The Activity Patterns of Tamworth Pigs and their Effects on the Knepp Castle Estate Wildland Project: An analogue for wild boar

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Abstract

Wild boar (*sus scrofa*) have been accidentally reintroduced to Britain in the last two decades after being extinct on our island for 300 years. This has raised concerns and questions about their effect on British ecosystems. At the same time, revolutionary 'rewilding' projects such as the Oostvaardersplassen and the Knepp Castle Estate Wildland Project have emerged out of changing views about conservation. These new conservations ideals have been influenced by theories stating that large herbivores can and do drive vegetation dynamics and that in the past this resulted in a more open and dynamic landscape in Europe. This study uses the Tamworth pigs of Knepp as an analogue for wild boar and identifies the spatial and seasonal patterns they exhibit within this project, as well as highlighting some effects these patterns have on the vegetation of the Knepp Wildland Project. Tamworth pigs exhibit similar patterns to wild boar, such as concentrating rooting in winter, as well as in woodlands, denser grasslands and riparian environments. They also seemed to affect vegetation by facilitating the spread of scrub that aids regeneration, as their rooting breaks up dominant vegetation, providing areas for germination. They were found to damage woodland vegetation as well. However, the example of Knepp displayed that such effects in the landscape are a result of many interlinking processes.

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1. Introduction

Wild boar (*sus scrofa*) are a former native species that has been extinct in Britain for at least 300 years (Yalden 1999). Despite this, they can be considered part of the British fauna once again as populations have been established in south England as a result of various escapes from farms since the 1980s (Defra 2005). The return of this species has caused much interest and controversy, with 107 media articles appearing about the newly returned wild boar in six years (Goulding & Roper 2002). They have caused agricultural damage (Goulding & Roper 2002), yet the presence of such an animal can be seen as a valuable addition to the biodiversity of Britain. (Defra 2005). As well as this, they are a former keystone species of our woodlands that perform certain ecological roles (Defra 2005).

The timing of the wild boar's return is relevant, as recently theories stating that herbivores drive succession and developments of vegetation at a landscape scale have been proposed (Hodder et al 2005). The most prominent of these comes from Frans Vera who, in his book *Grazing Ecology and Forest History* (2000), argues that the pre-Neolithic landscape of western and central Europe (in the Atlantic period, approximately 7,000 years ago) was dominated by a shifting mosaic of half-open, park-like landscapes similar to modern wood pastures. The cyclical succession of vegetation within this landscape was (Vera argues) created and maintained by large grazing herbivores, including wild boar.

Furthermore, ideas about conservation and the management of natural areas in Europe have also started to change. 'Naturalistic grazing regimes' have been given more attention in recent years and the question of whether they represent the best option for conserving natural areas has been extensively debated (eg. Hodder et al 2005). Naturalistic grazing differs from normal grazing systems in that herbivores are allowed to drive changes in the system through their activities, with little or no human management. There are no set densities of animals and no specified targets or features that conservation is aimed at; the natural processes are aims in themselves (Hodder & Bullock 2009). Vera (2000) has proposed that 'rewilding' areas by restoring these more natural systems presents an optimal form of conservation that would improve and maintain much of Europe's biodiversity.

The theories and practises of naturalistic grazing and rewilding have been pioneered in the Netherlands (Hodder et al 2005), largely through the revolutionary project at the Oostvaardersplassen, where 6,000ha of reclaimed polder land has been allowed to develop naturally with large herbivores driving such developments. Analogues of the former herbivores that would (if Vera's theories are correct) have driven vegetation dynamics have been introduced. These include Heck cattle (analogues for the extinct auroch *Bos primigenius*) and Konik ponies (analogues for the also extinct tarpan *Equus ferus ferus*), as well as large numbers of red deer (*Cervus elaphus*). The densities of the animals are resource limited, with the only noticeable form of human intervention being the extermination of dying animals (Vera 2009). Such minimal management systems have demonstrated that there is an alternative way of conserving nature.

These projects have generated much interest in Britain, with rewilding and naturalistic grazing systems being advocated by many and even some calling for the creation of an English Oostvaardersplassen (Hodder et al 2005). This interest, as well as the sharp decline in agricultural profitability between 1996 and 2006, has led to a similar project being implemented at the Knepp Castle Estate in West Sussex (Anon. 2011). Intensive agriculture has been ceased and a 'Wildland Project' implemented in much of the 1,400ha estate. This involved stopping the use of pesticides and herbicides, as well as introducing large herbivores such as fallow deer (*Dama dama*), Old English Longhorn cattle, Exmoor ponies and (the subject of this study) Tamworth pigs, to the area. Currently, the project encompasses 1,000ha of land that is divided into three block: the Middle, North and South Blocks (Anon. 2010), which are separated by fencing and have experienced slightly different treatments. The Tamworth pigs have been present in both the Middle and South Blocks. Their main role in the project is to disturb ground through their rooting, which creates openings that vegetation, and invertebrates can take advantage of.

This Wildland Project at Knepp presents a unique opportunity to study the effect of large herbivores on a developing English landscape and will provide insightful information about how accurate Vera's theories on this are. For this study, the Tamworth pigs of Knepp are used as analogues for wild boar. Their patterns of activity are identified and their effects on the vegetation structure and overall development of the Knepp landscape assessed. This will inform about the role of wild boar within a more naturalistic system and could provide insights into how wild boar in England could affect landscapes and their vegetation structures and dynamics.

2. Aims and objectives

Aims

The key research questions of this study are:

What patterns of activity do the Tamworth pigs of the Knepp Castle Estate Wildland Project display and what are the effects of these on the Wildland Project?

To answer these questions, the following aims were established:

- To identify spatial patterns in pig activity.
- To identify seasonal patterns in pig activity.
- To identify effects that such activity is having on vegetation structure and overall landscape development.

Identifying such patterns and effects of the Tamworth pigs is not just important for Knepp but also in wider contexts as an analogue of the effects and patterns of wild boar.

Objectives

In order to achieve these aims the following objectives were also outlined:

- To conduct vegetation surveys in a range of habitat-types in each of the three blocks of the Knepp Wildland Project in order to identify effects the pigs are having on vegetation.
- To observe groups of pigs in both the Middle and South Blocks and in both summer and winter in order to determine their spatial and seasonal patterns of activity, as well as identify any effects they could be having on vegetation structure.
- To devise a rooting index that will allow the assessment of the severity of rooting.

3. Context of this study

The return of wild boar to Britain

Commercial farming of wild boar for meat production was established in Britain in the 1980s (Booth et al 1998), with the number of breeding sows reaching 400 by the mid 1990s (Kyle 1995). The majority of wild boar populations now living wild in England are a product of escapes from these farms. One such example is the escape of animals from Kent and East Sussex farms in 1987 due to storms that damaged fencing (Defra 2005).

There are three main breeding populations in England, located in Dorset, The Weald area of East Sussex/Kent and in the Forest of Dean (as shown in figure 3.1), although various other groups also exist (Defra 2005). Many of these populations are thought to be expanding, such as the Dorset group, which was estimated to contain no more than 15 original escaped animals; despite this 72 kills were reported in 2003 (Wilson 2003).

Population increases in wild boar have also been seen generally across Europe since the 1980s (Geisser & Reyer 2005). For example, the number of kills made by hunters in the Thurgau region of Switzerland increased from 30 in 1992 to over 100 in 1993. The numbers of animals killed stayed above 100 in most years after this, despite the amount of hunters actually decreasing after 1992 (Geisser & Reyer 2005). Indeed, ungulate populations as a whole have been increasing across Europe, perhaps due to beneficial management practises (Kuijper et al 2009) and a lack of predators.

Expanding populations of wild boar are bringing them into increasingly frequent confrontations with humans. In England, their rooting has been reported to cause agricultural damage (Wilson 2004) and direct encounters with wild boar, which are large, potentially dangerous animals, have created a certain level of public fear.

However, much of this is unfounded. There are no reports of unprovoked attacks and wild boar live in vast areas of Europe with few such problems (Goulding & Roper 2002). Views of wild boar can even be reversed, such as in France. Here, economic losses due to damage caused by wild boar have been offset by hunting revenues, which has led to a drastic change in perceptions of these animals (Vassant 1999).

Figure 3.1: Map showing the locations of the three main English breeding populations of wild boar (Natural England)
Source: http://www.naturalengland.org.uk/ourwork/regulation/wildlife/species/wildboar.aspx

The ecology of wild boar

Wild boar are distributed widely across their native Eurasia (figure 3.2), but introduced populations also flourish in areas of the Americas and also Australia. These non native groups can cause severe damage to indigenous communities and species, such as in the Great Smoky Mountains National Park of the USA, where feral pigs have a severe affect on vegetation, rooting (the digging-up of ground) up to 80% of an American beech (*Fagus grandifolia*) forest (Howe, Singer & Ackerman 1981).

In Britain however, wild boar are a keystone species (Defra 2005) that have inhabited our landscapes for thousands of years, thus their return can be seen as restoring part of our depleted fauna. Article 22 of the European Community Habitats Directive 1992 (92/43/EEC) requires member states to investigate the desirability of reintroducing 'Species of Community Interest' to parts of their former range (Defra 2005). Wild boar are not actually listed in this, but they have been suggested (Yalden 1999).

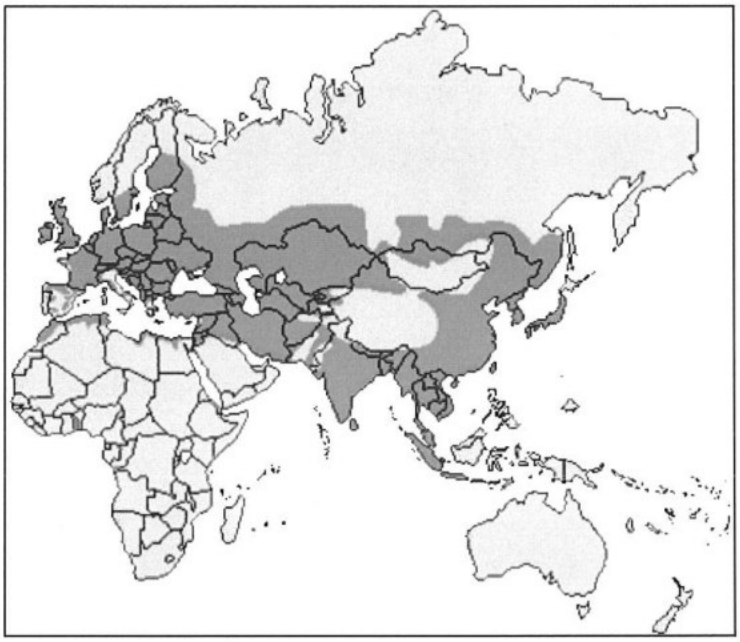


Figure 3.2: The reconstructed native range of wild boar in Eurasia and North Africa (redrawn from Oliver et al 1993)
Source: http://www.ultimateungulate.com/artiodactyla/sus_scrofa.html

Wild boar are omnivorous, with a diet that can contain various vegetative matter, acorns, nuts, fruits, roots and rhizomes, as well as invertebrates, small mammals and even carrion. Roughly 90% of their diet is vegetative material (Groot Bruinderink & Hazebroek 1996), but this is still varied, exemplified by observations in the Białowieza Forest (on the Polish-Belarussian border) of wild boar eating at least 137 different species of shrub, forb and tree sapling (Peterken 1996). In autumn and winter, the acorn mast is also a very important food resource for wild boar (Groot

Bruinderink & Hazebroek 1996) and the availability of this resource between years can affect the extend of their rooting (Welander 2000).

