey objectives and questions can be clarified face-to-face. Additionally, more time can be spent on subjects about which the respondent may have more interest or knowledge.

Table 7.2 Advantages and disadvantages of questionnaires and interview methods (see Oppenheim, 1992).

Questionnaires		Interviews	
Advantages	*Disadvantages*	*Advantages*	*Disadvantages*
• Relatively cheap • Relatively easy to analyse • Can survey large numbers • No bias of present interviewer	• Low return rate • Misinterpretation of questions • Limited range of questions/ responses	• Rapport between interviewer and interviewee. • More flexible • High response rate • Possibility for clarification(of question and response) • Greater depth and subtlety	• Time consuming • Costly (T&S) • Presence of interviewer may create bias • Less straight-forward to analyse

Subsequent to the questionnaire survey, an invitation to participate in an interview-based survey was sent to 26 out of 42 of the SPTA farmers. The 16 not invited were those who had stated a preference on the questionnaire not to be involved in this part of the study. It was stressed that non-participation in the earlier questionnaire survey did not exclude participation in this part of the study. The invitations were accompanied by an explanation of the aims of the study and a summary of the results of the questionnaires, with the intention of raising participatory interest in the work. A cut-off reply slip was provided, with a FREEPOST envelope for return. Additional options were given of replying by phone, fax or email.

Twelve farmers responded positively to the proposal of being interviewed, either by returning the response slip at the bottom of the invitation letter, or after being approached directly via a telephone request. This represented 28.6% of the population. A list of those who had volunteered was presented to the Defence Land Agent who considered it to be a good spread of the different types of farmers currently leasing land from MoD on the SPTA.

There were three probable reasons why more farmers did not volunteer to participate in the interviews:

(a) Too busy – the interviews were conducted during February, partly to fit in with schedule of the research project, and partly because this was deemed to be a relatively quiet time of year for farmers. However, farming is a year-round activity and farmers can be busy at most hours of most days.

(b) 'Survey saturation' – during the course of the interviews it transpired that the farmers in this area are frequently approached by people conducting some kind of survey or another, ranging from GCSE coursework projects to MAFF surveys. Although the purpose of this particular piece of work was clearly stated, there was no reason to assume that farmers would choose to participate in this piece of work over another.

(c) Wariness and privacy – interviews by their very nature are intrusive in that they seek to extract information from a person. This is not necessarily an activity with which all people will feel comfortable, regardless confidentiality statements. Equally, the issue being investigated here was essentially that of landlord-tenant relationships, and anxiety about not wanting to upset this relationship may have discouraged participation.

The interview surveys were designed to investigate in more detail particular issues raised by both the questionnaire survey and the Defence Land Agent. These topics covered:

(a) Schedule I disturbance: How much of a nuisance is this disturbance and is the compensation system working?
(b) Schedule III disturbance: Compared with Schedule I, how much of a nuisance is this disturbance?
(c) SSSI management: How much does this affect management of Schedule III?
(d) Land restoration: Is there support for farmer-led restoration?

The interviews were conducted during February 2000 at a time and place agreed between the interviewer and the farmer, usually the farm on SPTA. The same interviewer conducted all the interviews. Interviews usually lasted about an hour. The shortest session was curtailed after 30 minutes due to the arrival of a MAFF vet. The longest session lasted about 3 hours, and included an excursion around the interviewee's Schedule III land.

The interviews were analysed using content analysis (Weber, 1985). Responses in the interviews were collated thematically in order to assess the range of attitudes towards each issue.

7.3 RESULTS

General overview of questionnaire results

Response to the questionnaire was considered to be good - 26 questionnaires were returned (61%). Just over three-fifths of these were returned non-anonymously (Figure 7.1). This may imply a relatively high degree of confidence on the part of the respondents towards the credibility of the study and the issue of confidentiality. The distribution of respondents between the West, Centre and East (Figure 7.2) were close to the distribution of all SPTA farms (41%, 23% and 35% respectively) and therefore non-response probably represented no geographical bias.

Acreage of Schedule I rented by respondents ranged from 40 acres to 1000 acres, with a mean of 370 acres. Schedule III acreage ranged from 55 acres to 2500, with a mean of 840. It was felt therefore that the responses received came from a good distribution of large and smaller farms.

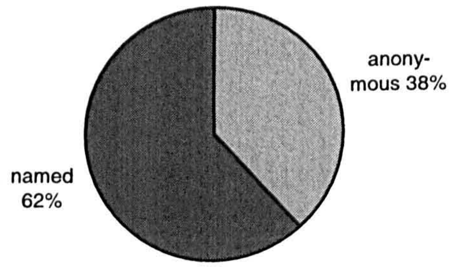


Figure 7.1 Percentage of SPTA disturbance questionnaires returned anonymously or named.

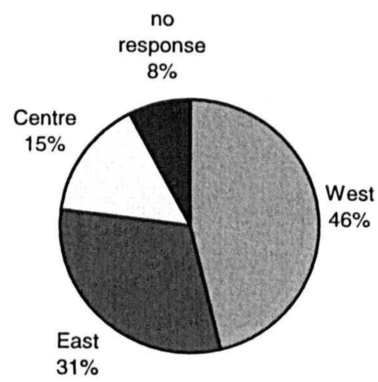


Figure 7.2 Response to questionnaire by farm location on SPTA.

Summary of questionnaire responses

Frequency and type of disturbance

Questions about frequency and type of disturbance focussed on that which had occurred in the year prior to the survey, to avoid ambiguity. The vast majority (84%) of respondents had experienced military disturbance on their land during 1998, although 12% had not (Figure 7.3). This disturbance was predominantly on Schedule III land, or a combination of Schedule I and III (Figure 7.4). There were no farms where disturbance was reported as having occurred exclusively on Schedule I land, and Schedule I disturbance, compared to that of Schedule III disturbance was uncommon. The Schedule I disturbance reported in this study was equally split between vehicular disturbance and damage to walls, fences or hedges (Figure 7.5). Other types of reported disturbance included cases of damage to crops by infantry troops. Schedule III disturbance was dominated by vehicular disturbance, with about one-third citing damage to field boundaries and other types of disturbance. In the 'other' category, two farmers reported the digging of slit trenches.

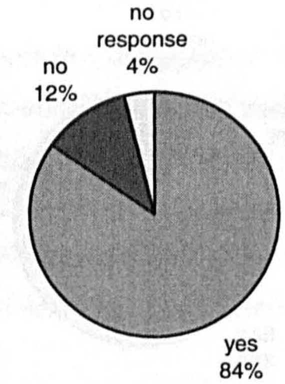


Figure 7.3 Was there military disturbance on your SPTA leased land in 1998?

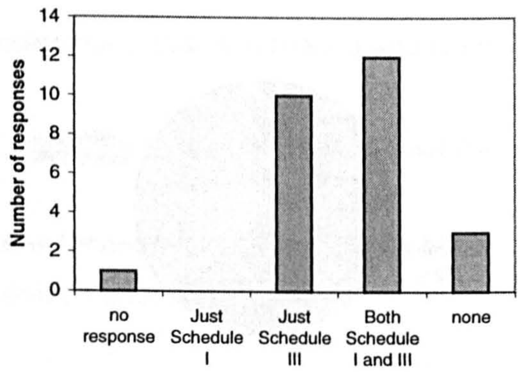


Figure 7.4 On what type of land was this military disturbance on SPTA?

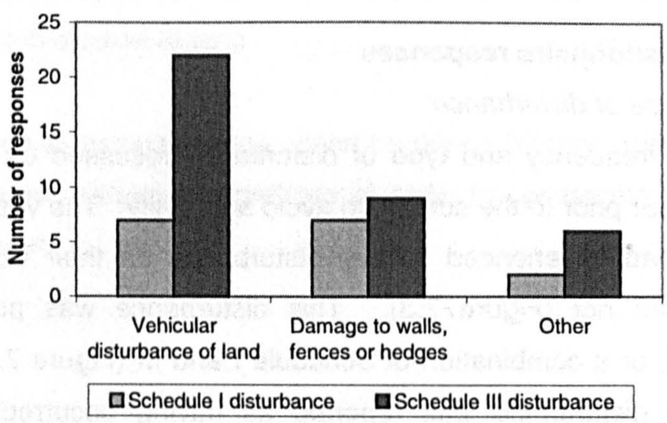


Figure 7.5 What was this military disturbance?

There was little agreement amongst respondents as to whether disturbance was more common at certain times of year than others, with reasonably equal proportions answering 'yes', 'no' and 'not sure' (Figure 7.6). Even those who thought that disturbance was more common at certain times of year failed to agree as to when this time was, although there was a small bias towards spring and summer (Figure 7.7). Farmers are outside more frequently and for longer periods of time in the spring and summer, and therefore are more likely to notice the disturbance.

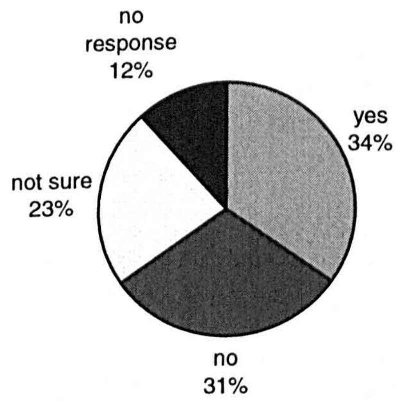


Figure 7.6 Does military disturbance on SPTA occur more at some times of the year than others?

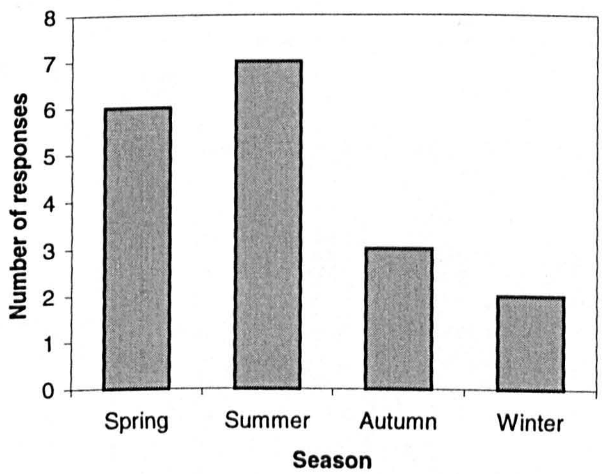


Figure 7.7 When is there more disturbance on SPTA?

The majority of respondents (61%) felt that there was no particular time of day when disturbance was more likely than others, although this was probably dependent on the times of day when the farmer was outside on his or her land (Figure 7.8). All those who responded positively to the question regarding daily peaks in disturbance said that Schedule I disturbance was more likely to occur at night. As this is the time when tanks and foot soldiers are more likely to lose their bearings or not see signs indicating Schedule I, this was perhaps not an unexpected response.

Over half of the respondents (54%) felt that disturbance had been getting worse (Figure 7.9). One farmer commented that, *'. . . there's been a big build-up over the last 5 years.'* No one thought that it had been less than normal and only 4% were not sure - the lowest percentage for a 'not sure' response in the questionnaire. These responses confirm the hypothesis that the farming experience of disturbance on SPTA is real and likely to be increasing, and therefore is more likely to impact on the everyday activities of the farming community.

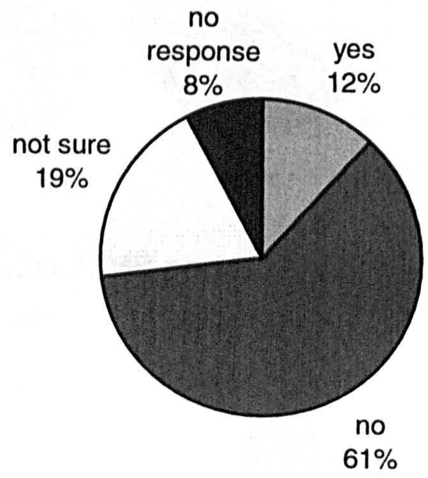


Figure 7.8 Does more disturbance occur on SPTA at certain times of day?

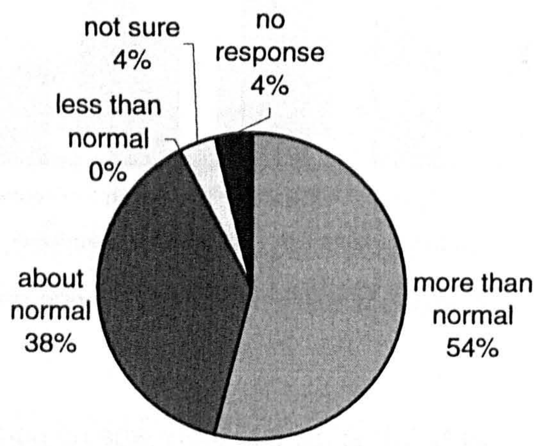


Figure 7.9 How does 1998 disturbance on SPTA compare to that of previous years?

Investigating compensation on Schedule I.

This section prompted a much smaller response than had been anticipated. Just over three-quarters of respondents had experienced military disturbance on Schedule I at some point in time (Figure 7.10), but nearly half of these people had claimed for between none and 50% of incidents (Figure 7.11). This was surprising as the presumption was that the majority of farmers would apply for the funds to which they were entitled. Additionally, the length of time between submission of a compensation claim and receiving the money was very variably reported by respondents, ranging between a couple of weeks to a maximum of 15 months. A typical response was 'several months'.

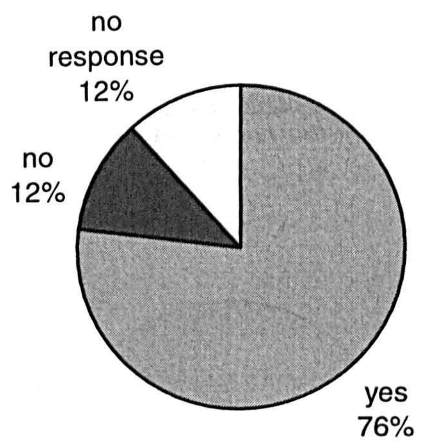


Figure 7.10 Proportion of respondents having experienced Schedule I disturbance on SPTA.

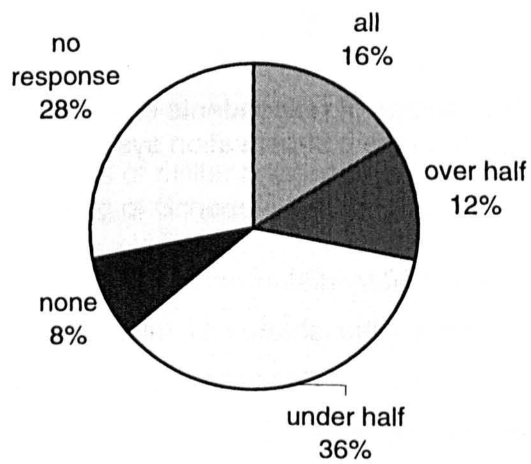


Figure 7.11 Proportion of disturbance incidents on SPTA for which compensation was sought.

A large proportion of respondents did not answer the question regarding satisfaction with the compensation system, and there was no significant difference between the number who were dissatisfied and those who were content (Figure 7.12), although slightly more fell into the latter category (35% satisfied against 27% dissatisfied). A common complaint of the system was the length of time between submission and payment: *"The system takes far too long"*, wrote one farmer, and another suggested that, *"...we should be compensated when damage occurs, not wait for it to be* *assessed at harvest."* Other suggestions as to how the system could be improved included the provision of materials or assistance to repair damage as a compensation alternative, and the concept of 'goodwill payments'. One farmer suggested that MoD should:

> *". . . give authority to the person who assesses the claim to pay it - a 'goodwill' payment (with no 'strings') would often be much more satisfactory than the full claim. For a £50 or so claim the paperwork must cost more than the claim itself!"*

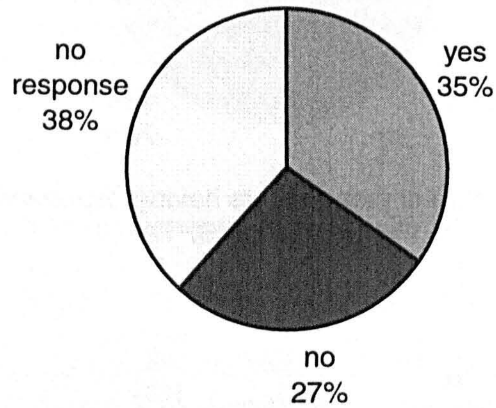


Figure 7.12 Percentage of respondents expressing a preference for changes in the compensation system on SPTA.

Farm decision-making and military disturbance.

Farmers were asked whether the chance of military disturbance influenced their planning of Schedule I and III land. Responses implied that the possibility of military disturbance on Schedule I played very little part, if any, in deciding how to use the land (Figure 7.13), but in contrast, disturbance on Schedule III was a strong consideration. When asked to elaborate further on these responses (Figure 7.14), farmers rated the vulnerability of Schedule III land to disturbance quite highly. A number of farmers also mentioned that the SSSI management agreement determined their use of Schedule III as much as military considerations. Farmers made comments such as *"we have to comply with conservation policy"* and *"the Schedule III management plan imposed by MoD restricts the use of fertilisers and sprays".* Some farmers felt that the amount of disturbance was not high enough to affect their decision-making at all, and one said that in his view, *"the Schedule III is primarily for army training so we have to expect it".* With this acceptance of disturbance, there were indications that farmers are adopting their own strategies for coping with the disturbance:

> *"Schedule I disturbance is not enough to alter our planning but on Schedule III we obviously try to minimise disruption to crops and stock by assessing the current military activities."*

> *"We grow spring barley rather than winter wheat to avoid damage [when the crop is young]."*

> *"We put set-aside around woods constantly used for training."*

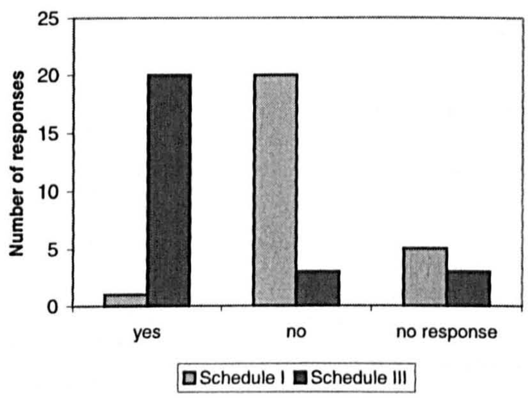


Figure 7.13 Does the chance of military disturbance on SPTA affect the land use planning of Schedule I or Schedule III?

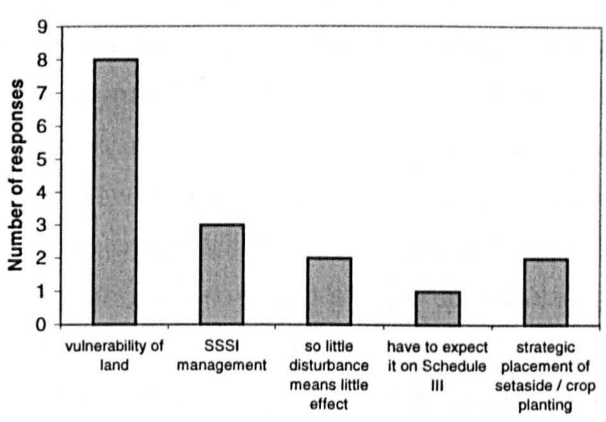


Figure 7.14 What factors affect land-use planning on SPTA farms?

Over half of the respondents (54%) felt that there were times of the year when crops or stock were more vulnerable (Figure 7.15), but when this time was varied from farm to farm, due to the particular stock or crops under production (Figure 7.16).

Surprisingly few farmers responded that the ground was more vulnerable to disturbance when wet. *"Nearer to harvest"* was a popular answer because there is little chance for either re-growth or rectification of physical damage towards the end of the growing season. However, others felt that crops were just as vulnerable when recently germinated or early in the growing season.

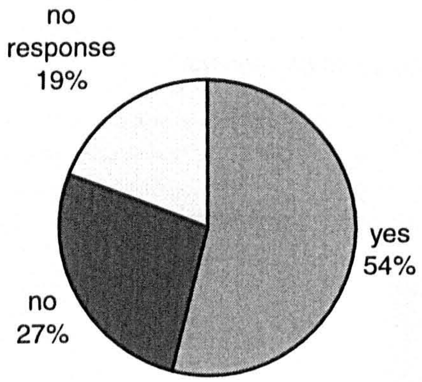


Figure 7.15 Are there certain times of the year when crops or stock are more vulnerable to disturbance on SPTA?

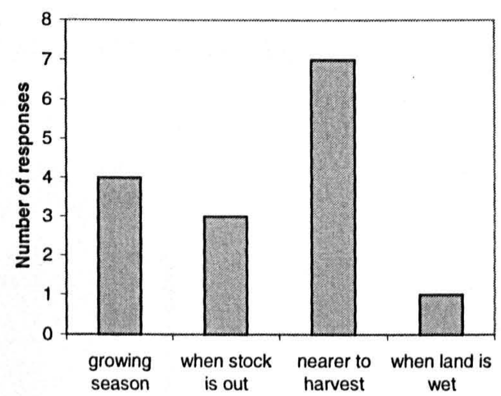


Figure 7.16 When are crop or stock more vulnerable to military disturbance on SPTA?

With regard to tolerance of disturbance, nearly three-quarters of respondents said that at current amounts and with the current compensation system, the disturbance that they experience was bearable (Figure 7.17). Nearly all of those who said that it was tolerable agreed that disturbance was an inevitable part of renting land on a military training area (Figure 7.18). However, fewer agreed with statements regarding unaffected profit margins or job satisfaction; around 70% those who are currently tolerating disturbance believe that there is some loss of profitability and/or job satisfaction. The most common stated reason for disturbance being intolerable (19% of respondents) was a loss of job satisfaction (Figure 7.19). None of those who responded believed that there should be no disturbance at all if they were paying MoD for the land.

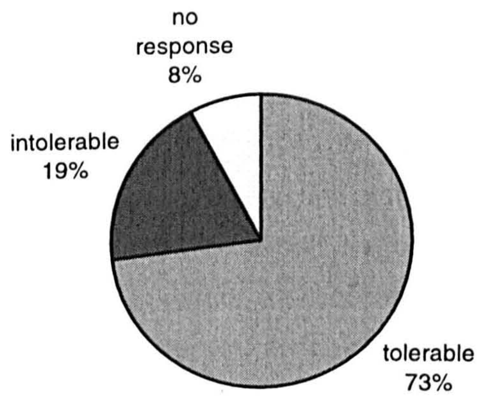


Figure 7.17 Is disturbance on SPTA currently tolerable?

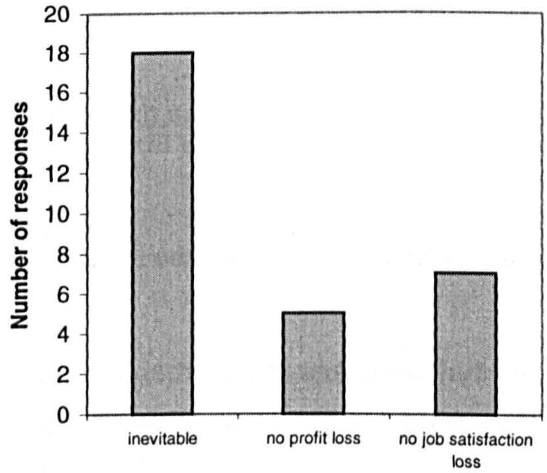


Figure 7.18 Why is disturbance currently tolerable?