Rooting involves the turning over of ground in order to find subterranean food items. This disturbance is significant for soil, vegetation and ground-dwelling organisms (Bueno et al 2009) and constitutes a way in which wild boar 'engineer' ecosystems (Jones et al 1997). It can occur over small areas of a few square centimetres, or extend over large areas of several hundred hectares (Welander 2000). The majority of this rooting activity occurs in deciduous woodlands, where there is a wealth of food matter, such as acorns. This is exemplified in the Tullgarn Nature Reserve in Sweden, where 54% of rooted surfaces were observed in deciduous forest, despite this environment only covering 11% of the studied area (Welander 2000). Rooting also has seasonal patterns, with the majority of disturbances being created in and around the non-growing season (Welander 2000).

Such disturbances can be damaging, as was seen in the Veluwe of the Netherlands by Groot Bruinderink & Hazebroek (1996). They found that higher rooting frequencies resulted in fewer young trees in 1993 compared to 1992. This has led to fears that wild boar in England may damage woodland vegetation, such as bluebells (Goulding et al 1998), as well as potentially damaging species rich grassland (Defra 2005). However, rooting has also been shown to benefit environments. Indeed, Groot Bruinderink & Hazebroek (1996) stated that rooting enhanced soil properties which create favourable conditions for germination. It is higher frequencies of rooting that can overrule these positive impacts.

An example of rooting's beneficial impacts on germination comes from the Białowieza Forest, where seedlings of small-leaved lime (*Tilia cordata*) and common hornbeam (*Carpinus betulus*) were found to occupy patches of ground previously rooted by wild boar. These patches were also seen to be the same size as rooted patches (Pigott 1975).

Open spaces created by rooting breaks up dominant species, allowing new species to establish (Welander 2000). This was seen in the Tullgarn Nature Reserve (Sweden), where rooting was found to enhance plant species diversity (Welander 1995). Intermediate disturbance levels maintain the highest species diversities (Connell 1978), as if disturbance is too frequent it can damage vegetation too much, while if too infrequent certain species can remain dominant (Welander 1995). Jonsson & Esseen (1990) also observed similar results in relation to the diversity of bryophyte species, with 112 species recorded in disturbed areas compared to 56 in undisturbed areas.

Wild boar can also facilitate the interaction jays (*Garrulus glandarius*) have with oak (*Quercus spp.*) regeneration. Jays collect and bury acorns as a form of food storage, however many of these are left to germinate. The open spaces created by rooting provide suitable areas for the burial of acorns and so in this way rooting aids the regeneration of oak (Vera 2000). In these various manners wild boar rooting represents a 'disturbance regime' (Welander 1995) that could once again be affecting British ecosystems.

They do eat a lot of acorns...!

The role of large herbivores in vegetation structure and regeneration

Vera's theories have questioned the orthodox view that pre-agricultural Europe consisted of closed canopy forest (Kirby 2004). This alternative view suggests that the activity of large herbivores creates a more open landscape where vegetation mosaics shift through cyclical turnovers (Vera 2000). The large herbivores driving this system include species such as the extinct auroch and tarpan, as well as extant species like European bison (*Bison bonasus*), red deer, roe deer (*Capreolus capreolus*), elk (*Alces alces*) and, most importantly to this study, wild boar.

Vera's theory of cyclic turnovers of vegetation entails landscapes going through phases of different vegetation types. Figure 3.3 demonstrates this graphically. If the cycle is said to start from the more open parkland stage (stage B of figure 3.3), it is theorised to have evolved as follows:

- Open grassland areas are maintained by the grazing of specialist grass-eaters, such as wild cattle and horses. This and the rooting of wild boar provide opportunities for unpalatable herbaceous vegetation to develop which eventually leads to thorny scrub.
- This thorny scrub is not attractive to herbivores and so these areas act as a nursery for young trees, with regeneration taking place within its protection.
- Eventually groves of trees develop from the thorny scrub, which then causes the decline of the scrub under the shaded canopies of the groves. No further regeneration occurs in these groves due to this shade as well as the disturbances of large herbivores.
- As no regeneration occurs, the centres of the groves degenerate back into grassland as trees decay through age and other factors. Regeneration does occur at the fringes of groves though, as the light-loving thorny scrub is present here, providing protection for young trees against herbivores
- Thus the cycle starts again when groves degenerate back to open grasslands (Vera 2000).

In this system, the landscape maintains a 'half open' vegetation structure that is constantly in transition due to the driving force of large herbivore activity. Modelling by Kirby (2004) predicted that any one patch of land would take approximately 500 years to complete the full cycle. Vera (2000) argues that previous views of grazing limiting regeneration arise from situations that had deviated from this apparently natural cycle. The example of 'tree forests' are used. The scrub that provides protection for regenerating trees was cleared in the past, which created forests purely comprised of trees. Thus, regeneration was hindered by grazing, as there was no protective scrub. This leads to the conclusion that grazing inhibits regeneration, when in fact it could do quite the opposite (Vera 2000).

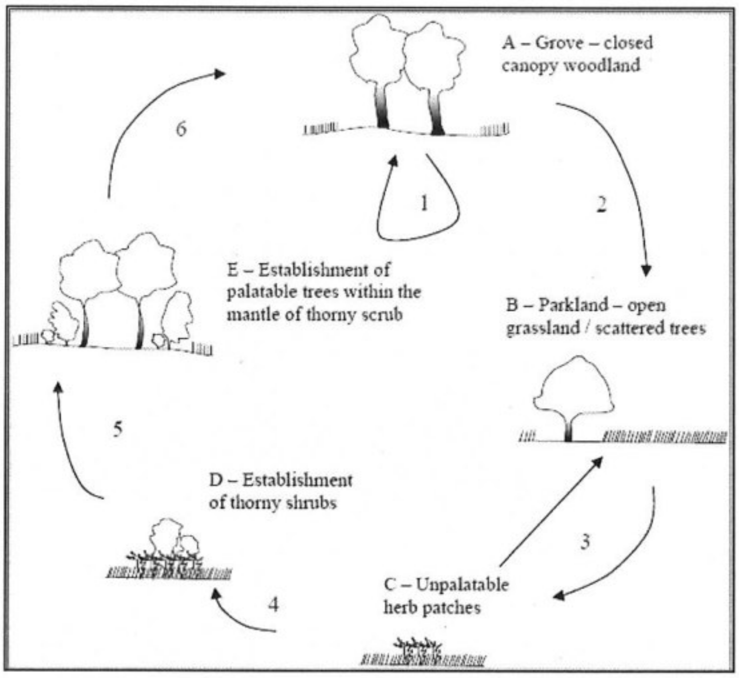


Figure 3.3: The cyclic vegetation turnover that could occur in Vera's mosaic, park-like landscape (Hodder et al 2005, adapted from Olff et al 1999).

There are various reasons why Vera came to conclude that vegetation structures developed in this way. One such reason is the fact that in pollen records from the period in question (the Atlantic period, c7,000 years BP), hazel (*Corylus avellana*) and oak are well represented, despite these trees needing more light than most (Vera 2000). It is thought by Vera that hazel and oak cannot regenerate in closed canopy forest and therefore the period in question could not be dominated by this type of vegetation. Also, Vera cites the fact that grazing animals known to be present at the time, such as tarpan and auroch, probably did not reside entirely within closed forest, meaning that this did not cover much of the range of these animals (Vera 2000). Added to this, the fauna of pre-Neolithic lowland western and central Europe is thought to pre-date the flora, therefore the herbivorous fauna could have directed developments in the flora (Vera 2000). As well as this, a model produced by Kirby

(2004) did recreate these vegetation dynamics in some areas. However, certain areas of the model created more closed conditions, indicating that the scenario might be more complex than is theorised by Vera.

Evidence that contradicts Vera's claims can be found in many instances. Firstly, pollen data indicates oaks dominated the closed canopy of the Białowieza Forest for around 600 years (Mitchell & Cole 1998), which suggests that oak can regenerate in such situations. Similarly, regeneration of sessile oak (*Quercus petraea*) was observed under a canopy of the same species with a south-easterly aspect (which creates light conditions conducive to regeneration) in the English Pennines (Pigott 1983). Contrastingly, no regeneration of this species occurred in a wooded area of Killarney (Ireland), possibly due to greater cloud cover and a denser understorey (Kelly 2002). This suggests that oak regeneration is possible in closed canopies, providing that conditions are favourable.

Also, evidence from Holocene Ireland suggests that large herbivores such as red deer and auroch did not play such a key role in driving succession. These species are lacking in the Irish record for this time compared to Britain and mainland Europe, yet pollen evidence indicates that the vegetation structure was remarkably similar to the rest of western Europe (Mitchell 2005).

It has also been suggested that large herbivores did not affect vegetation structure, merely its composition. For example, holly (*Ilex aquifolium*) was recorded invading gaps in the canopy of a cattle grazed island in a lake in Killarney. After cattle grazing ceased, however, yew (*Taxus baccata*) replaced holly in these gaps (Mitchell 1990).

As well as this, small herbivores such as rabbits (*Oryctolagus cuniculus*) have been claimed to have an affect on Vera's proposed system. Young oak trees were found to be protected from cattle grazing by thorny scrub in Dutch floodplains, but when the density of rabbits was high, oak saplings were damaged as rabbits could negotiate the scrub (Bakker 2003).

Despite these criticisms, this alternative view of European ecosystem dynamics is valuable. It is likely that European landscapes were more open than previously thought and "the role of large herbivores in past landscapes has almost certainly been underestimated" (Kirby 2004, p. 414). Various factors influence vegetation structures, resulting in some areas being more open, but others being more closed, while some shift according to Vera's theories (Hodder et al 2005). Vera himself acknowledges that his cyclic system would not occur in all areas (Vera 2000). Figure 3.4 shows how these variations could interact to create different vegetation structures. Many factors, such as fertility and water levels, could also cause herbivores to concentrate grazing in certain areas (Kirby 2004). Perhaps then, the difference between Vera's hypothesis and that of a closed forest is just "a matter of degree" (Hodder et al 2005, p.53).

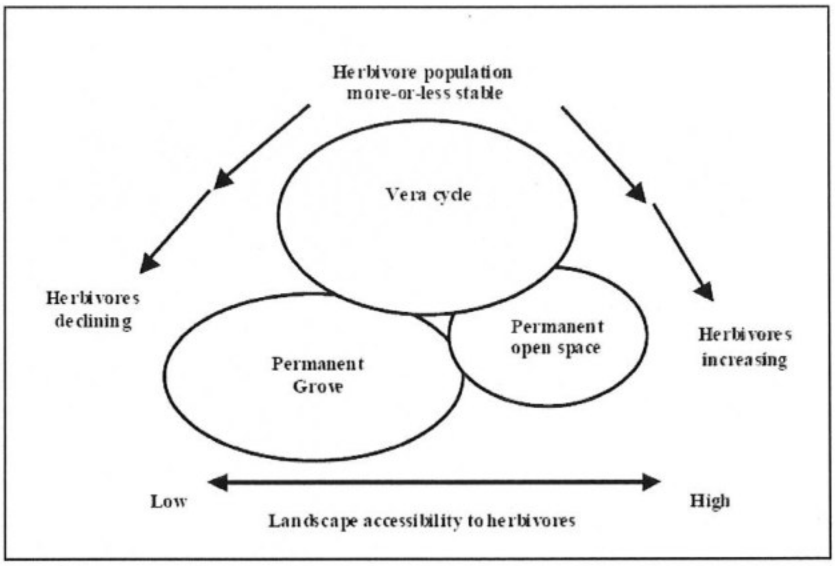


Figure 3.4: This diagram shows how certain areas could be structured differently depending on factors that affect the impact herbivores have, creating areas that are permanently closed, open, or shift according to Vera's vegetation cycle (Kirby 2004).