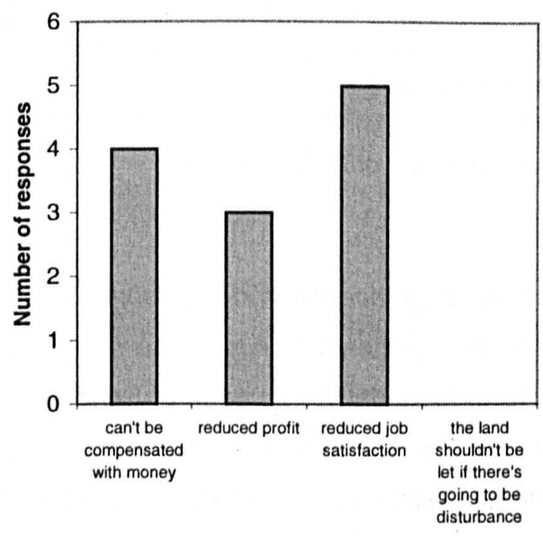


Figure 7.19 Why is disturbance currently intolerable?

Changes in disturbance

This short section asked whether increases in disturbance would be acceptable or unacceptable. A surprising number (nearly one-fifth) of respondents left this question blank (Figure 7.20). However, 73% of farmers felt that this would be unacceptable, whereas 8% felt this would be acceptable. The most common comment made by those who felt increases would be unacceptable was that they considered Schedule III land to be on a threshold between sustainable production and non-profitability, and any increases in the amount of disturbance experienced on these leases would decrease profitability:

> *"Due to tank damage and SSSI restrictions our Schedule III land would be unprofitable [with increased disturbance] as it is at present only poor rough grazing - too poor to cut for hay or silage."*

> *"At the moment it is tolerable but bordering on the intolerable. If I have many more tracks created by tanks, lorries or Land Rovers, I shan't have any grass left to graze!"*

> *"Penning up animals more frequently would be a nightmare, as would [more] vehicle damage."*

Some of those who felt that increases in disturbance would be acceptable, or who left the question blank qualified this with statements such as:

> *"It would depend on various other factors such as the amount of land that was available."*

> *"It all comes down to the level of damage - are you allowed to fix the damage e.g. on ploughing consents where [if you don't fix it] the damage gets worse and then the army stops worrying about it being a mess."*

> *"If you don't like the heat, get out of the kitchen."*

Statistical bias of responses by location and farm size.

There were no statistically significant trends in the responses of farmers to certain questions, neither by farm location nor acreage of Schedule I or Schedule III (Table 7.3). This suggests that the experience of military disturbance on farm land, in terms of these questions answered, was independent of where a farm was located on SPTA, and the acreage leased.

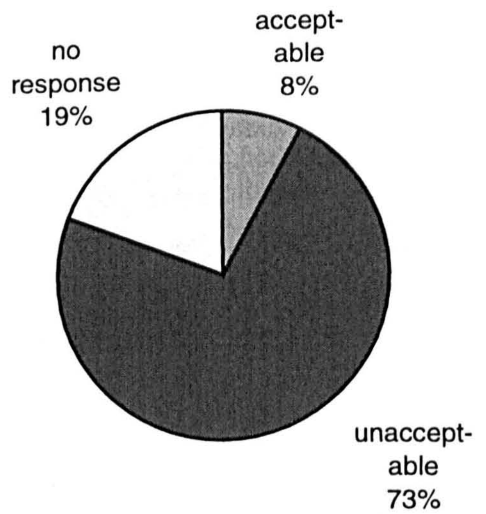


Figure 7.20 Would an increase in military disturbance on SPTA be acceptable or unacceptable?

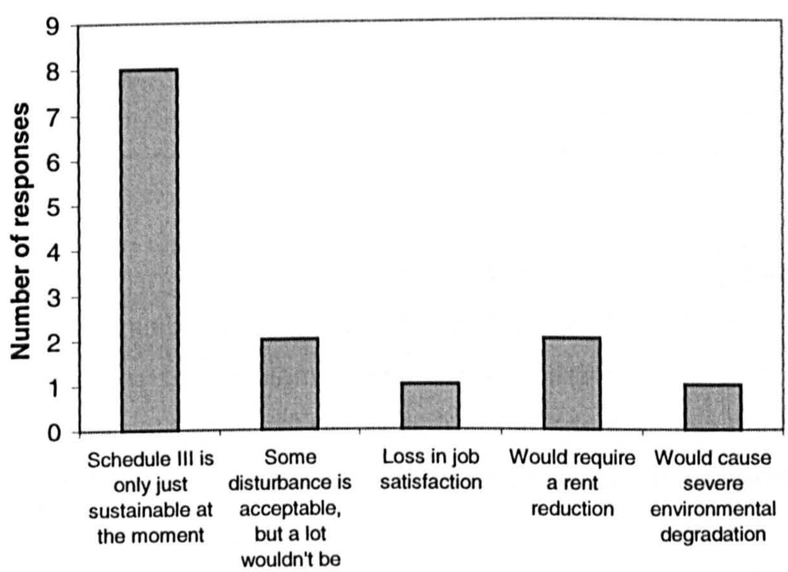


Figure 7.21 Why would an increase in military disturbance on SPTA be unacceptable?

Table 7.3 Results of Chi-Squared (χ^2) tests on responses to certain questions by location and size of farm.

Factor	Location (W,C or E)			Acreage Schedule 1			Acreage Schedule III			Length of lease		
	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p
1998 disturbance (Y/N)	1.9	2	ns	2.79	2	ns	0.73	2	ns	0.78	2	ns
Daily peaks in disturbance	1.09	4	ns	5.11	4	ns	4.67	4	ns	6.43	4	ns
Recent increases in disturbance	2.8	4	ns	1.65	4	ns	1.25	2	ns	3.39	4	ns
Proportion of compensation claims made	4.82	6	ns	4.04	6	ns	6.9	6	ns	5.03	6	ns
Tolerance of disturbance	0.15	2	ns	0.26	2	ns	2.84	2	ns	0.04	2	ns
Attitude towards proposed increase in disturbance	1.81	2	ns	3.95	2	ns	1.05	2	ns	3.33	2	ns

Summary of interview survey responses

Frequency of Schedule I disturbance and compensation claims

Responses from the questionnaire survey implied that military disturbance on Schedule I land was rare and of low concern to the tenant farmers. Almost all those interviewed confirmed that either there had been no disturbance of this kind on their Schedule I land, or it was insufficient to be a worry, and that there had been no significant increase in Schedule I disturbance over recent years:

> *"Apart from the odd fence, we've had no disturbance on our Schedule I, although we don't actually have that much anyway. We've never made a claim for compensation."*

> *"Schedule I disturbance is minimal. Vehicles venturing onto our land usually realise fairly quickly, and normally they haven't got very far before they turn around. The only difficulty is that they rarely go out of the field in the same place that they came in!"*

The questionnaire surveys showed that few farmers actually claim for disturbance compensation on Schedule I. Non-adoption of this scheme was revealed to be due to farmers never having had any disturbance on Schedule I, as above, or through a disinclination to claim, for a number of reasons. For example, farmers sometimes write-off 'small' events as not being worth reporting, given the time and paperwork that the process requires:

> *"The palaver it takes to get a claim through the land agent, who has to consult Defence Estates, etc. etc. is a disincentive to try."*

> *"Unless an incident was valued at over £100 I think that I'd be very unlikely to claim for it. There's a degree of stoicism. The amount of protocol means that if you want to stay on good terms with MoD you tend not to make a fuss."*

Equally, a number of the farmers said that they were worried about affecting their relationship with MoD by making claims for financial compensation. Many of the tenant farmers treat the MoD with some deference:

> *"It's a PR thing – the land at the end of the day belongs to MoD. Usually the damage isn't that great a thing so it's not a problem to me and I don't claim."*

> *"It's a highly political situation. MoD has a powerful machinery and if you dare to say what you think, then you can make yourself very unpopular."*

Nevertheless, the implication was that if disturbance was to become a more frequent event, or events of greater intensity, then more farmers would feel prepared to make a claim for compensation. This willingness to claim may also be precipitated by other external forces, such as rent rises. One farmer said:

> *"Until last year I never claimed for any of the Schedule I disturbance because it just didn't seem worth it. Now, though, with the rents going up and up, I'm claiming for everything."*

Possible improvements to the current system

The amount of paperwork and time delay involved in making a compensation claim were the main stated reasons for non-adoption of the compensation system, and these were the areas most frequently suggested for improvement. The speed of processing claims was said by a number of the farmers to be most important where stock were involved. A previous system, for example, allowed farmers to mend damaged fences and then submit a claim for the cost. Now, the damage has first to be assessed, creating the problem of what to do with the animals in the intervening period. One farmer said:

> *"I remember a time when a tank had taken down one of my fences and there were cattle loose. I mended the fence because my cattle needed to be fenced!*

> *MoD threatened me with non-payment of the compensation claim because I wasn't a registered contractor. I wasn't best pleased."*

This statement also suggests a slightly over-rigid system that fails to accommodate claims on a case by case basis. Another farmer commented that '...*the system works quite well, just as long as you can find the green paint*[3] *on the gatepost that's gone down...'* Bureaucracy such as this may be why many of the farmers rarely make claims, yet had ideas for areas of possible improvements.

During the questionnaire survey a couple of respondents had suggested that an appropriate alternative to the compensation system might be for MoD to provide the farmers with material or labour rather than cash. One of the farmers interviewed implied that this already happens:

> *"The last damage I can think of was when some fence posts came down. MoD provided some new posts and I put them in myself. I'm not sure that I've ever had any money compensation so I can't really comment on that."*

One farmer however thought that this would not be something he would encourage:

> *"I don't think providing materials would be a good idea because they'd [MoD] start to cut corners and not replace like with like. I'd want to know that the job's been done as well as I would've done it."*

Another suggestion made was to give land agents authority to pay small claims to speed up the process, especially if disturbance incidents were to become more frequent in the future.

The dilemma faced by many farmers is that they fear that claiming for damage on Schedule I will damage their relationship with MoD. One farmer wanted there to be an ombudsman who could intervene on the part of farmers without disrupting relations with MoD, as well as more public scrutiny of the system to enable a wider appreciation of the type, frequency and cost of disturbance events. In an ideal world, there is no reason to think that farmers would be judged for making claims for compensation as they pay full rents for this land, and the compensation system has been running for many years. However, given that so many of them do not claim, it does imply that this is could be a problem area. Partly, this may be due to individual

[3] Green paint: i.e. prove that it was a military vehicle responsible for the damage.

personalities, in both farming and MoD; one farmer interviewed had a second farm, also on MoD land, but under the auspices of a different land agent. He said that in comparison, the SPTA office had a tendency to be much more laborious in its affairs.

Schedule III disturbance

Compared with the issue of Schedule I disturbance, Schedule III disturbance provoked a large response from the farmers. Most of those interviewed agreed with the questionnaire result that the number of tracks and the amount of disturbance had increased in recent years:

> *"I've been here for 8 years now and back then the tracks were about half what they are now. The new stone tracks do improve my access to the range though."*

> *"It's been busier even in the last year, but we've stepped up our winter grazing so we've been out there more."*

> *"More recently the problems have definitely been getting worse. I've lost a number of permanent pennings and changes up at [place-name] have meant that access and disturbance on some of the Schedule III has worsened."*

All of those interviewed said that the amount of time and resources used in remedial activity, and the stress and loss of job satisfaction, that disturbance on Schedule III land causes, is not given high enough priority by the MoD. The two main issues were damage to fences and the physical disturbance of land.