Within this proposed system, wild boar play a pivotal role. As well as grazing, their rooting is also proposed to aid the scrub development that allows tree regeneration, as it breaks up dominant vegetation and provides good conditions for germination (Vera 2000). As has been discussed, rooting can be extensive and so its effects on these systems could be significant (Hodder et al 2005). This study aims to establish whether the rooting of Tamworth pigs is causing such effects in the context of the Knepp Wildland Project.

The Oostvaardersplassen

Vera's theories are being tested in the Oostvaardersplassen nature reserve in the Netherlands. Naturalistic grazing has been implemented here and intervention kept to a minimum to allow natural processes to dictate landscape dynamics. This type of management has produced some evidence of Vera's theories. The grass-eaters (ponies and cattle) create the conditions that give rise to hawthorn (*Crataegus monogyna*) and blackthorn (*Prunus spinosa*) scrub, which protects seedlings, while the mixed feeders (red deer) slow this process down, which results in a system of "checks and balances, preventing any single type of vegetation from totally dominating" (Vera 2009, p. 33). This produces a half open landscape, known as wood-pasture (Vera 2009). Animals do not graze all parts of the reserve with the same intensity adding to the mosaic characteristic of the area (Vera 2009). These characteristics have attracted bird species rarely seen in the Netherlands, such as the White-tailed eagle (*Haliaeëtus albicilla*), which were thought to not breed in densely populated countries like the Netherlands, however this has happened at the Oostvaardersplassen (Vera 2009).

One of the most striking results seen at the Oostvaardersplassen is the way Greylag Geese (*Anser anser*) can drive changes in the ecosystem. They are able to turn reedbeds into open water through excessive grazing, which was thought to only be achievable by human management. This displays how herbivores have a greater impact on environments than has previously been thought. Many species have benefited from the mosaic of open water and reedbeds that the geese have created, just as the geese have benefited from the open grasslands created by the grazing of ponies and cattle, which they congregate in before and after their moult (Vera 2009). Thus, the Oostvaardersplassen system is highly linked, with the activities of many species interacting with each other.

However, the Oostvaardersplassen is not a perfect situation. If herbivore densities are too low in such projects, more closed conditions can occur. If densities are too high, environments become too open, as is thought to be the case in the Oostvaardersplassen (Hodder et al 2005). The project has run for over two decades, yet currently there is little sign of regeneration as densities of grazing animals are now too high. It is thought that a population crash is needed for this regeneration to take place, but the patterns of the effects of this are hard to predict (Hodder & Bullock 2009). This may just be part of the cycle though and as natural processes are the real aim, nature is left to run its course.

The Knepp Castle Estate and its Wildland Project

The Knepp Castle Estate practised intensive agriculture on the majority of its land up until 2001. Since then however, a revolutionary project at Knepp called the 'Wildland Project' has taken form. The project aims to achieve a greater level of biodiversity in the area and allow natural processes to predominate in the landscape. As in the Oostvaardersplassen, this is facilitated by free-roaming grazing animals (Anon. 2011).

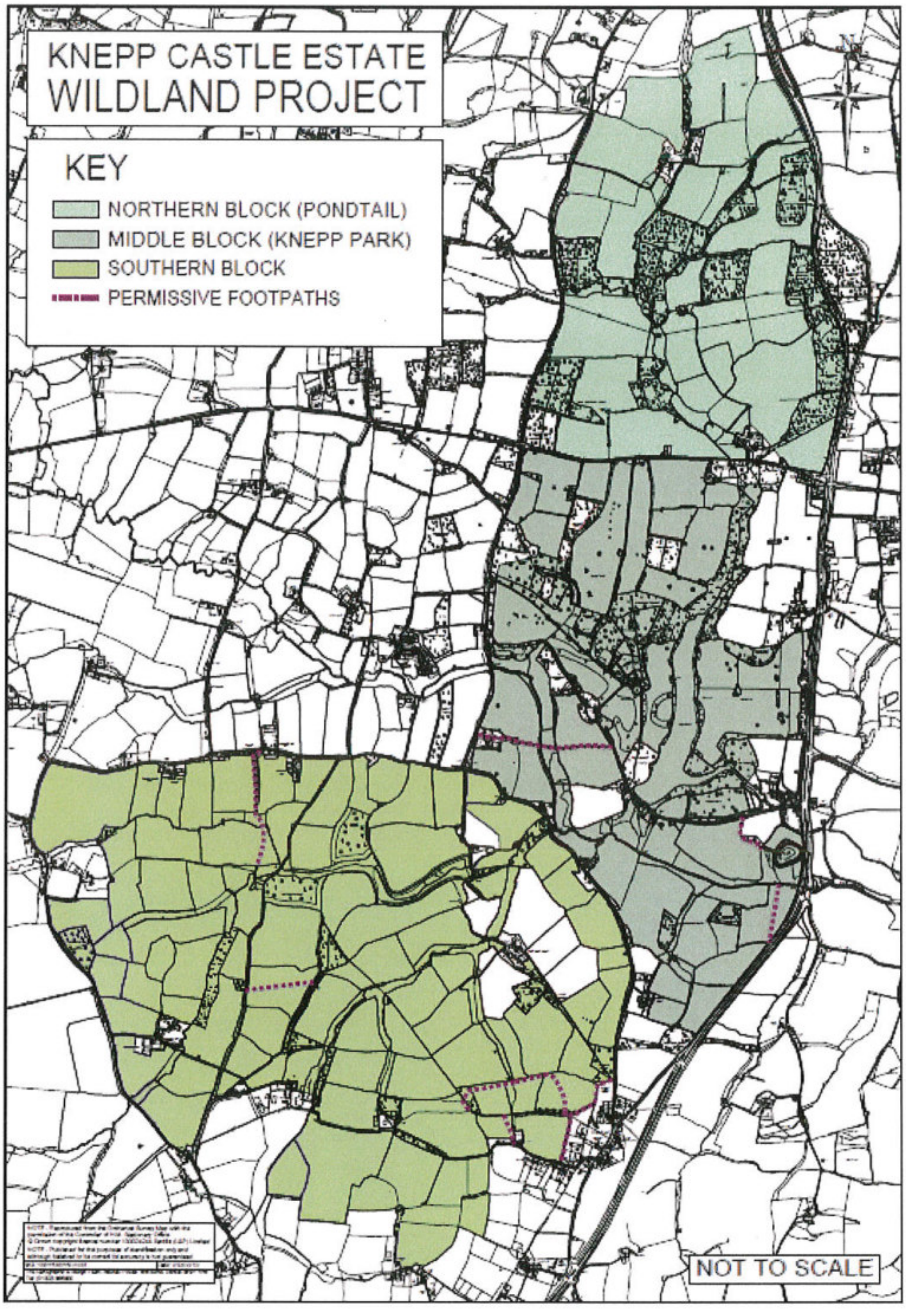


Figure 3.5: The area of the Knepp Castle Estate included in the Wildland Project. This map also shows the division of the project area into the North, Middle and South Blocks (Knepp Castle Estate).

The project area is separated into three 'blocks' (see figure 3.5), however there is a culvert connecting the South and Middle Blocks which allows pigs and deer to travel between the two (Anon. 2010). The blocks were all entered into the Wildland Project at different times and have been treated differently. The Middle Block was the first to be entered, with some areas being reverted from arable in 2001 and grazed in 2002 and others being reverted in 2004 and grazed in 2005. The North Block was then reverted from arable in 2005 and grazed in 2006. Various areas of both of these blocks were reseeded with wild seed mixes (Greenaway 2006). The South Block was treated differently, as the majority of agriculture was ceased in 2004, but the area was not grazed until 2009 (Jason Emrich, personal communication), thus vegetation was left to develop in this area unchecked apart from grazing by wild rabbits and roe deer.

Like in the Oostvaardersplassen, analogues of past species are used to recreate the proposed pre-agricultural herbivore-driven system. Old English Longhorn cattle are substituted for aurochs, Exmoor ponies for tarpan and Tamworth pigs for wild boar, while fallow deer were also introduced. The cattle are present in all three blocks while the ponies, fallow deer and pigs have been present at some point in both the Middle and South Blocks (Jason Emrich, personal communication). Wild roe deer and rabbits also occur throughout the Wildland Project (Anon. 2011).

The Knepp Wildland Project is not completely comparable to the Oostvaardersplassen. The latter started from a poor ecological baseline as it is sited on reclaimed land (Hodder et al 2005), while Knepp is former agricultural land. It still has a relatively poor ecological baseline (Greenaway 2007), but there are cultural and environmental features that need to be considered in the project, such as traditional English hedgerows (Greenaway 2007).

Knepp is located in the highly cultural and densely populated landscape of lowland England. Local communities are kept involved, but it is impossible to keep everyone happy with such projects and legislation can sometimes limit the lengths that the project can extent to. It is partly due to this that the Knepp Wildland Project is not entirely resource-limited, as animals are slaughtered for sale as meat and are occasionally moved around the project for various reasons. Thus the grazing system cannot be claimed to be 'naturalistic grazing' in the purest sense, however in the context of an ex-arable lowland English estate, it has pushed the boundaries of such alternative systems as far as they are permitted to go. The estate needs to be economically viable and comply with regulations so certain compromises have to be made. It is also important to remember that the past can never really be re-created, we can only recreate certain conditions that may be similar to past ones (Hodder et al 2005) and so we must think of a 'future-naturalness' instead of 'original naturalness' (Peterken 1996).

Despite these slight limitations, the Knepp Wildland Project has produced some exciting results. Vegetation development in the project has provided some evidence of Vera's theories, such as the encroachment of hedgerows and scrub into fields (Anon. 2010) and some regeneration that is seen to be occurring. Definitive effects of the project on landscape structure are not expected to be seen until years 20-25 though, as such processes work on long time scales (see figure 3.6). Many species have returned and indeed colonised the area, such as the bittern (*Botaurus stellaris*) and in the future it is hoped that other former species of the area such as elk, red deer, bison and beaver (*Castor fiber*) can be included in the project (Anon. 2011). Wild boar from the newly established feral population at Romney Marsh in Kent may also migrate to Knepp. This project is progressing our understanding of the interaction between herbivore activity and vegetation structures, thus the 'rewilding' of Knepp is an invaluable asset to such studies.

2007 **Year 20-25**

Figure 3.6: These drawings show how vegetation is expected to develop between 2007 and year 20-25 of the project (Anon 2007).

The Tamworth pigs of the Knepp Castle Estate Wildland Project and their use as analogues for wild boar

Two Tamworth sows and eight piglets were introduced into the project in January 2005, with the first boar introduced in December 2006 (Anon. 2011). As with the other large herbivores introduced into the project, the pigs are free to roam the blocks that they are in. No supplementary feeding is given and so the pigs use any food resources they can find in the landscape. Like wild boar, the pigs graze on vegetation, as well as foraging and rooting for food stuffs such as roots, rhizomes, invertebrates, fruit and some occasional meat. Also, as in the wild, the autumn and winter acorn mast in the Wildland Project is a major component of the pig's diet, which is provided by the estate's many oak trees (Anon. 2011)

Wild boar are elusive animals that would be difficult to observe. Therefore an analogue of them was required for this study. The Tamworth pigs of Knepp presented the best option. Firstly, the unique situation at Knepp means they act as naturally as is possible for a domestic animal and their interactions in a complete system can be seen. Also, Tamworth pigs are thought to be the most typical descendant of the Old English Forest pig (Anon. 2011), meaning they are probably the breed of pig most similar to wild boar. Obviously they are not identical to wild boar, yet they are a suitable subject for this study and present the closest analogue possible.