Damage to fences

Most farmers who electrically fence herds on the ranges have to check these fences once or twice a day for breaches. One of the farmers interviewed, with a high acreage of Schedule III, employs a school leaver solely to check and mend these fences, as well as going out everyday to check the fences himself. This particular farmer felt very strongly that although it was MoD land, the fences were his, and their perpetual damage was a great annoyance. On the other hand, one of the farmers with a smaller acreage said:

> *"The breaking of an electric fence takes about 10 minutes to mend, and because the rent's so low, I'm not actually that bothered about the cost."*

Therefore, the degree of nuisance the farmer perceives is likely to be related to how much of this type of damage he or she experiences, or the acreage of land in question. However, broken fences rarely affect just one farm:

> *"Loose cattle can be a real headache. You can be up until 3am trying to get them in again. Around once a month either your or your neighbours' cattle will be out. There are no fences on SPTA and when there's a break, heifers can get 5 or 6 miles from where they're supposed to be before they're caught. A cow out on SPTA is a 'drop everything and run situation' and you have to call upon your neighbours for help."*

> *"Our biggest problem has been our neighbour's cattle getting out onto our ploughing consent. His sheep almost wiped out a crop of oats."*

Some concern was expressed as to the potential impacts that an increased use of the SPTA may have on breaches of fences:

> *"I'd be afraid that the disturbance on Schedule III will increase more. We used to see just one tank a year, but there again we used to spend more time than we do now rounding up cattle. Perhaps it's due to us farming better, with better cows and fencing. I remember chasing cows almost all the way to Warminster!"*

There are additional problems associated with fence breaches. One farmer described how during an outbreak of *Campylabacter* in his herd, the vet had advised separating the cattle into a clean- and dirty-herd. However, when the fences between them were broken, there was no way of telling which was which without re-testing the whole herd.

Physical disturbance of land

Most of the farmers complained that the damage done to Schedule III land by tracked vehicles persists long after the vegetation has 'greened over'. Making hay on these rutted areas is hampered by the difficulty of getting cutting equipment over the land. Some contractors refuse to take their machinery onto the area for fear that it will become damaged.

> *"We don't make any silage because of SSSI restrictions, but we do make some hay and haylage. We do this on the smoothest of our land but that's becoming less and less."*

> *"Making hay on rough ground can also be a problem because discarded metal can end up in the mower. We did have a lovely big flat ley up at Everleigh but within 10 years it was unusable."*

Additional restrictions on Schedule III

Many of the SPTA farmers have had some form of conservation management agreement with English Nature (or its predecessors) for some time, and most consider these not to have greatly changed their approach to land management. Some said that their Schedule III was so rough or steep (or included ancient monuments) that SSSI restrictions had hardly impacted at all. However, although each was manageable separately, some said that the combination of military disturbance and SSSI restrictions on Schedule III made farming these areas quite difficult:

> *"The physical damage is not as bad in my view as the external restrictions like the SSSI regulations – they're a very strict set of rules."*

> *"We get no compensation for having to change our farming techniques – the regulations are foisted upon us and it doesn't feel to me to be a system that 'works with the farmer'."*

And there was the minority which, from the farming standpoint, saw little point in the SSSI designation:

> *"As far as I can tell, the SSSI agreements don't make better grassland."*

But despite the restrictions, most of the farmers were sympathetic to the concept of SSSI management and conscious of the ecological importance of Salisbury Plain:

> *"I'm really quite proud of all that variety out there. I do like to see those orchids."*

> *"When the management agreements came we were scared stiff! But actually much of it hasn't changed things that much, and it's just a case of having to adjust to that change. The SSSI agreement says I can graze one beast an acre but when I saw a cow eat an orchid on Cheverell Hill, right in front of me, I decided myself to take them all off!"*

> *"I am sure that without the grazing we have on the SSSI land, the flora wouldn't be as good as it is. We have to do some brush clearance which also helps to keep the rabbits down – anything that keeps the rabbits down is good."*

The SSSI designation for SPTA affects the management of Schedule III in two main ways: restrictions on spraying and controls over grazing.

(i) Chemical spraying

Spraying controls, especially of herbicides, greatly concerned all those interviewed. There is a particular problems with ragwort (*Senecio jacobaea*) on Salisbury Plain as it regenerates easily from a large persistent seed bank following disturbance. Native and increasing, ragwort is a designated injurious weed as it can kill cattle and horses if eaten in quantity, and landowners are legally required to remove it. Therefore, for the SPTA farmers, there are two problems in one – not only does military disturbance produce rough ground, but it also encourages the spread of a noxious weed. Ragwort is normally controlled by spraying, but this is against SSSI restrictions, so the two methods available to farmers for controlling this weed are pulling and topping. When abundant, these methods of managing ragwort are not straightforward:

> *"The family thing is to pull any ragwort we see, where ever it is! But however much you pull it, it comes back. I think some of it must blow in from my neighbours' farms."*

> *"In this day and age of selective weed killers, I'm sure that there must be something we could use in the SSSI. Every year we lose 2 or 3 cows for no apparent reason, and sometimes we wonder whether that's from the ragwort."*

Topping is considered too laborious and ineffective, as cattle will avoid the plant when it has flowers, but will eat it when it has not. One farmer had been advised by an organic farming group to organise a 'pulling party' whereby he could recruit local volunteers to pull ragwort in return for a meal. A mechanical ragwort puller has been trialled on the Salisbury Plain but after travelling for about 15 yards, the machine was reported to be full up.

Most of those interviewed commented that the ragwort problem had been worsening over the last few years, probably due to ineffective alternatives to spraying, wet summers and increased disturbance. However, uncontrolled spread of ragwort may not be entirely due to the SSSI restrictions on spraying. There has also been a shift away from sheep grazing on SPTA to a greater prevalence of cattle grazing. Sheep can, and will, eat ragwort, thus providing an effective means of control:

> *"Until about 4 years ago we had a couple of thousand sheep on the ranges which was good for the ragwort. But we were spending 16 hours a day, 7 days a week having to round them up when a fence came down, so we gave up on them."*

> *"Ragwort used to be better controlled on our farm because my father was more sheep oriented. Sheep will eat it no problems. We're probably going to change to accommodate for more sheep – but it won't happen overnight."*

The difficulties associated with sheep farming on the Plain, especially maintaining the low unit value and the effort expended maintaining fences, mean that farmers on the whole are reluctant to return to large-scale sheep production. One farmer commented:

> *"Where there's sheep grazing, it's [ragwort] not so bad, and we do hand pull some of it. But they should be paying us to graze it: the cost of fencing and labour to put some sheep out for a week is greater than the value derived from the grazing."*

(ii) Grazing regimes

SSSI restrictions also affect grazing regimes. There should be no winter forage, which in combination with fertiliser restrictions have reduced stocking rates for some of the SPTA farmers by up to a half:

> *"We used to keep the cattle out all winter but now we have to use the bottom field which gets trodden and wet. The downland that's now SSSI stayed dry and was less prone to waterlogging. The 30 years of grazing we did on what's now SSSI never seemed to harm it."*

> *"We used to put the cattle out in winter. Up until January they were moved around so there was no particular damage. From January to mid or end of March there would be no grass left so I used to put them on some 'old' downland and took silage out to them. The same 20-30 acres got messed up every year and I would re-seed it. That was stopped. Now, I have to put the cattle on some Schedule I which is later put into a spring crop. Because this isn't in grass, the cattle are up to their hocks in mud, and are not happy cows at all."*

Additionally, in SSSI agreements 50% of ploughing consents are granted only for spring crops. One farmer thought this a great inconvenience:

> *"March and April are a very, very busy time. We have spring calving and the previous year's calves are being prepared for a big market in May. The spring crops are a big hassle because there's already too much to do in the spring. These types of crops are less profitable on this farm anyway..."*

Land restoration

In the past, farmers were able to restore severely disturbed Schedule III land by harrowing, but this system was stopped because an ancient monument was accidentally damaged (Defence Land Agent, pers. comm.). Farmers greeted the idea of re-starting a scheme of active land restoration with caution, implying that the extent and severity of rutting on parts of the SPTA would require more substantial remedial action than plain harrowing:

> *"[restoration] would be a good thing because it would maintain the usefulness of the land. But it would mean really quite big machinery would be needed though, because much of the damage would be beyond a plough or harrow."*

Some envisaged that restoration would be beneficial because immediate action could be taken, before the disturbance had greened over, rather than having to wait for a designated team to be mobilised. However, many said that strict guidelines would be necessary, to prevent the re-seeding of freshly harrowed sites, or to restrict the timing of harrowing so as not to disturb ground-nesting birds. Many said that although it was a good idea in theory, in practice they would not be able to afford to restore land themselves. Indeed, one farmer said:

> *"Farmers shouldn't have to do it [restore land] because technically it's not their land, and they didn't cause the disturbance."*

Another pointed out that:

> *"Some parts of the down are rough anyway, and some are ancient grassland – you wouldn't expect to get to harrow them. But if some restoration was allowed it would be a step in the right direction. If the number of vehicles on SPTA increase then it may be necessary anyway."*

It would appear that a number of farmers are already attempting land restoration in areas not covered by the SSSI agreements. One farmer reported having hired a bulldozer to flatten ground, which apparently was costly, but worked. He thought, however, that a disc-harrow would be more effective. Another had tried power-ploughing which again was costly and time-consuming, but had had the desired effect.

Communication between landlord and tenant

The farmers interviewed made a distinction between communication with MoD regarding the interface between military training and farming, and that about purely agricultural matters. Most acknowledged that this was a very unusual landlord-tenant situation, and that they faced problems that 'normal' farmers would not necessarily have to face. Generally, the farmers work comfortably alongside the Army, adapting practices as necessary:

> *"I just get on with farming my land and I'm not bothered by MoD. I think if people weren't used to it and were new to the area they'd find it very difficult. I've learnt to live with it though."*

> *"It's been much more hands-on since Jelfs [Commandant HQ SPTA] arrived. We used to have 'state visits'. The Commandant has a designated Land Rover and when he sees you he'll stop and chat."*

> *"MoD are reasonably responsive. We were once herding cattle down a track and we met some marines route marching who didn't get out of the way of the cows, so the cows scattered and went through the fences. After we complained, MoD got a proper apology from those involved."*

But an appreciation of the requirements of military training by the farmers does not necessarily mean that they are immune to the aggravation it causes to them. Two separate farmers described the same incident when a frustrated neighbour had reported excessive tank disturbance on Schedule III to the land agent. Apparently, the land agent:

> *"...just laughed, saying, 'it's Schedule III and there's nothing you can do about it.'"*

If this is a true account of events, then there is clearly room for improvement in mutual relations between the MoD and their tenant farmers; feelings of frustration should be dealt with appropriately. This farmer summed up the dilemma:

> *"We accept the gamble that is the decision to do anything on Schedule III but it doesn't mean that I don't get upset and depressed when I see a field trashed, be it wheat or grass."*

And with respect to the agricultural side of the tenancy, farmers were divided as to the benefits of being an MoD tenant. One farmer said:

> *"I know people with other landlords that are much more restrictive in the agricultural terms of the tenancy. This works out as quite a cheap farm to run, and to be honest, I think it would be hard to find a better landlord. I do feel though that they're not necessarily interested in the farming on the land, just the estate."*

Alternatively:

> *"The system's full of bureaucrats. We farmers are being policed by so many people. There are additional problems faced by the MoD tenants – ordinary farmers would just be dealing with MAFF. When environmental policy and military needs are constantly changing, it does all seem quite an inconvenience. It just gets you up the wrong way!"*

Farmers did question the quality and quantity of communication with the land agent. A rapid turnover in land agent staff, acknowledged by the land agents themselves, means that there is little opportunity for a rapport to develop between land agents and tenants, or for the acquisition of a local knowledge-base as to the particular circumstances of each farm. There was a feeling of dissatisfaction about the detachment with which problems were handled:

> *"People come and go very quickly. No one takes a personal interest in you any more."*

> *"The quality of communication with our landlord has deteriorated. In the old days the land agent would've had a particular patch and would've known exactly what was happening and where all the time. We're treated more as numbers than real people with everyday problems."*

> *"It's really quite difficult continually dealing with people who aren't known to you – you don't know what their position is, nor actually have we ever been told how the system is supposed to work up at the DLA[4]. It's OK when you get used to someone. I'm not even sure what the organisation's called anymore. I'm certain that my dad would still call it the War Office!"*

Communication between MoD and the farmers requires mutual appreciation of each other's activities. The following is a fine example of how misunderstandings can occur:

> *"I had an automatic pigeon scarer in a field to prevent rooks from eating my pig feed. You know the sort – it goes off about 3 times every 5 minutes. Well, it was in a field next to where some troops were training and they'd clearly got fed up with it banging away. The tracks we found in the field showed that they'd driven into the field, squashed the scarer flat, and then driven out again. I thought, 'Damn it! I'm going to claim for this!' and submitted a claim for £300 compensation for a new pigeon-scarer. MoD wrote back to me saying that if I thought they were going to give me £300 for a new scarecrow, I must be mad! I did eventually manage to explain what it was, and I did get my money in the end, but it does make you exasperated."*

[4] DLA: Defence Land Agent.