4. Methods

Study Site

Field work for this study was carried out at the Knepp Castle Estate Wildland Project. The estate is located to the south of Horsham, in West Sussex, south England (see figure 4.1). Knepp was chosen due to the unique opportunities here for researching the patterns of activity and effects of their Tamworth pigs on vegetation structure.

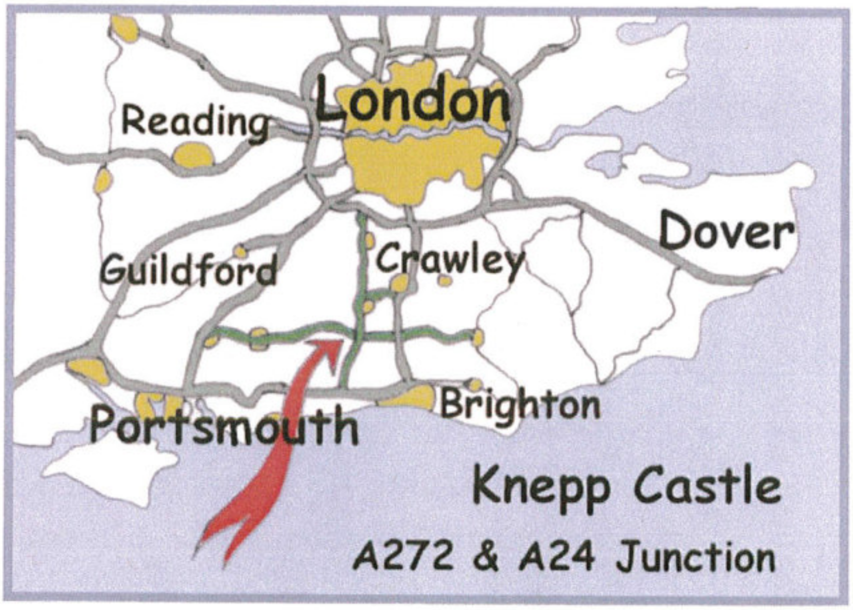


Figure 4.1: A map showing the location of the Knepp Castle Estate in south England (Knepp Castle Estate).

Vegetation surveying

In order to discern what the pig's effects on vegetation structure are within the project, it was first necessary to conduct a vegetation survey to gain an impression of this vegetation structure. Four habitat types were identified: floodplain, woodland, old pasture (pastures not re-seeded) and re-seeded pasture, with one 1m^2 quadrat being sampled in each habitat in the three blocks (North, South and Middle). The South

Block was different in that there are no re-seeded sites here, so instead an exclosure site was sampled (this site was a small plot of land, roughly 10m x 10m in area, which had been fenced to prevent animals from grazing on it). Thus in total there were twelve quadrats sampled in the vegetation survey: three floodplain sites, three woodland sites, three old pasture sites, two re-seeded pasture sites and the one South Block exclosure site. The sample sites for each habitat type in each block were chosen randomly. The location of each quadrat is mapped in Appendix I.

The vegetation survey was carried out in August 2010. This was an optimal time of year as it was within the growing season and thus plants would be easier to identify. Sampling plots on the same habitat-types in each of the different blocks would allow comparison between them. This was desired as each block has had different treatments and contain different compositions of animals, thus comparing the North Block (which has no pigs) to the Middle and South Blocks (which contain pigs) would be possible, providing an insight into the effects pigs have on vegetation. Plots sampled were selected randomly for each habitat in each block.

For each plot surveyed, species of vascular vegetation were identified and recorded using a plant identification book (Rose 2006, 2^{nd} edition). Mosses and grasses were not identified by species and were categorised as 'moss' and 'grass' due to time constraints. The number of species was counted giving species diversity data for each plot. Also, the percentage cover of different categories of vegetation was estimated. Table 4.1 displays what these categories were and examples of each category.

Vegetation Type	Description	Examples of Species
Short vegetation	The shortest vegetation	Grasses, mosses, white clover (*Trifolium repens*)
Shorter weeds and herbaceous vegetation	Taller than short vegetation but still fairly short (ie. shorter than ~20cm)	Buttercups (eg. *Ranunculus repens*), silverweed (*Potentilla anserine*), common fleabane (*Pulicaria dysenterica*)
Taller weeds and herbaceous vegetation	Tallest non woody vegetation (ie. taller than ~20cm)	Creeping thistle (*Cirsium arvense*), common ragwort (*Senecio jacobaea*), pale persicaria (*Polyganum lapathifolium*), nettles (*Urtica dioica*)
Woody vegetation	Scrub-like, thorny vegetation as well as young trees, etc.	Brambles (*Rubus fructicosus agg.*), tree seedlings (eg. *Quercus petraea*)
Non vegetated material	Features such as bare ground, leaf litter, dead wood etc.	N.A.

Table 4.1: The categories of different vegetation cover types and examples of species categorised within them.

Pig activity

Extensive observations of the pigs were made by following groups of them during daylight hours (roughly between 9:00 and 18:00), as undertaking such field work in darkness would have been difficult and potentially dangerous. This was done in order to determine what the pig's patterns of activity were. Observations took place in two periods: summer (August 2010) and winter (January 2011). This was necessary to identify any seasonal patterns of activity. During summer the pigs were present in the Middle and South Blocks, whereas in winter they were only present in the South Block, as they had been moved here in the autumn of 2010. Thus, for the summer data comparisons could be made between activity patterns between the Middle and South Block, while this was not possible for winter data. Table 4.2 displays the animal composition of each block. In summer there were around 48 pigs in the project, while in winter (after the slaughter of some in autumn) there were 17.

Block of Wildland Project	Summer Study Period	Winter Study Period
North Block	Cattle, wild roe deer and rabbits	Cattle, wild roe deer and rabbits
Middle Block	Pigs, cattle, fallow deer, ponies, wild roe deer and rabbits	Cattle, fallow deer, ponies, wild roe deer and rabbits
South Block	Pigs, cattle, fallow deer, ponies, wild roe deer and rabbits	Pigs, cattle, fallow deer, ponies, wild roe deer and rabbits

Table 4.2: The animals present in each block in the two study periods.

Detailed notes were taken recording all aspects of the pig's behaviour, as well as other general observations. Also, accurate times were recorded. The pig's activities were then classified into five categories: grazing, rooting, foraging (defined as consuming food but not through grazing or rooting), travelling and resting. The time spent by the pigs doing each of these activities was then calculated, which allowed percentages of time spent doing each activity to be derived. The activity that the majority of the group seemed to undertake was the one that was recorded. Also, regular GPS readings were taken with a handheld GPS, which allowed spatial patterns of pig activities to be analysed using Esri's ArcMap software.

Rooting index

Allied to the pig activity data was an assessment of the severity of rooting. A 'Rooting Index' ('R.I.' 1-3) to measure this was derived (see table 4.3). As the pigs were followed, any rooting observed during this time was given a score. Additionally any sign of previous rooting that was identified while following pigs was also scored, which gave two types of rooting data: observed rooting and signs of past rooting. GPS readings were also taken for all recorded examples of rooting. This data allowed spatial and temporal patterns of rooting severity to be seen. ArcMap was again used to analyse spatial patterns.

Rooting Index (R.I.) Score	Description	Photographic Example (Appendix II)
R.I. 1	Single snout marks with vegetation removal. Shallow disturbance (less than 5cm) and covers small area	Figure 1
R.I. 2	Ground turned over. Vegetation removed leaving bare ground. Deeper than 5cm. Continuous cover less than $1m^2$	Figure 2
R.I. 3	Ground turned over and vegetation completely removed. Deeper than 5cm. Extensive cover (over $1m^2$)	Figure 3

Table 4.3: Rooting Index scores and their descriptions, as well as examples of each score (in Appendix II).

Analysing the vegetation survey data in conjunction with the data on pig activity was hoped to yield some evidence of the effects of pig activity on vegetation.

Limitations

The main limitation involved pigs altering behaviour due to human presence while research was being conducted. Observation required being close to pigs, although as much distance was kept as possible to restrict the effect of human presence. Also, individual pigs within a group sometimes carried out different activities which made classifying the group activity difficult; however a decision was made at the time as to the majority activity. As well as this, time restrictions meant that only rooting that was seen while following the pigs was recorded, therefore signs of rooting in other areas were not taken into account.

5. Results

Vegetation structure

Both the old and re-seeded pasture sites in the North and Middle Block were structured similarly (see figures 5.1 and 5.2), with short vegetation comprising at least 70% in each site. In the Middle Block re-seeded pasture, the plot was 100% short vegetation. The North Block re-seeded site contains 25% taller weeds and herbaceous vegetation, while the Middle Block re-seeded pasture did not contain this type of vegetation.

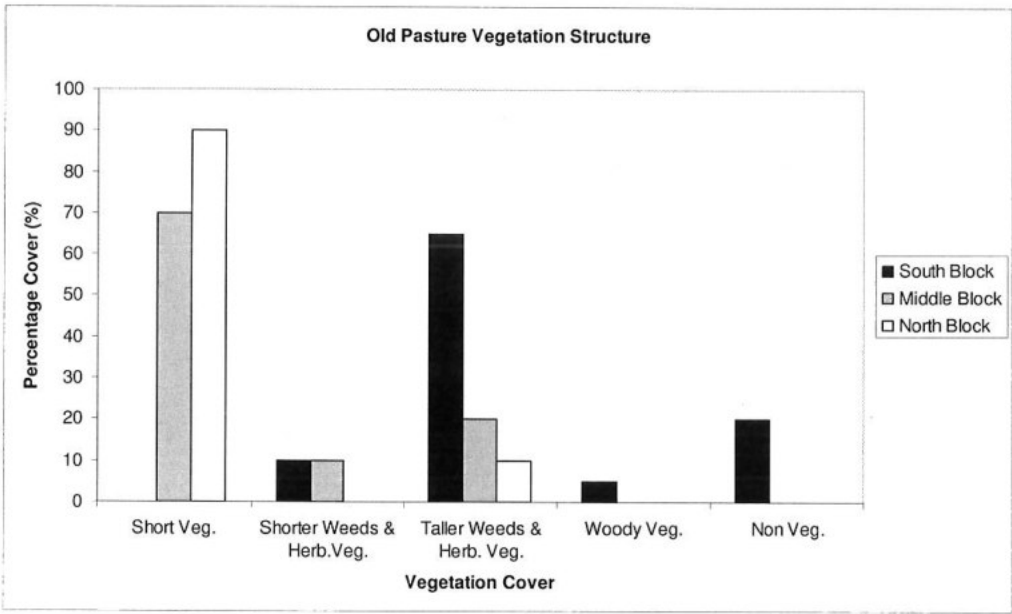


Figure 5.1: The percentage cover of different types of vegetation in the old pasture plots.

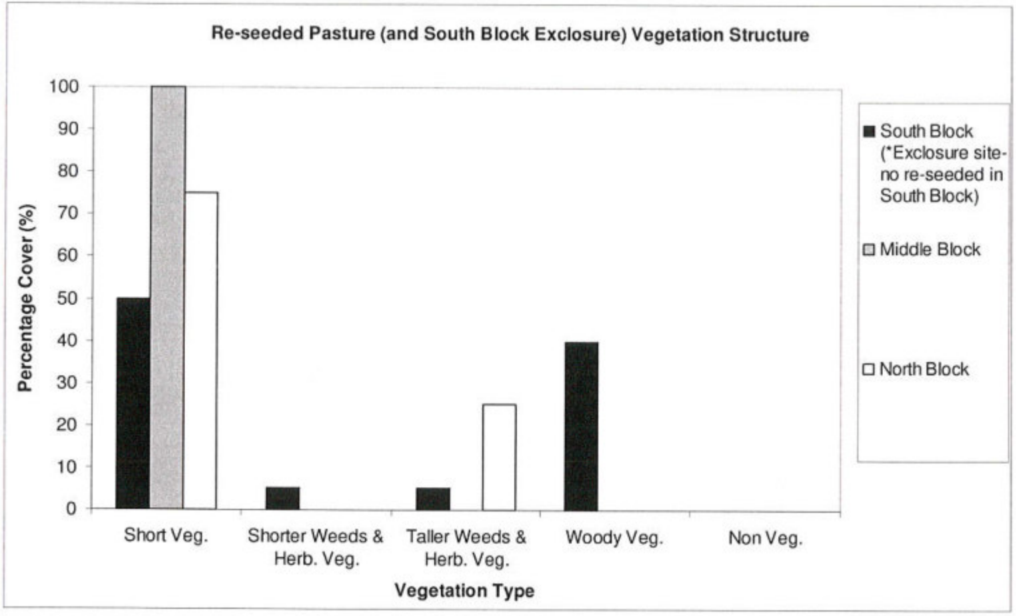


Figure 5.2: The percentage cover of different types of vegetation in the re-seeded pasture sites and the South Block exclosure site.

The South Block old pasture site differs as it contains no short vegetation and is mostly comprised of taller weeds and herbaceous vegetation (65%) with a 20% proportion of non-vegetated material (see figure 5.1). This shows that fields in the South Block are scrubbier, with less short vegetation and more weeds and shrubs. The non-vegetated material would imply more rooting in the South Block old pasture as well, as there is no non vegetated material in old and re-seeded sites in both the North and Middle Block. This also applies to woody vegetation, which was recorded in small amounts (5%) in the South Block old pasture, but was not present in the old or re-seeded pastures in the North and Middle Blocks. This woody vegetation was actually an oak (*Quercus spp.*) sapling, which provides evidence of some level of regeneration.

WEEDS wrong use of word.

The South Block exclosure site has near equal levels of short and woody vegetation (50% and 40% respectively; see figure 5.2). The general area the exclosure was situated in was quite scrubby; it seemed that the exclosure was actually less densely vegetated than immediately outside it. The high proportion of woody vegetation was probably because there was less suitable ground to place the quadrat in (as the area was enclosed) and so the woody vegetation in the exclosure (bramble, *Rubus fructicosus agg.*) is highly represented.

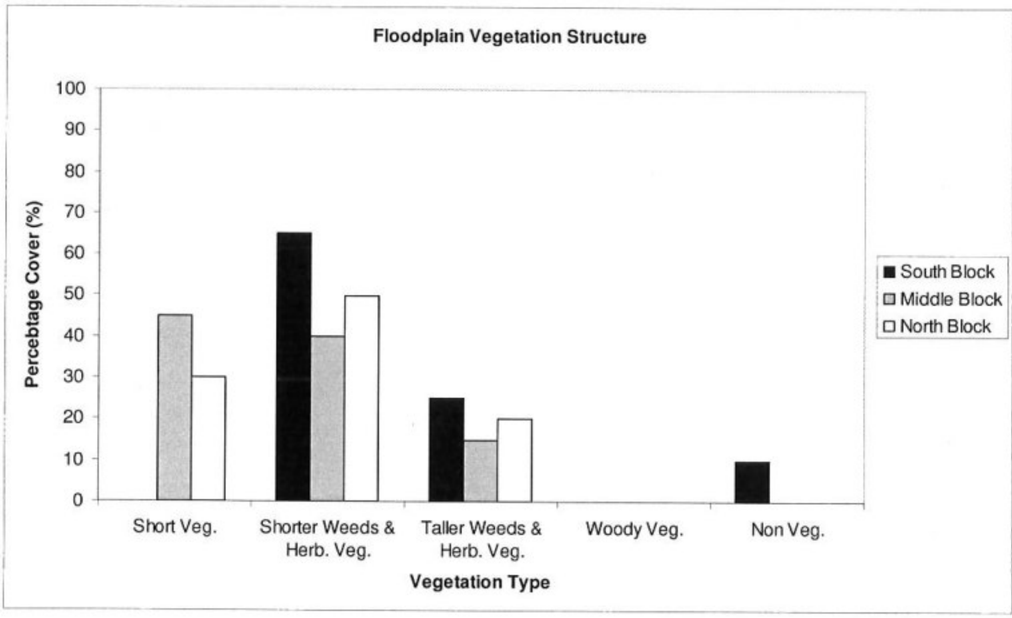


Figure 5.3: The percentage cover of different types of vegetation in the floodplain plots.

Floodplain sites are structured differently to the pastures, being comprised of more weedy and herbaceous vegetation (see figure 5.3). This could be because higher water levels here produce denser vegetation. Spatial patterns seen in the pastures are still present, with the South Block floodplain having no short vegetation, while the Middle and North Block sites have 45% and 30% respectively. This again belies the scrubbier nature of this area. The South Block floodplain differs from the South Block old pasture in that the floodplain is dominated by shorter weeds and herbaceous vegetation (at 65%) while the old pasture is mostly taller weeds and herbaceous vegetation (at 65% as well). Shorter weeds and herbaceous material are also prominent in the Middle and North Block floodplains. This could be because floodplains are less accessible to grazers sometimes, so the more attractive shorter herbaceous material can persist here. Again the South Block site is the only floodplain to have non-vegetated material, suggesting increased rooting here. The proportion of non-vegetated material in the South Block floodplain is lower than in the old pasture, despite the floodplain having wetter ground which makes rooting easier. Perhaps the floodplains are sometimes too waterlogged for the pigs to access. No woody vegetation is present in any of the floodplain sites. This may also be due to excessive waterlogging.

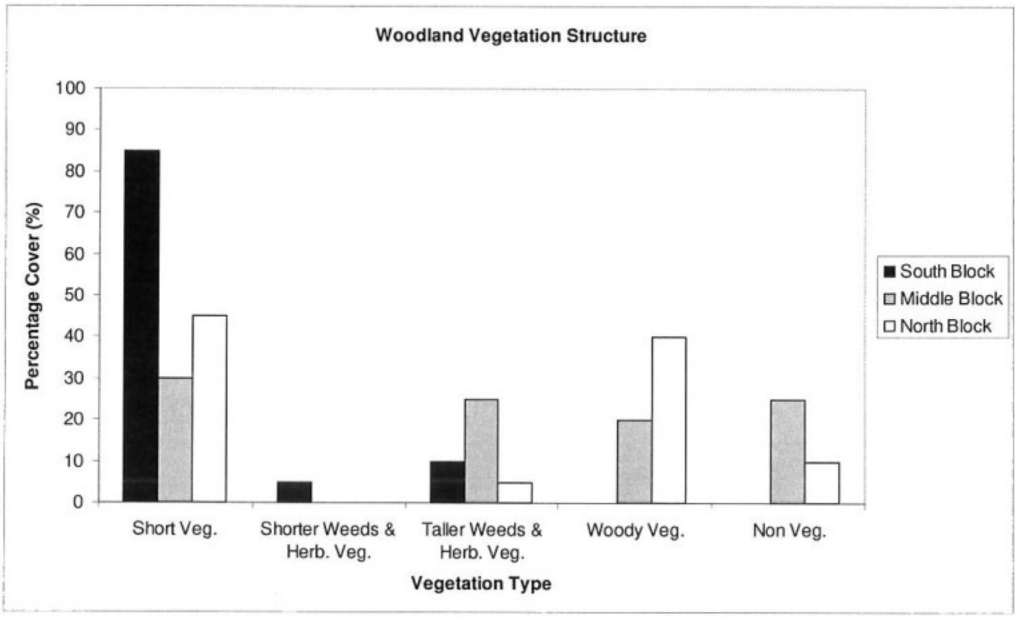


Figure 5.4: The percentage cover of different types of vegetation in the woodland plots.

Woodland sites were more varied (see figure 5.4). Contrastingly to the other sites, the South Block woodland was dominated by short vegetation (85%). However, this plot was in a 13 year old plantation woodland (Jason Emrich, personal communication) with a light canopy, thus light penetrated easily to the ground. As this woodland was very young, it would probably be disturbed less by the pigs, as they are more attracted to older deciduous woodlands, thus dominant shorter vegetation would persist. Another oak sapling (*Quercus petraea*) was seen in this woodland (not in the quadrat) as well, which again shows some regeneration.

The North and Middle Block woodlands were more established. The North Block site had a denser understorey, with more short (45%) and woody (40%) vegetation, despite the Middle Block woodland having a lighter canopy. This, plus the higher level of non-vegetated material in the Middle Block (25%) could show some of the impacts the pigs are having (ie. removing woodland ground flora), as pigs are not present in the North Block.

Plant species diversity

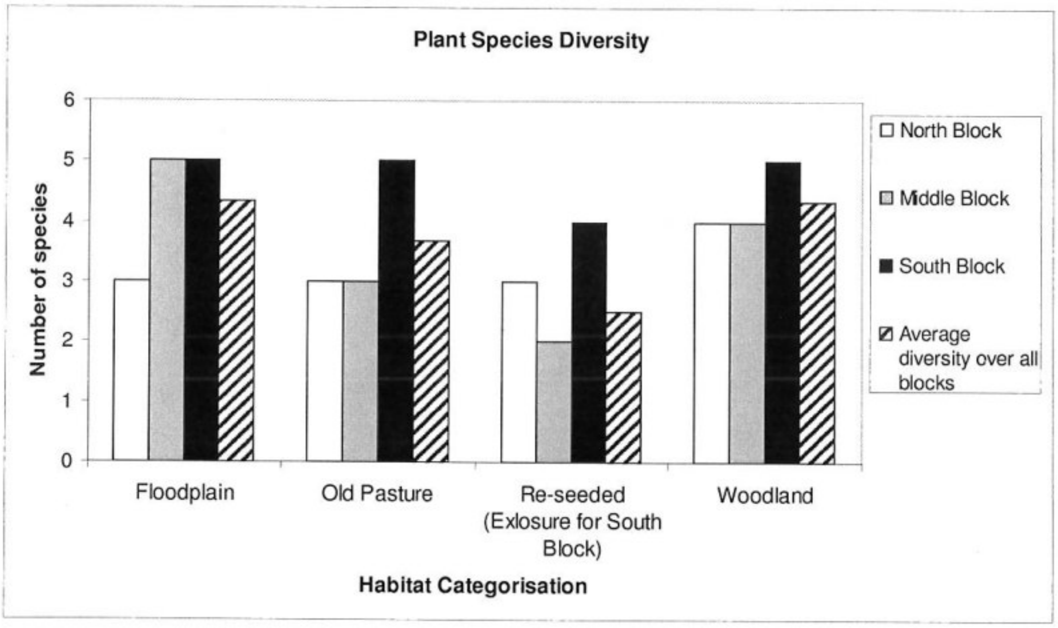


Figure 5.5: The plant species diversity of each site. This graph also shows the average species diversity for each type of site across all three blocks (the average score for re-seeded sites does not include the score for the South Block exclosure site).