Another example is the recent introduction of a new system for the co-ordination of tactical exercises with Schedule III grazing. Previously, MoD would inform the farmers as to what exercises would be happening and where, and the farmers would move their stock accordingly. The new system is known among the farmers as the 'half grid squares system', whereby the farmers inform MoD in which 'half grid squares' they want their cattle, and MoD supposedly work around these positions. Only one of the farmers seemed entirely content with this change, the most common complaint being that the two month notification period required by MoD is difficult to implement in farming where decisions are influenced by unpredictable factors such as the weather, or illness:

> *"There's no way I can make decisions about April's grazing in February. I've got no idea how the weather will go!"*

> *"I don't know why they changed the old system to the half grid square system. A fixed date for army activity was much easier to work with – now we don't really know what's happening."*

Although brought in by MoD with the intention of better accommodating farmers' activities, in practice many farmers are finding the half grid squares system unworkable. Some acknowledged that they were going through the motions of filling in the forms, regardless of whether or not what they put down was a realistic expectation. The farmers are also sent Daily Range Summaries that detail the training programme day by day. This should give the farmers greater information as to the type and location of daily activity on the Plain, but some claimed not to understand the documents, consigning them immediately to the bin. Many said that they usually noted when live firing was going to be, but rarely went out onto the ranges to move the cattle in preparation, it usually being impractical to do so for each live firing exercise.

The Future.

In terms of visions of the future of farming on SPTA, two main schools of thought were identified, between which farmers were reasonably evenly split:

(i) those who were resigned to the current situation and were accepting of the inevitable redundancies and lower profit margins this would entail (58% of those interviewed):

> *"We're quite happy here. Military pressures are minimal compared to collapsing prices and pressures from the environmental groups. We used to have a workforce of six, but we're having to reduce the dairy and have had to make two people redundant. We knew about the military when we arrived here so we've no cause for complaint."*

> *"At the end of the day you live and work on a military training area, and there's no point in trying to change that. It would have to become very much worse for me to consider packing up and leaving – we get on and work around the army rather than trying to make the army work around us. ...The ranges aren't really farmland at all. My neighbour across the road has a proper farm, with large arable fields and so on. The Plain's rough grazing land and that's about it. But both are ways to make money, if you do it properly."*

(ii) those who saw the need for increased flexibility by farmers or MoD. This included those who thought that government incentive schemes such as Countryside Stewardship may be worth pursuing, or even conversion to organic production methods (42% of those interviewed):

> *"I'm changing to organic. The grants available for us to convert are like being paid not to go bust. My cereal prices are on the floor and Angus beef is getting a premium. I've also been looking into Stewardship. Wheat prices are so low that I could seriously consider producing 'countryside' instead. Along with the organic beef, this'll be the way to survive in farming these days."*

> *"We once looked at entering the SSSI land into Stewardship. We would've had to reduce our stock numbers by 2-3 cattle, and the £1000-£1500 payment wouldn't really have covered this loss. We would've increased this by another £1000 by allowing more public access, so it might have been worth it then, but MoD said no to the increased access."*

One farmer commented that *"...on a bad day I could consider giving up..."*, but it is hard to tell whether these feelings are due to the difficulties associated with farming on SPTA, or because of the current depression in agriculture across the UK. Although almost all the farmers expressed frustration about disturbance on Schedule III land there were only a couple who really felt strongly enough about it to indicate that they felt something in the system 'had to give'. One farmer was anxious to articulate that he was not against the MoD *per se*:

> *"I accept that we need an army to protect the country, but why do we want to protect our country? It's nothing to do with nationality any more, and in terms of protecting a culture, about the only thing we can identify as being 'British' is our countryside. You therefore have to have sensitive land management too! Priorities on the Plain used to be 1. Army, 2. Farming, and 3. Conservation. Now it feels like 1. Army, 2. Conservation and 3. Farming."*

In this time of depression in British agriculture, the SPTA tenant farmers arguably have a more important a contribution to make towards the conservation of Salisbury

Plain as they do to food production. Without the grazing management provided by these farmers, many of the current approaches to grassland conservation would not be possible. Apparent separation of the roles of farming and conservation in the minds of the farmers suggest that the value to MoD of farming activities on the SPTA is not made sufficiently explicit.

7.4 DISCUSSION AND CONCLUSIONS

Why do qualitative research?

Qualitative studies such as those presented here allow the investigation of the social world, in order to analyse attitudes and perceptions from the point of view of those people being studied (Bryman, 1992). They by definition tend to be used within case study contexts that may or may not be representative of the whole, and provide accounts rather than explanations of situations (Eyles, 1988). Compared with quantitative techniques, qualitative methods produce richer and deeper data, resulting in idiographic rather than nomothetic research findings.

The questionnaires and interviews used here enabled an investigation of farmer perceptions of, and responses to, military disturbance. In terms of the research questions posed at the outset, the results suggest that most farmers on SPTA are experiencing an increase in military-related disturbance, and while monetary compensation remains a low concern, disturbance of the more extensive Schedule III land is becoming more contentious. However, attitudes and perceptions are important drivers of socio-economic behaviour (Falconer, 2000), and the qualitative approach used here revealed more than just facts regarding military disturbance on farmland. It has also enabled some appreciation of the attitudes of farmers towards disturbance and how these may influence their behaviour.

Understanding farmer attitudes and behaviour

Previous qualitative studies involving the farming community have primarily focussed on the response of farmers to agri-environment schemes and environmental policy for the wider countryside (Battershill and Gilg, 1996; Carr and Tait, 1991; Neve, 1997; Beedell and Rehman, 1999). Many of these studies have identified responses as being a complex interaction between structural (external) and attitudinal (internal) variables. Structural variables include financial considerations and economic constraints, farm size and type, quality of land, and length and type of tenure, whereas internal variables can include personal preferences for particular crops or stock breeds, for methods employed or the timing of activities (Wlison, 1996; Battershill and Gilg, 1996; Morris and Potter, 1995; Carr and Tait, 1991; Brotherton, 1990 and 1991; MacDonald, 1984; Gasson and Potter, 1988; McHenry, 1996; Newby *et al.*, 1977; ADAS, 1976). As part of a multi-disciplinary study of farmer behaviour, Willock *et al.* (1999) represented schematically this interaction of internal and external variables, whereby internal aspects of the individual ('antecedent variables') determine both attitudes to, and objectives in, farming ('mediating variables'). These combine with external factors ('outcome variables') to determine farming behaviours (see Figure 7.22).

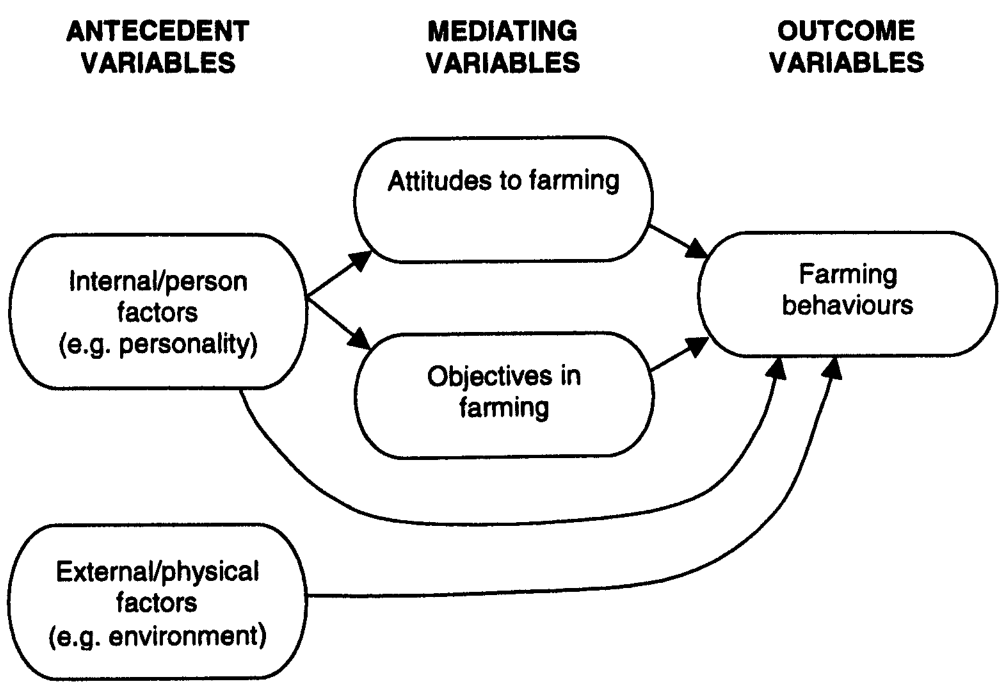


Figure 7.22 Schematic relationship among individual differences in personality traits, attitudes, objectives and behaviour. After Willock *et al.*, 1999.

This model indicates that farmer response to disturbance is likely to be a product of personal attitudes towards the disturbance or military, and external factors, such as financial constraints. Gasson and Potter (1988) showed that willingness to adopt conservation policy on a farm depends on how financially constrained a farmer is. Accordingly, during the course of the interviews, there was some evidence that those who were more financially constrained seemed less ready to make any statement that would seem anti-Army. Mediating variables (see Figure 7.22) include 'coping styles', and it was apparent that SPTA farmers with greater disposable incomes were more able to adopt coping strategies, such as the purchase of a quad-bike, better suited to riding rough ground than a Land Rover or tractor. Having the flexibility to adapt to external pressures in this way requires both imagination and the financial resources to do so.

One difficulty with this functional approach is that behaviour is not always related to attitudes (McHenry, 1996). Most of the farmers who participated in the survey said, for example, that they felt their relationship with the Ministry of Defence could be best maintained by minimal opposition to disturbance. However, this did not always correspond with their behaviour; two of the farmers who agreed with this statement have made themselves unpopular with MoD through measured confrontation. Nevertheless, this approach allows an appreciation of constant and variable factors across a sample of farms. No two farms are the same, and farmers are not automatically a coherent attitudinal group (Wilson, 1996), without necessarily acting entirely as individuals either (see for example the 'farmer culture' identified by Young *et al.*, (1995), and also Potter and Lobley, 1992; Morris and Andrews, 1995 and Ward *et al.*, 1995). There perhaps needs to be a greater appreciation of difficulties faced by particular farmers on SPTA. This would be helped by greater continuity of land agent cover.

Losses: economic and otherwise

Farmers tend to be profit-maximisers and profit-traders (Brotherton, 1990, 1991). Robinson (1983) found that the highest rated aim among farmers was to make sufficient profit. Some of the SPTA farmers expressed concern about falling profit margins, although this is likely to be as much about farming at the end of the 20th century as it is about military disturbance. Farmers were concerned about potential additional losses in productivity, particularly if disturbance was to increase. Some are buffering economic losses caused by disturbance on SPTA through the adoption of coping strategies and agri-environment schemes. These include placing set-aside in areas more prone to disturbance, planting crop types that are less vulnerable to disturbance, and 'disguising' Schedule III as Schedule I to reduce the amount of tank encroachment.

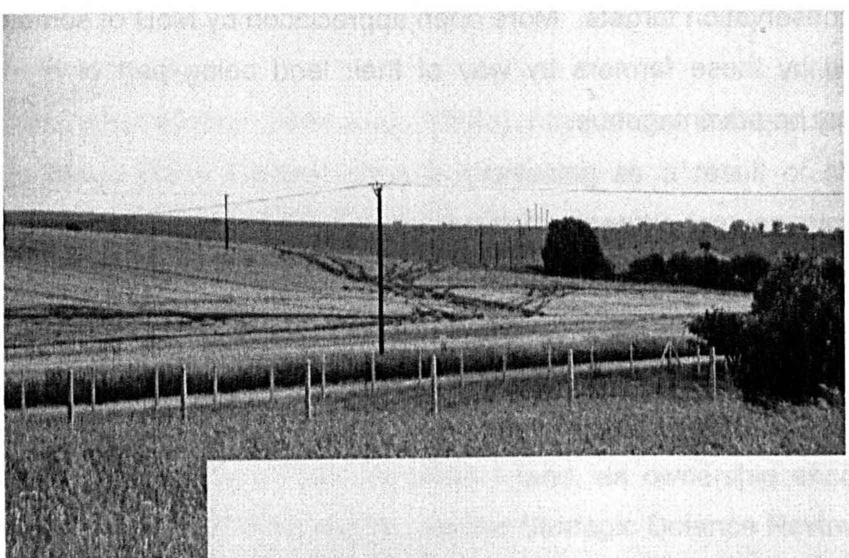
Farmers tend to (or at least used to) be more job-satisfied than almost any other profession (Coughenour and Swanson, 1988), and in studies where farmers were asked why they participated in farming, intrinsic values such as job satisfaction tended to be ranked most highly (Gasson, 1973; Casebow, 1981; Gilmor, 1986). Many of the respondents in this study explicitly stated that disturbance detracts from their job satisfaction. Farming behaviour has been shown to be dominated by perceptions of efficiency and tidiness, as well as productivity (Carr and Tait, 1991), and the negative impact on these ideals through military disturbance should be seen as a real and possibly increasing problem for farmers. However, reforms of the CAP and changes in the emphasis of farming towards the management of the countryside as well as the production of food may in the future affect these perceptions of 'tidiness' and productivity. The Salisbury Plain farmers play an extremely important role in the conservation management of the training area, maintaining the landscape and natural history interest of the area through controlled grazing and mowing. Extensive farming systems such as this are relatively uncommon in the intensively farmed lowlands of southern England. The contribution of these activities to meeting MoD's statutory conservation targets for the area perhaps need to be more widely and openly acknowledged.

Looking to the future

This, and other studies (Hirst *et al.*, 2000a), have shown that ground disturbance on the Salisbury Plain Training Area is increasing as a result of changing military demands on the area. Although it is inevitable that the farming community will also experience increases in disturbance, it remains to be seen whether disturbance on Schedule I land and compensation will become more significant issues in the future. A report made by the Defence Lands Committee nearly 30 years ago regarding Salisbury Plain suggested that better land management might be achieved by allowing farmers to purchase Schedule I land, as ownership encourages greater interest in the farm (HMSO, 1973). As the Strategic Defence Review (MoD, 1998b) identified a shortfall in UK training lands, this now seems unlikely to be implemented.

Farming perhaps has more external pressures than any other business (Willock *et al.*, 1999), and there is some evidence that sectorial high job satisfaction is now giving way to greater pessimism and stress (Deary *et al.*, 1997). Farmers are often considered to be highly resistant to change (Battershill and Gilg, 1996), risk averse and slow to accept unproved ideas (Fearne, 1989; Guerin and Guerin, 1994). Although this may be so in some cases, it should not be used by MoD as a universal response to discontent amongst farmers. Indeed, the interviews revealed that the SPTA farmers *are* responding to change and the need for innovation, such as experimenting with restoration techniques in the areas where this is allowed. Of the farmers who saw some degree of change to be a necessity, most felt that a proportion of this had to come from MoD as well as the farming community. Land agents confirm that although the disturbance of Schedule I land is currently a rare event, they are trying to increase the efficiency of processing claims (Watts, pers. comm.). However, in preparation for increases in disturbance incidents and compensation claims, greater flexibility in the current compensation system may become a necessity.

Much of the rural defence estate is farmed, and farming tenants generate a substantial income for the MoD through rents and fees (MoD, 2000). As tenants on training areas, farmers are helping to create and maintain a working landscape and, in some cases, are providing a realistic environment for military training exercises. The SPTA farmers are attempting to derive a livelihood from the land in an increasingly difficult economic climate, but without them MoD are unlikely to meet their statutory conservation targets. More open appreciation by MoD of some of the difficulties faced by these farmers by way of their land being part of a military training area may be advantageous.



Tracked vehicle disturbance on Schedule 1

Grazing cattle, SPTA West

8. PERSPECTIVES OF MILITARY DISTURBANCE ON THE SALISBURY PLAIN TRAINING AREA: REFLECTIONS AND RECOMMENDATIONS

Army training areas in Britain remain unique refuges for wildlife in otherwise crowded and anthropogenically altered landscapes. Military demands on these areas are frequently changing, both temporally and spatially, in response to geopolitics and new technologies. The Ministry of Defence has recently been taking a more active role in the sustainable management of its estate, but an informed response to changing demands requires comprehensive knowledge of training lands. This calls for information about the impacts of different training activities and equipment, the intensity and frequency of use of land, and the response of land to those activities. A combination of historical study and field experimentation have been used in this thesis to reveal some of the mechanisms of habitat disturbance and recovery operating on the Salisbury Plain Training Area (SPTA), and through this research it will be possible to base training area management on more sound principles.

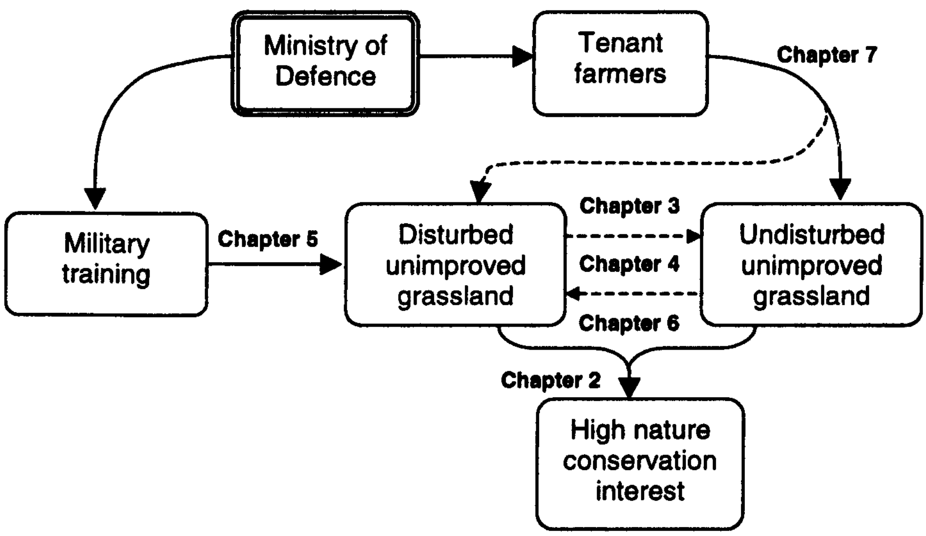


Figure 8.1 Selected ecological and socio-economic land management processes on the Salisbury Plain Training Area, and thesis chapters in which they have primarily been considered.

As with most semi-natural habitats, a combination of ecological and socio-economic processes are responsible for the mosaic of grasslands found on the SPTA, and the issues covered in this collection of papers have a number of interconnecting themes (Figure 8.1). Successful management of SPTA is dependent on full consideration of ecological relationships between disturbed and undisturbed habitats, above and below ground species assemblages, herbivory and soil characteristics (Lovich and Bainbridge, 1999). Research questions posed in Chapter 1 provided a framework for characterising and quantifying habitat disturbance and recovery on Salisbury Plain. The contributions of each of these papers to the direction of future management of SPTA are reconsidered here.

How much disturbance is occurring on the Salisbury Plain Training Area? How does this compare to past rates of disturbance?
The balance between disturbed and undisturbed grassland on Salisbury Plain over a 50 year period was investigated in Chapter 2. Such landscape-scale studies are useful for an overview of an environmental problem. The use of aerial photographs to investigate temporal trends in training area-wide disturbance provides a repeatable framework for future monitoring. These data have given MoD and Defence Estates a greater appreciation of both the extent of change across SPTA since WWII, and the recent increases in the rate at which bare ground is being created.

The high nature conservation interest of Salisbury Plain is a product of both disturbed and undisturbed grassland patches. This mosaic allows the co-existence of plant and animal species associated with a range of successional stages, from bare ground and ruderal communities to extensive parcels of high quality, unimproved calcareous and mesotrophic grassland. However, such disturbance needs to be balanced by the potential for spontaneous restoration. Time periods characterised by increases in the area of bare ground on SPTA are indicative of periods of unsustainable management, as re-establishment of bare ground is lagging behind its rate of creation. Army training areas tend to be finite resources, and it is necessary to avoid irreversible land degradation (Jones and Bagley, 1998). Not only is bare ground less useful for training purposes, the cost and inconvenience of land rehabilitation are high (McDonagh *et al.*, 1979).

Recent work using aerial photographs from 1999 suggest that since the semi-metalling of a number of tracks on SPTA, disturbance has, at least, stabilised (Hirst, 2000). The winter preceding these photographs was particularly wet, and during this time a moratorium on tracked vehicle training was called. These supplementary data may not therefore represent a typical training year. Nevertheless, such a halt on tracked vehicle training as a response to land condition indicates that MoD are taking an increasingly serious approach to sustainable land management. However, it is difficult to ascertain the policy implications of these results in the absence of data regarding vehicle tracking characteristics during training exercises. For example, the temporal trends in bare ground seen in Chapter 2 have not been compared with the number of vehicles training on SPTA over the same time period. Although it is likely that disturbance is closely related to vehicle numbers, land character and antecedent soil conditions will also play a part. The development of predictive models would require these types of data.

How long does it take grassland to recover spontaneously from disturbance?
Maintaining the balance between disturbed and undisturbed grassland requires some knowledge of the processes by which disturbed grassland recovers. Much restoration ecology focuses on achieving target vegetation community *composition*, without investigating whether the system is *functioning* as desired. Chapters 3 and 4 sought to address this imbalance, at least partially, as for any biotope, a full investigation would require consideration of fauna and flora, decomposers and micro-organisms (Mitchell *et al.*, 2000). Consideration of habitat components such as post-disturbance seed bank composition and soil nutrients greatly extended estimates of habitat recovery periods from those derived using just surface vegetation community composition. The between-community variation in habitat resilience identified here for mesotrophic and calcareous grasslands as a result of differences in productivity and component species strategies, may be one strategy by which disturbance can be managed. Preferential use can be made by the military of more resilient habitats at times when grassland communities are less resistant to disturbance. Shaw and Diersing (1989) recommend a rotation scheme of training area usage to allow the return of perennial cover to disturbed areas. Knowledge of the resilience of different types of grassland enables the estimation of realistic exclusion times, and permits the implementation of such a scheme.

The investigation of habitat dynamics over long time periods such as this can provide valuable insights into habitat functioning. Although estimates of habitat recovery were limited by the availability of photographic material, this resource provided the framework for a space-for-time analysis that otherwise would have been beyond the capabilities of a three year research project. Long-running experiments frequently cannot be reconciled with the decision-making time scales required by land managers. These papers considered the resilience of a number of ecosystem components to disturbance, but there remain significant gaps in our knowledge of community functioning. The responses of soil microbial and mycorrhizal populations to disturbance, for example, require further investigation. Nevertheless, these data have helped to reinforce the finite nature of the Salisbury Plain grasslands and their limited carrying capacity. When disturbance is commonplace, the vulnerability of grasslands and the subtleties of the regeneration process may not be fully appreciated. The 50 year minimum exclusion time for full habitat recovery proposed here was substantially longer than that expected by military personnel with responsibility for the SPTA.

How resistant is grassland to disturbance from different sources?