South Block sites consistently have the highest species diversity, with only the exclosure plot having a diversity score below 5, with 4 (see figure 5.5). This again displays the more diverse and scrubby nature of the South Block. The North block sites are least diverse overall. Woodland and floodplain sites are the most diverse habitat-type, while re-seeded sites have the lowest average diversity. A difference exists between the diversity of old pastures, with the North and Middle Block sites both having a lower score of 3, while the South Block has a high score of 5. Again this shows the more diverse nature of the South Block. The exclosure site in the South Block has a relatively high score of 4, although this is the lowest score within this block. A list of plant species recorded can be found in Appendix III.

Seasonal patterns of pig activity

Figure 5.6 displays how most time is spent rooting in winter (70%), with travelling being the only other significant activity. Summer patterns are more varied, with grazing being predominant (at 36%), followed by resting (25%) and rooting (23%). The lack of resting in winter would suggest that the pigs have to be active for longer, searching for food as resources are not so readily available in winter. The higher percentage of time spent foraging in winter was due to pigs eating seed from game bird feeders (which was classed as foraging).

Autumn is the time of plenty with Acorn mast ...

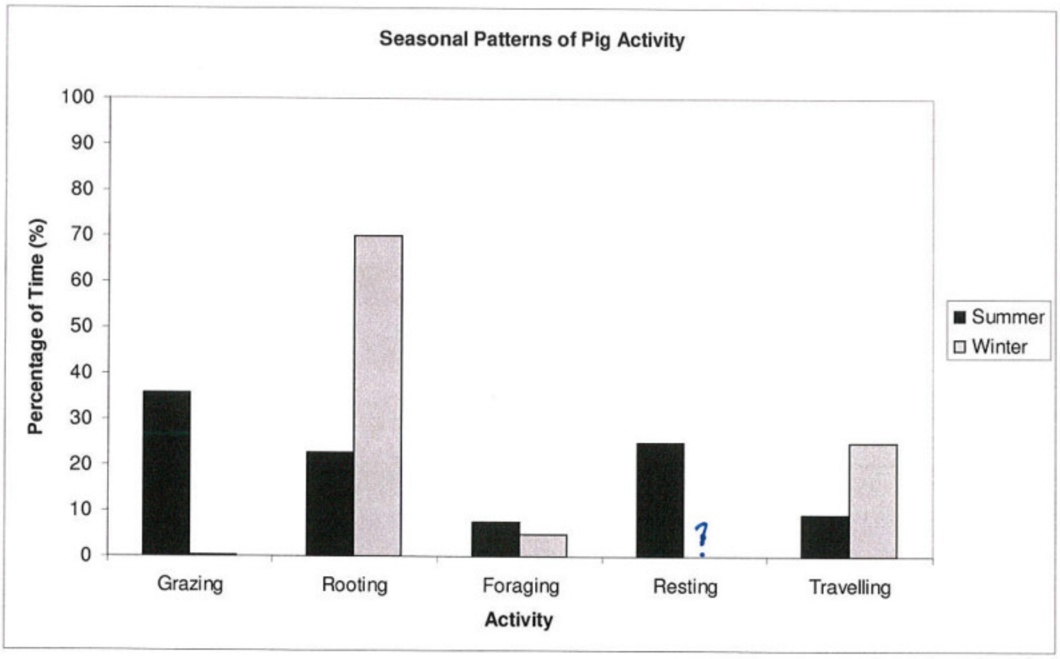


Figure 5.6: The temporal division of pig activity in summer and winter. Data for the Middle and South Block in summer was combined so that a comparison between the two seasons could be made.

Spatial patterns of pig activity

When comparing summer data from the Middle and South Blocks, it can be seen that most time is spent grazing in the Middle Block (at 44%) with rooting being less significant at 9% (seen figure 5.7). This contrasts to the South Block, where rooting was the most observed activity at 36%. Grazing in the South Block is also significant though with 28% of time spent doing this. Resting was observed in both blocks, with 28% of time observed resting in the Middle Block and 22% in the South Block. This could be expected as observations took place during the daytime and so higher temperatures in summer would cause pigs to rest in shaded areas. Percentages of time spent travelling were similar in both blocks. There is a slight difference in levels of foraging with more time spent foraging in the Middle Block (12%) than in the South Block (3%). Reasons for this are unclear as it does not seem that opportunities for foraging are any lower in the South Block.

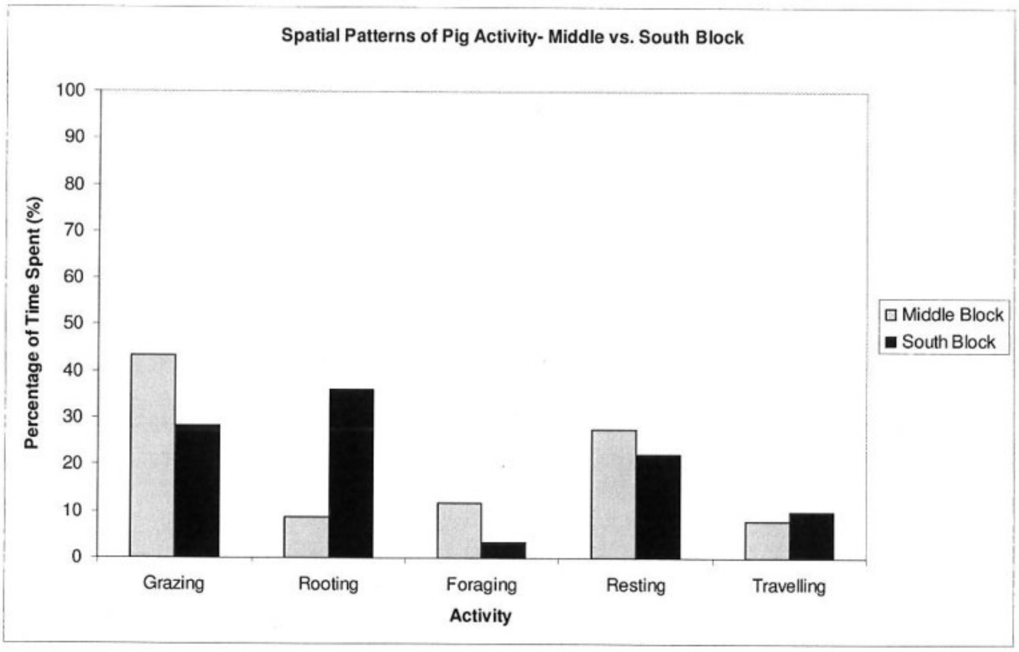
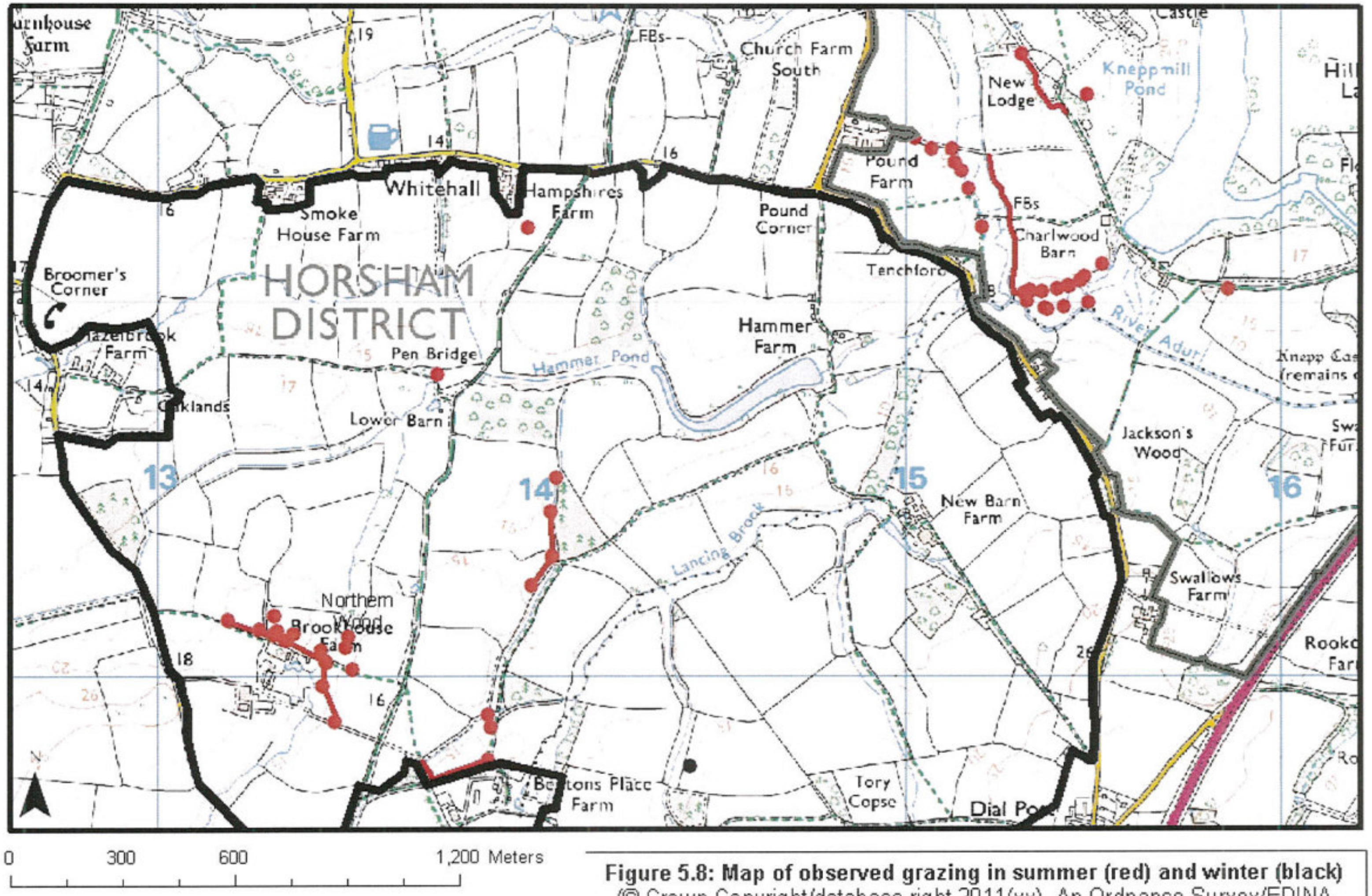


Figure 5.7: The patterns of pig activity in the Middle and South Blocks during summer. This comparison was not possible during winter as the pigs were only present in the South Block at this time.

Figure 5.8 displays spatial patterns of grazing. There is only one incidence of grazing during winter (at the south of the South Block). It can be seen that grazing was almost exclusively observed along the edges of fields and woods, as well as along streams and paths. Pigs grazed almost exclusively on grasses and white clover (*Trifolium repens*). Often pigs would alternate between grazing and rooting. Also, grazing was frequently carried out as the pigs travelled, which is denoted by the lines on figure 5.8. As well as this, pigs would graze in select areas for extended periods of time, such as in the fields around the River Adur at the south end of the Middle Block.