Maintaining an appropriate balance between disturbed and undisturbed grassland on a training area also requires knowledge of the relative disturbance effects of military vehicles. The management response to chronic and widespread vehicle disturbance, such as that found across SPTA, is often more complex than that for acute, high intensity disturbance events (Milchunas *et al.*, 2000). It is necessary to understand disturbance/damage thresholds and the equilibrium between disturbance and recovery to predict the directions in which disturbance might force an ecosystem. In Chapter 5 it was shown that the disturbance created by a tracked vehicle slew (or ten tracked vehicle passes) surpasses a disturbance threshold beyond which chalk grassland recovery appears to be less predictable. It was also this kind of disturbance that farmers identified in Chapter 7 as particularly hindering their access for hay cutting. It is unknown as to how many of these very localised but high intensity disturbance events may occur during a typical exercise, and how many could be avoided without impeding the realism of training programmes. It may be appropriate to include information in the 'Train Green'[1] programme regarding the types of tracking manoeuvre to minimise.

The disturbance experiment used in Chapters 5 and 6 was specific to one grassland type at a particular time of year. Ideally, this work should be extended to investigate

[1] Train Green: A number of schemes are currently used to brief exercising units using the Salisbury Plain Training Area about the environmental consequences of training. These include a video entitled 'Plain Sense Too', an *aide memoire* with specific reference to pollution and conservation issues, and more recently a publication called 'The User's Guide to SPTA' which incorporates maps and information regarding the archaeology and conservation interest of the training area (source: Defence Estates conservation officer, HQ SPTA).

the resistance of other grassland communities to different forms of military disturbance, such as shelling and burning, and at other seasons. Additionally, although the thresholds of disturbance and damage identified in Chapter 5 were related to particular tracking manoeuvres, the distances travelled by vehicles in a training exercise over different surfaces and habitats are unknown. If these data were made available, then in combination with ecological assessment it will be possible to devise reasonable and valuable strategy.

What are the specific mechanisms of habitat recovery?

Habitat disturbance on the Salisbury Plain Training Area is important for maintaining the heterogeneity of the grassland mosaic, especially in areas where more traditional forms of management such as mowing and grazing are problematic. Patches of bare ground, for example, can be particularly important for invertebrate populations. However, the importance of the undisturbed grassland resource cannot be understated. In Chapter 6, it was shown that species regenerating from the seed bank were primarily early successional ruderals, necessary for the modification of site conditions for later successional, more desirable, chalk grassland species. The primary source of propagules for the re-establishment of these target species was seed rain from the surrounding vegetation. These data emphasise the need for high quality undisturbed chalk grassland around bare areas to provide such propagules for regeneration. More work is needed in order to understand the spatial limits to this method of dispersal in chalk grasslands, and how the size and distribution of disturbance patches in the landscape affect grassland resilience to disturbance.

It is possible that disturbance on SPTA is creating new vegetation communities. Certain species typical of disturbed areas persist in the sward long after the disturbance event, due to altered light and nutrient conditions, and the availability of propagules from adjacent disturbed areas. The character of the Salisbury Plain grasslands may be changing in such a way that communities might be becoming more resilient or resistant to disturbance. How this may be affecting the composition of recognised calcareous grassland communities and statutory designations on the SPTA requires further investigation.

How does military disturbance affect the farming contribution to conservation on SPTA?

Chapters 3-6 focused on the processes of habitat disturbance and recovery from an applied ecology perspective. However, it is recognised that in order to meet statutory conservation objectives for the chalk grasslands of the SPTA, effective management of the undisturbed chalk grassland resource is required. Mosaics of short and tall unimproved calcareous and mesotrophic grassland communities must be maintained by appropriate cycles of grazing and cutting to prevent succession to scrub and woodland. Although disturbance by military vehicles is sometimes likened to grazing management ('tank grazing'), tracked vehicles are indiscriminate in their contact with vegetation, while stock are comparatively selective (Milchunas *et al.*, 1999). The passage of tracked vehicles over the landscape is therefore no real substitute for controlled grazing management.

Questionnaire and interview surveys in Chapter 7 revealed that grazing management can be problematic for tenant farmers in areas where there is continued disturbance of land, for which they are not compensated except through reduced rents. It has been recognised that grazing can facilitate the restoration of calcareous grassland, through the dispersal of propagules by stock (Fischer *et al.*, 1996). If grazing or cutting regimes are also disrupted by military disturbance, then potential recovery rates of the grassland will be further reduced. The management of this disturbance requires a combination of real commitment towards reducing the disturbance wherever this is possible, and effective human relations. Although these commitments have been recognised as being important (MoD, 2000), training and greater clarity of strategy are required to ensure their implementation.

Wider implications of the study

Habitat disturbance is now endemic across Britain, as a result of a whole range of processes. Investigation of the responses of natural systems to disturbance are becoming increasingly important as conflicts between human activity and the surrounding environment become more commonplace. Human disturbance is shaping vegetation communities in a range of locations, such as urban waste ground and cleared woodland (Rodwell, 2000). These are factors that have contributed to the emergence of disturbance and restoration ecology as recognised disciplines, and the rise of 'creative conservation' (Sheail *et al.*, 1997).

The composition of calcareous grasslands has been comprehensively studied but their functioning is less well understood. Data regarding succession trajectories and resilience and resistance to disturbance, such as those presented here, may be useful in predicting or assessing the success of calcareous grassland restoration. These data also indicate the potential information deficit across the UK training estate regarding the response of habitats to disturbance; habitats that range from the lowland dry heaths of the Longmoor Training Area in Hampshire to the upland moors of the Otterburn AFTC. All these areas will require ecological information for their Integrated Land Management Plans.

The disturbance impacts that even wheeled vehicles can have on grasslands have implications beyond military training areas. Off-road recreational use of 4x4 vehicles is increasing, and agricultural and forestry machinery is becoming larger and heavier. As disturbance of the wider countryside from these types of activity becomes more widespread, the potential effects of soil compaction and vegetation change needs to be assessed and understood (Webb, 1982; Dickerson, 1976). Smaller scale disturbances such as that resulting from livestock or human trampling may also pose management problems in areas where they are judged sufficient to have negative impact on habitat quality (Liddle, 1975; Harrison, 1981). Outside SPTA, the chalk downlands of southern England are popular recreational areas, and habitat disturbance from a number of sources (vehicular and non-vehicular) pose particular management problems.

Aspects for further work

This thesis has answered some of the more pressing management questions that were demanded of it. Some research areas stemming from this work have already been considered above, and a summary of recommendations for management can be found at the end of this chapter. There are, however, many additional issues regarding the ecology of Salisbury Plain that still need addressing. There has been no systematic classification of the vegetation communities associated with disturbance on the SPTA, nor thorough investigation of their importance for faunal species (see Carvell, 1999). Little is known about the edge-effects of tracking, or the encroachment of disturbance communities into undisturbed grassland parcels. This type of information would assist the prediction of chalk grassland losses as a result of increased vehicle use or laying of different track surfaces.

Better predictive models are needed for spatial analysis of grassland response to disturbance. This would allow better estimates of training area vehicle carrying capacity. Disturbance caused by military training does not occur uniformly or randomly across a landscape. The aerial photographic analysis showed clearly that certain types of topographical and vegetation features have particular tactical value, for example, for concealment or observation. These locations are foci for military units and hence habitat disturbance. The potential value of such landscape-scale studies was highlighted by Langmaid (1998). This study used a simple GIS approach, combining grassland habitat quality mapping with analysis of preferential tank routes on the SPTA, to produce maps of habitat vulnerability to disturbance.

The Future

Changes in the approach of the military towards estate management seem to be occurring. There has been an environmental appraisal of the recent Strategic Defence Review, and reassessment within Defence Estates regarding targets and coherent strategy. However, as with many governmental institutions, change is slow and unsystematic, hampered by internal gerrymandering, a lack of independent, objective advice and personnel with appropriate specialisms.

Integrated Land Management is one possible approach for training areas where interests are not exclusively military, and the adoption of the ILMP on the UK training estate is certainly a step in the right direction. However, such plans need substance, and monitoring systems have to be in place to assess whether or not targets are being met. Additionally, management systems have to be tailored to the needs of the training area in question. Many US training areas use models such as that based on the Universal Soil Loss Equation (see Diersing *et al.*, 1988) to calculate vehicle carrying capacity, or the Land Condition – Trend Analysis (LCTA) approach to monitoring (Diersing *et al.*, 1992). However, these schemes are focused on the need for soil conservation, rather than botanical or faunal interest. We must resist the temptation to adopt management strategies just to appear proactive. Although standardisation of approach can be useful, financial resources are limited, and therefore approaches must be tailored to the specific needs of individual training areas.

The advantage of the military presence on Salisbury Plain should not be overlooked. Without it, it is unlikely that this high quality chalk grassland habitat would have survived. The presence of the military in the area also provides important services for a predominantly rural community, through civilian employment and support for local amenities such as shops, schools, bus services and pubs (Woodward, 1996). However, it is important to recognise that the conservation interest of the Salisbury Plain grasslands was the product of a fortunate accident of history, rather than by design, and that its future management can now not be left to chance. Salisbury Plain provides a unique opportunity to investigate the functioning of chalk grassland flora and fauna at a local landscape level, a refuge for declining grassland species and potentially an invaluable species pool for the re-colonisation of biodiversity in biologically impoverished parts of southern Britain. These data have added impetus to the need to implement sustainable management on the defence estate, and future research should be commissioned accordingly.

SUMMARY OF RECOMMENDATIONS

- Increasing area of bare ground on SPTA could be indicative of unsustainable management. Annual assessment of bare ground is necessary to ascertain effectiveness of control strategies. This will be best achieved using remote-sensing techniques.

- The NVC map for SPTA should be used more during the planning of training exercises. There must be better accommodation of the vulnerability of the chalk grassland resource, and time periods required for recovery.

- In the future, data must be collected and made available regarding tracking characteristics of training units on the SPTA (type, quantity and location). Combined with ecological data, these will enable the production of predictive models of the impacts of training exercises.

- Environmental briefings for units prior to training on the SPTA should include detail regarding the potential impacts of different manoeuvres, and those that are to be minimised.

- Efforts should be made to increase the continuity of land agent cover, and the quality of communication with farmers. Reviews of Schedule III disturbance and discourse with farmers are imperative.

- Better use must be made of Geographical Information Systems as a management tool. Highly skilled GIS personnel would allow the production of dynamic and interactive multi-layered spatial analysis tools that would assist rapid response to, and future planning for, many of the difficult land management problems on the SPTA.

- MoD is one of the key partners in the UK Biodiversity Action Plan. Environmental research across the Defence Estate must therefore be less piecemeal; clear strategy, direction and coordination are necessary for structured contribution to ILMPs.

Negotiating with a tank crew

APPENDIX 1
CEH Biotope Occupancy Database

Species preference scores for calcareous and mesotrophic grasslands

For vascular plants and bryophytes, an objective evaluation of biotope occupancy has been developed using the constancy tables from the National Vegetation Classification (Rodwell, 1991 *et seq.*). Published constancy tables from the NVC give a measure of the frequency of vascular plant species in British natural and semi-natural plant communities. Complementary data on species frequency in man-made biotopes were obtained from the CS1990 field survey, a major survey of the British countryside (Barr *et al.*, 1993). These frequencies have been used widely to document similarities and differences between habitats.

For each species and biotope, the observed frequency in the biotope, *o*, was compared with its expected frequency in all biotopes, *e*. Species whose constancy was less than 5% in a sub-community were omitted from the analysis.

The habitat-specificity of a species was graded by its preference index:

$$P = \{ (o - e) * \text{abs}\,(o - e)\} / e$$

P is therefore independent of the number of quadrats per community and can be used to compare the degree of preference of species for heavily or less heavily sampled habitats. Species within each habitat category were ranked by preference value, and grades of habitat specificity were assigned to species in each quartile, which may be defined as follows:

0 Lower quartile. Occurs within habitat (also in many others).
1 Poor indicator (usually present, also occurring elsewhere).
2 Moderate indicator (present in habitat more often than elsewhere).
3 Upper quartile. Good indicator (seldom found elsewhere).

This approach should provide a more objective selection of indicator or preferential species for assessing habitat condition.