Spatial patterns of rooting

Figure 5.9 shows spatial patterns in rooting and also rooting severity. Like with grazing, rooting is mainly concentrated along the edges of fields, woods and paths. Most rooting is focused in areas of the South Block, with noticeable concentrations of summer rooting around Northern Wood and winter rooting around Wickwood and Tory Copse. Even in woodlands pigs rooted at the edges of these areas. Rooting or signs of rooting were frequently seen on floodplains or near water bodies, such as in Northern Wood (where a drain is present), as well as around the River Adur in the Middle Block. This is most likely due to wet ground being easier to root. There also seems to be a separation between frequently rooted areas in summer and winter. For example, much rooting occurred around Northern Wood in summer, whereas a lot of winter rooting occurred near Wickwood and Tory Copse. This could be due to differences in accessibility, resources or ease of rooting in these areas between seasons. Rooting of all three index scores (R.I. 1-3) occurred in similar areas, however rooting in the Middle Block was usually less severe (R.I. 1-2). There also seems to be more rooting nearer the centre of fields during winter (eg. in the south of the South Block). Some of this was done in pre-rooted patches along the edges of paths through the middle of fields, as well as under large oak trees, thus this rooting was still focused at landscape features. Compared to grasslands, rooting in woodlands was contained in a smaller area, perhaps because woodlands were richer in food items. Also, rooting was sometimes carried out while travelling like grazing; however this was for shorter distances that are not represented on figure 5.9.

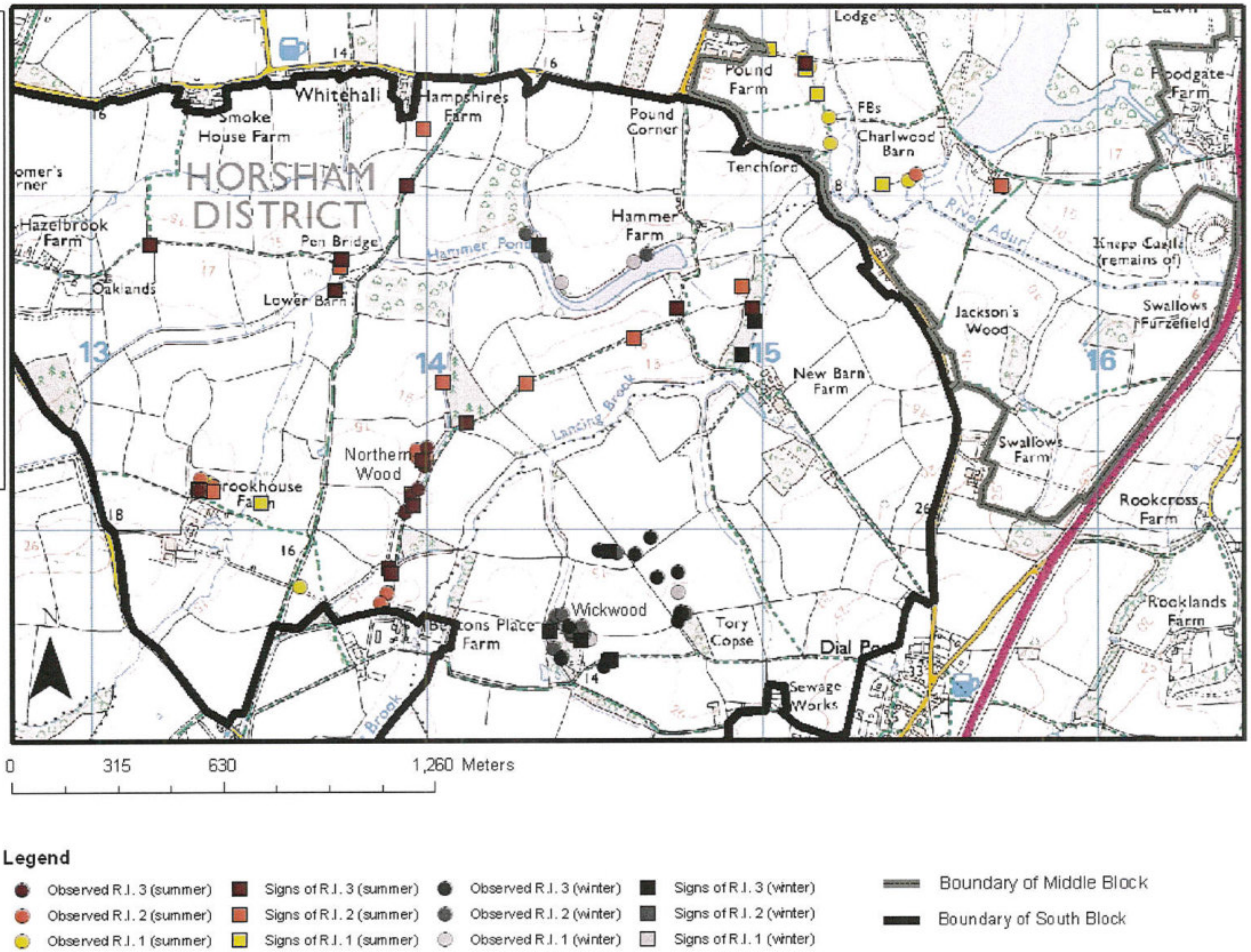


Legend

- Summer grazing
- Winter grazing
- Grazing Routes
- Boundary of South Block
- Boundary of Middle Block

Figure 5.8: Map of observed grazing in summer (red) and winter (black)
(© Crown Copyright/database right 2011(yy). An Ordnance Survey/EDINA supplied service)

Figure 5.9: Map of obeved rooting and signs of rooting (R.I. scores 2-3) for summer (red, orange and yellow) and winter (black, dark grey and light grey) (© Crown Copyright/database right 2011 An Ordnance Survey/EDINA supplied service)



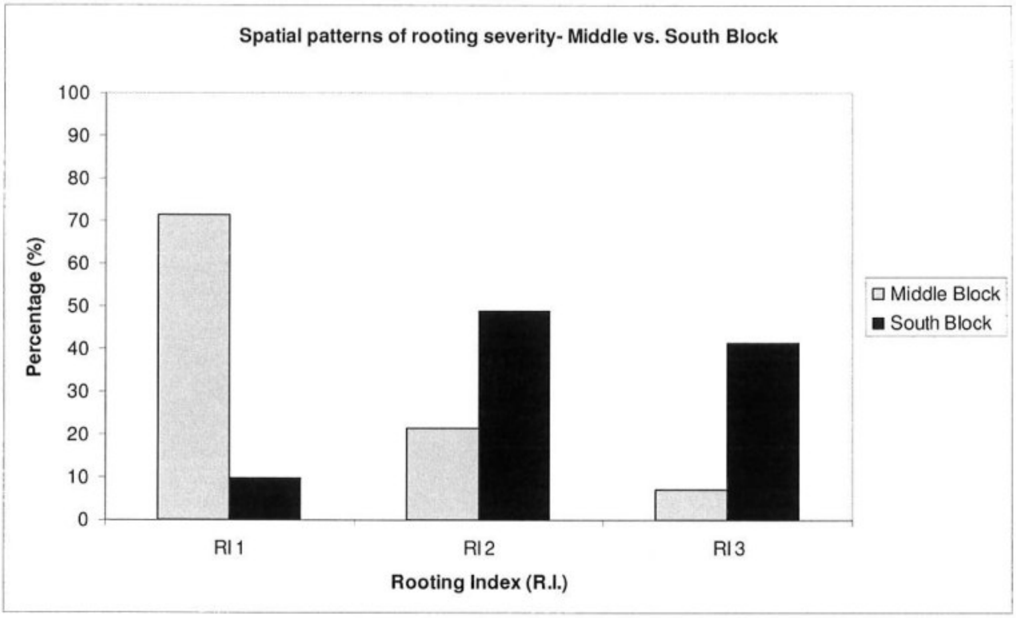


Figure 5.10: The percentages of recorded rooting assigned to each Rooting Index score in the Middle and South Blocks during summer. This comparison was not possible during winter as the pigs were only present in the South Block at this time.

Rooting severity also differed between the two blocks pigs inhabited in summer. The majority of recorded rooting in the Middle Block was scored R.I. 1 (see figure 5.10) at 71%, while R.I. 1 rooting only comprised of 10% of rooting in the South Block. Most South Block rooting was scored R.I. 2 (49%), with 41% of rooting here being R.I. 3. Only 7% of Middle Block rooting was considered R.I. 3, while R.I. 2 rooting comprised 21% of rooting here. Thus it can be said that during summer observed rooting was more severe in the South Block.

The habitats that rooting was seen in were also categorised into grassland, semi-natural deciduous woodland habitats and coniferous plantation habitats. The proportion of time spent rooting in each was recorded (see figure 5.11). In summer rooting time is evenly split between grasslands and semi-natural woodlands (50% each), while in winter grasslands predominate with 64%. Winter rooting in semi-natural woodlands is lower at 19%, while 16% of winter rooting was seen in coniferous plantations. No rooting was seen in coniferous stands in summer.

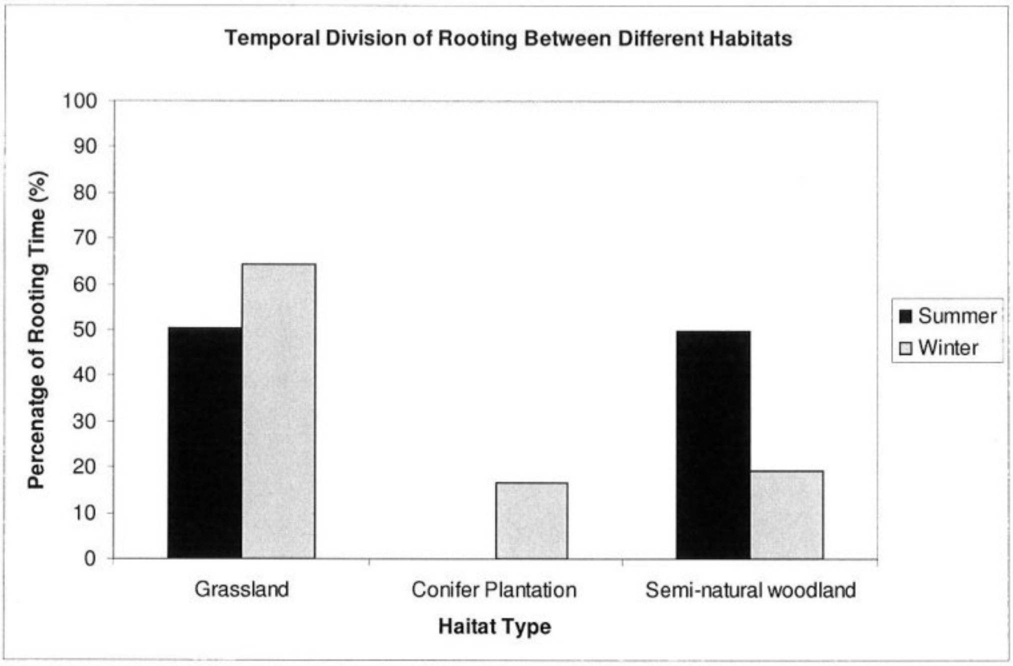


Figure 5.11: The percentage of time spent rooting in each habitat for both summer and winter. Summer data for the Middle and South Blocks was combined to allow this comparison.