Preference indices for calcareous and mesotrophic grasslands of species found during this study:

Species	Calcareous grasslands	Mesotrophic grasslands
Achillea millefolium	2	3
Agrimonia eupatoria	3	2
Agrostis stolonifera	0	2
Allium vineale		
Alopecurus pratensis		3
Anacamptis pyramidalis	3	
Anagallis arvensis		
Anisantha sterilis		0
Anthoxanthum odoratum	1	3
Anthriscus sylvestris		1
Anthyllis vulneraria	2	
Aphanes arvensis	1	
Arenaria serpyllifolia	2	
Arrhenatherum elatius	1	3
Artemesia vulgaris		2
Asperula cynanchica	3	
Atriplex patula		
Barbarea vulgaris		
Bellis perennis	2	2
Blackstonia perfoliata	3	
Briza media	3	2
Bromopsis erecta	3	0
Bromus hordaeceus		
Campanula glomerata	3	
Campanula rotundifolia	3	1
Capsella bursa pastoris		1
Cardamine flexuosa		2
Cardamine hirsuta		
Carduus nutans	3	1
Carex caryophyllea	3	0
Carex flacca	3	0
Centaurea nigra	3	3
Centaurea scabiosa	3	1
Centaurium erythraea	3	
Cerastium arvense		
Cerastium fontanum	2	3
Cerastium glomeratum		1
Chaenorhinum minus		
Chenopodium album		
Cirsium acaule	3	
Cirsium arvense	1	3
Cirsium eriophorum	2	
Cirsium vulgare	2	1
Clinopodium acinos	2	
Clinopodium ascendens		
Clinopodium vulgare	2	2
Convolvulus arvensis	0	1
Crataegus monogyna	1	0
Crepis biennis		
Crepis capillaris	3	0
Crepis vesicaria		
Cynosurus cristatus	2	3
Dactylis glomerata	2	3
Daucus carota	2	0
Deschampsia caespitosa	1	3
Echium vulgare	1	
Elytrigia repens		1
Erophila verna	1	
Erucastrum gallicum		
Euphrasia nemorosa	3	0
Fallopia convolvulus		
Festuca arundinacea	2	2
Festuca ovina	3	0
Festuca pratensis		3
Festuca rubra	1	3
Filipendula vulgaris	3	
Fumaria officinalis		
Galium aparine		0
Galium mollugo	3	1
Galium verum	3	1
Genista tinctoria	2	
Gentianella amarella	3	
Geranium columbinum		
Geranium dissectum		2
Geranium molle		
Geranium pratense		
Glechoma hederacea		1
Helianthemum nummularium	3	0
Helictotrichon pratensis	3	
Helictotrichon pubescens	3	1
Heracleum sphondylium		3
Hippocrepis comosa	3	
Holcus lanatus	1	3
Hypericum perforatum	2	2
Hypochoeris radicata	1	2
Juncus bufonius		1
Kickxia spuria		
Knautia arvensis	3	2
Koeleria macrantha	3	0
Lamium pupureum		
Lathyris nissolia		
Lathyris pratensis	2	3
Leontodon autumnalis	1	1

Species	Calcareous grasslands	Mesotrophic grasslands
Leontodon hispidus	3	1
Leontodon saxatilis	2	0
Leucanthemum vulgare	3	3
Linaria vulgaris	1	
Linum bienne		
Linum catharticum	3	0
Lolium perenne	1	3
Lotus corniculatus	3	1
Luzula campestris	2	2
Malva moschata		
Matricaria discoidea		0
Medicago lupulina	3	0
Melilotus altissimus		
Minuartia hybrida		
Myosotis arvensis		1
Odontites vernus		1
Onobrychis viciifolia	3	
Ononis repens	2	
Origanum vulgare	2	2
Orobanche elatior	2	
Orobanche minor		
Papaver dubium		3
Papaver rhoeas		2
Pastinaca sativa	2	2
Phleum bertolonii	3	2
Phleum pratense	1	3
Picris echioides		
Picris hieracioides	3	
Pilosella officinarum	2	0
Pimpinella saxifraga	3	1
Plantago lanceolata	3	3
Plantago major	0	1
Plantago media	3	0
Poa annua		0
Poa humilis		
Poa pratensis	1	2
Poa trivialis		3
Polygala vulgaris	3	0
Polygola calcarea	3	
Polygonum arenastrum		
Polygonum aviculare		
Potentilla anserina		3
Potentilla erecta	0	2
Potentilla reptans	2	3
Potentilla sterilis	1	
Primula veris	3	2
Prunella vulgaris	3	2
Ranunculus acris	0	3
Ranunculus bulbosus	3	2
Ranunculus repens	0	3

Species	Calcareous grasslands	Mesotrophic grasslands
Reseda lutea	1	
Reseda luteola	0	
Rhinanthus minor	2	3
Rubus fructiosus		0
Rumex crispus		2
Rumex obtusifolia		1
Sagina apetala		
Sagina procumbens		0
Sanguisorba minor		
Scabiosa columbaria	3	0
Scrophularia nodosa		2
Senecio jacobaea	3	1
Senecio vulgaris		
Serratula tinctoria	2	2
Sherardia arvensis		
Silene latifolia		
Sinapis arvensis		
Solanum dolcamara		0
Sonchus arvensis		0
Sonchus asper		1
Sonchus oleraceus		
Stachys officinalis	2	1
Stellaria graminea		2
Stellaria media		0
Succisa pratensis	2	3
Taraxacum sp.	2	2
Thesium humifusum	3	
Thymus polytrichus	3	
Tragopogon pratensis	3	
Trifolium campestre		
Trifolium dubium	0	3
Trifolium medium	1	2
Trifolium pratense	3	3
Trifolium repens	2	3
Tripleurosperum inodorum		1
Trisetum flavescens	3	3
Ulex europaeus	2	0
Urtica dioica	0	1
Verbascum thapsus		
Veronica chameadrys	2	2
Veronica hederifolia		
Veronica persica		
Veronica serpyllifolia		1
Vicia cracca	2	3
Vicia hirsuta		
Vicia sativa agg.		3
Vicia tetrasperma		
Viola arvensis		
Viola hirta	3	

MILITARY DISTURBANCE ON FARMLAND QUESTIONNAIRE

Name: (optional) ____________________

Section 1. Facts and figures about your farm.

1. Is your leased land in:
   - ☐ SPTA West
   - ☐ SPTA Centre
   - ☐ SPTA East

2. How long have you leased land on SPTA? ____________ years.

3. We would like to know about your tenancy of Schedule I and III land:

   Schedule I: Acreage: ____________
   Rent per acre: ____________

   Schedule III: Acreage: ____________
   Rent per acre: ____________

Section 2. Frequency and type of disturbance

4. During 1998 was there any military disturbance on your leased land?
   - ☐ yes
   - ☐ no

5. If 'yes', was this (tick as many as apply):
   - ☐ Schedule I:
     - ☐ tracked vehicles over land
     - ☐ damage to buildings
     - ☐ damage to walls, fences or hedges
     - ☐ other____________
   - ☐ Schedule III:
     - ☐ tracked vehicles over land
     - ☐ damage to buildings
     - ☐ damage to walls, fences or hedges
     - ☐ other____________

6. Does military disturbance occur more at some times of the year than others?
   - ☐ yes
   - ☐ no
   - ☐ not sure

6a. If 'yes', when are the times of year when there is more disturbance?

____

____

7. Is military disturbance more likely to occur at certain times of day?
   - ☐ yes
   - ☐ no
   - ☐ not sure

7a. If 'yes', when are the times of day when disturbance is more likely?

____

____

____

8. How does 1998 disturbance compare to that of previous years, over the last 10 years?
   - ☐ More than usual
   - ☐ Same as usual
   - ☐ Less than usual
   - ☐ Not sure

Section 3. Investigating compensation on Schedule 1

9. Have you ever experienced disturbance on Schedule I land for which you were eligible for compensation?
   - ☐ yes
   - ☐ no

9a. If 'yes', for what proportion of incidents have you applied for compensation?
   - ☐ All (100%)
   - ☐ Over 50%
   - ☐ Under 50%
   - ☐ None

10. How long does it normally take between submission of a compensation claim, and receiving the money?______________________________

11. What is the typical rate of compensation?______________________

12. In your opinion, is this rate appropriate?
   - ☐ yes
   - ☐ no

13. Would you change the compensation system in any way?
   - ☐ yes
   - ☐ no

14. If 'yes', please explain your answer below:

____

____

____

____

Section 4. Farming decision making and military disturbance

15. Does the chance of disturbance influence your planning of the use of Schedule I and III land?

☐ Schedule I: ☐ yes
☐ no
☐ Schedule III: ☐ yes
☐ no

15a. Explain your answers here:

____
____
____

16. Are there certain times of the year when crops or stock are particularly vulnerable to disturbance?

☐ yes
☐ no

16a. Explain your answer here:

____
____
____

17. Given the current tenancy and compensation system, is the amount of disturbance you experience, in your view:

☐ Tolerable?
☐ Intolerable?

17a. If you have ticked '*tolerable*', is this because you think that (tick as many as you want):

☐ military disturbance is an inevitable outcome of renting land within an Army Training Area.
☐ at current levels, military disturbance does not decrease my profitability.
☐ at current levels, military disturbance does not decrease my job satisfaction.
☐ Other reason:______________________________

17b. If you have ticked '*intolerable*', is this because you think that (tick as many as you want):

☐ military disturbance causes problems that cannot be compensated with money.
☐ military disturbance is reducing my profitability.
☐ military disturbance is reducing my job satisfaction.
☐ MoD shouldn't lease out land to farmers if there is a chance of disturbance
☐ other reason:______________________________

Section 5. Changes in disturbance

18. If the current frequency of disturbance was to increase by 3-4 times, would this be:
    - ☐ Acceptable?
    - ☐ Unacceptable?

18a. Explain your answer here:

____

____

____

____

Section 6. Follow-up work

19. Would you like to be involved in follow-up interviews regarding the subject of military disturbance on farmland?

    - ☐ Yes, I would be happy to participate in an interview.
      I will fill out and return the slip in one of the pre-paid envelopes provided.

    - ☐ No, I would not like to participate in an interview.

Thank you for taking the time to complete the questionnaire. Please now post it back to us using one of the pre-paid envelopes provided.

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LIST OF ABBREVIATIONS

AFTC	Army Field Training Centre
AS90	Artillery System 90 (tracked artillery)
BAP	Biodiversity Action Plan
CCDA	Cross Country Driving Area
CEH	Centre for Ecology and Hydrology
CEMML	Center for Ecological Management of Military Lands
CG	Calcareous grassland
DE	Defence Estates (previously DEO)
DEO	Defence Estates Organisation
DERA	Defence Evaluation and Research Agency
DETR	Department of the Environment, Transport and the Regions
DZ	Drop Zone (for air-lifts)
EH	English Heritage
EN	English Nature
ESG	Environmental Steering Group
ESRC	Economic and Social Research Council
FIBUA	Fighting in Built Up Areas
GIS	Geographical Information Systems
GNAT	Gunfire Noise Analysis Tool
ILMP	Integrated Land Management Plan
ITAM	Integrated Training Area Management
ITE	Institute of Terrestrial Ecology (now CEH)
LCTA	Land Condition Trend Analysis Program
MG	Mesotrophic grassland
MLRS	Multi-Launch Rocket System (tracked artillery)
MoD	Ministry of Defence
NATO	North Atlantic Treaty Organisation
NERC	Natural Environment Research Council
NMR	National Monuments Record
NVC	National Vegetation Classification
OED	Ordnance or Explosive Device
RCHM	Royal Commission on the Historical Monument

RSA	Royal School of Artillery
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SAM	Scheduled Ancient Monument
SPA	Special Protection Area
SPTA	Salisbury Plain Training Area
SSSI	Site of Special Scientific Interest
USA-CERL	US Army Construction Engineering Laboratory
USLE	Universal Soil Loss Equation
WIMP	Whinging Incompetent Malingering Person

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Target tank, looking north over SPTA West