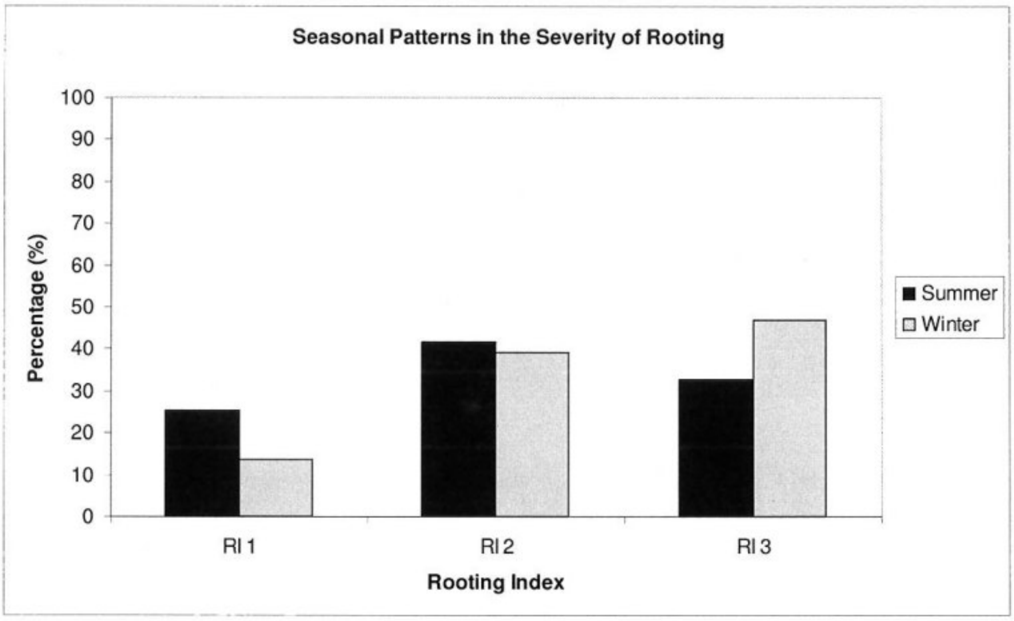


Figure 5.12: The percentage of recorded rooting given each Rooting Index score (R.I. 1-3). The summer data from the Middle and South Blocks was combined to produce this comparison.

Seasonal patterns of rooting severity

Figure 5.12 displays the differences in rooting severity between winter and summer. Percentages of rooting scored R.I. 2 did not differ significantly, however more winter rooting was scored R.I. 3 (47%) compared to summer (33%). The reverse of this pattern is seen with R.I. 1 rooting, with this comprising 25% of summer rooting compared to 14% in winter. From this graph we can also see that most rooting is generally medium to severe in nature (R.I. 2-3).

6. Discussion

Spatial patterns of pig activity

The higher proportion of time spent by the pigs rooting in the South Block compared to the Middle Block in summer (see figure 5.7) could be due to the greater density of vegetation in grasslands in this area. Thus, more rhizomes and other subterranean foods would be present (Bueno et al 2009), meaning levels and also severity of rooting is higher in the South Block. Bueno et al (2009) also found vegetation to be the main variable in the location of rooting. The looser soil in the South Block (resulting from the longer period of time it was left fallow without large herbivores) contributes to more extensive rooting as well. Also, the Middle Block contains a higher proportion of short vegetation such as grasses and white clover (*Trifolium repens*), which the pigs preferentially graze on, thus a higher proportion of time is spent grazing in the Middle Block.

The tendency for rooted patches to be located on floodplains and near water bodies (see figure 5.9) can be explained by the higher level of soil moisture at these sites. These damper soils are easier to root and may be richer in food resources. Wild boar have also been found to preferentially root mesic soils (Welander 2000). Again, this was put down to the ease of rooting in these areas, as well as the potentially richer food resources. Soil moisture content has also been identified as an important factor in rooting locations by other reports (eg. Bueno et al 2009).

This pattern is less noticeable for winter rooting, with more rooting in fields further away from water during winter. An example is the clustering of winter rooting around Tory Copse and the fields to the north of it (in the south of the South Block, figure 5.9). This could be because suitably moist soils occur over a greater area in winter, enabling more rooting in such areas that are too dry at other times of year.

Another type of habitat preferentially used by the pigs for rooting was woodland. In summer, 50% of observed rooting took place in semi-natural deciduous woodlands (with the other 50% in grasslands), which is a large figure considering the whole estate only contains 7.3% semi-natural woodland, while grassland comprises 77.15% (Greenaway 2006). Welander (2000) found a similar preference for rooting in woodlands, as 54% of rooting occurred in deciduous woodlands even though this habitat-type only covered 11% of the study area. This was said to be a result of these areas providing richer food resources, particularly in relation to the availability of acorns. Therefore this could be the case for the Tamworth pigs at Knepp.

In winter the figures for rooting in semi-natural woodland drops to 19% with 16% occurring in coniferous plantations and 64% in grasslands. However, in this period pigs were only present in the South Block, which contains even less woodland at 0.9% semi-natural woodland and 0.2% coniferous plantation, with a 93.5% grassland component (personal communication, Theresa Greenaway). Thus, the lower percentage of rooting occurring in woodlands is still overrepresented in relation to the area covered by this habitat-type

When rooting in grasslands, more ground was covered in less time, while longer periods were spent rooting smaller areas of woodlands. In deciduous woodlands this could be due to richer food resources. For this same reason the percentage of rooting seen in deciduous woodlands could have been expected to be higher for winter. Perhaps the low percentage of such woodlands in the South Block restricts the proportion of rooting that occurs in them.

Comparing figures 5.8 and 5.9 shows that summer rooting and summer grazing occurred in similar areas. Examples include areas around Northern Wood and around the River Adur in the south of the Middle Block. This shows that during summer the pigs were rooting and grazing in homogenous areas in many cases. Thus smaller scale features, such as soil moisture, local vegetation and features were influencing the locations of their activities.

The pigs tendency to root, graze and travel along narrow landscape features such as ditches, hedges and streams (see figures 5.8 and 5.9) has also been seen in wild boar (Thurfjell et al 2009). The preferential use of field edges for rooting was also seen in wild boar as well (Thurfjell et al 2009). Such use of marginal areas by wild boar is probably to enable escape into denser cover should a threat arise. For example, when hunting pressure is lower within fields compared to surrounding areas, boar use the centres of fields as refuges (Keuling et al 2008b), thus reversing the previous pattern. Perhaps the use of marginal areas by the Tamworth pigs is instinctual and comes from their wild boar ancestry. The presence of humans (such as was the case in the fieldwork of this study) could also have caused this behaviour. Evidence of rooting in the centres of fields has been seen, as is shown in figure 6.1, so perhaps the most likely explanation for the pig's use of edges and marginal areas in this study is that human presence caused such behaviour, which is also seen in wild boar populations that are subject to predatory threats.

Figure 6.1: Pig rooting in the centre of Brook's Platt field in the Middle Block. This contrasts with observed rooting in the study, which was predominantly at the edges of fields and woods (aerial photo courtesy of Sir Charles Burrell).

Rooting was also seen along footpaths of former arable fields. An example of this is seen in figure 6.2. The footpath rooted here was the only part of the field not ploughed when it was arable (Anon. 2010). The vegetation in the field seems uniform, yet this footpath is the only area seen to be rooted. Thus, the fact that this area was not ploughed attracts the pigs, perhaps because rhizomes and other such subterranean foods remain intact in this portion of ground. Similar spatial patterns of feeding that correlate to former agricultural use have been observed in the Swiss National Park, with red deer preferentially grazing formerly irrigated areas 80 years after agriculture was ceased (Schütz et al 2003). This could be happening at Knepp also, especially as agriculture has only recently stopped.

Figure 6.2: Pigs rooting along a footpath in a former arable field. This footpath was the only part of the field not ploughed, which the pigs are preferentially rooting (photo courtesy of Sir Charles Burrell).

Seasonal patterns of pig activity

Cahill et al (2003) reported that rooting comprised over 80% of wild boar activity in winter 1999 and roughly 25% in summer 1999 in an area of Spain. This is similar to the percentages seen in figure 5.6. Grazing was the most frequently observed summer activity (see figure 5.6); however it did not dominate as much as rooting did in winter. Rainfall occurred during the summer fieldwork which facilitated rooting through increased soil moisture, leading to 23% of the pigs time being spent rooting even in summer.

The predominance of rooting in winter is because ground is softer, as precipitation is higher. Winter research was carried out just after a period of prolonged snowfall and so snowmelt and rain would have increased levels of soil moisture significantly, creating conditions conducive to increased rooting. Also, vegetation for grazing is less prevalent in winter meaning more of the pig's time would be spent rooting, which caused the lack of grazing seen in winter.

As well as this, pigs root more in the non-growing season to capitalise on the acorn mast at this time of year. Rooting under large oaks was observed in winter and also in the late summer (August), when some early acorns were present. Mast was not taken into account in this study, but variations in mast years have been shown to influence rooting patterns in wild boar, with richer masts producing more rooting (Groot Bruiniderink & Hazebroek 1996) so a study of the effect of this on the Tamworth pigs would be beneficial.

Allied to this is the increased severity of rooting (see figure 5.12). Wetter ground conditions in winter would allow more severe rooting to occur over greater areas, thus giving the higher percentages of R.I. 2 and 3 rooting seen in winter. Also, as rooting is the dominant activity in winter, this rooting would be more severe, because it is the pig's main way of obtaining food at this time of year, so enough food needs to be obtained from it.

The increased use of grasslands compared to woodlands in winter (see figure 5.11) could be because larger areas of grassland become suitable for rooting as ground is wetter. This could also explain why coniferous plantation woodlands were utilised in winter and not in summer, as coniferous stands are possibly sited on drier soils than semi-natural deciduous stands. For example, in the Tullgarn Nature Reserve of Sweden, 23% of coniferous forest is on soils classified as dry, while the figure for deciduous is lower at 6% (Welander 2000). Thus during summer at Knepp, coniferous stands might not be so easily rooted, while in winter conditions are wet enough to allow this.

Effects of these patterns on vegetation structure and the landscape

The patterns already outlined have various effects on vegetation development at Knepp. One such effect is increases in bare ground as a result of rooting. Figure 6.1 shows how extensive and noticeable this can be. In a survey conducted in 2010 (a repeat of a survey conducted in 2005), many transects had increased amounts of bare ground compared to 2005, especially in woodlands (Greenaway & Miller 2010). This can partially be attributed to rooting. However, these increases were also seen in the North Block, where there are no pigs, so they are not the only animal creating disturbances. Some of these increases in disturbances also correlate with increases in species diversity (such as transect B2 in Greenaway & Miller 2010). This shows that the break-up of dominant vegetation is creating conditions conducive to greater levels of diversity, as was found by Welander (1995) with wild boar rooting.

Another effect of rooting is the removal of woodland undergrowth. Figure 5.4 shows higher levels of woody and short vegetation in the North Block woodland site compared to the Middle Block site, as well as lower levels of non-vegetated material (which includes bare ground). This could be related to rooting, as it could damage woodland ground flora in the Middle Block woodland creating more bare patches here. This contrast between the North Block and Middle Block woodland can be clearly seen in figure 6.3. The higher proportion of taller weeds and herbaceous material in the Middle Block could also be related to rooting, as these would be among the first plant species to occupy rooted patches.

An example of woodland ground flora that has been impacted by the pigs are bluebells (*Hyacinthoides non-scripta*). Pigs have been observed eating bluebells (personal communication, Sir Charles Burrell) and this has led to the decimation of some bluebell communities in woodlands in the project. An example is the Middle Block woodland site used in the vegetation survey (Swallow's Furzefield). Bluebells were recorded in this woodland in 2005 (Greenaway 2006), yet during the vegetation survey they were not seen. There are also reports of bluebells being damaged in Jackson's Wood, also in the Middle Block. This could be seen as a negative impact of pigs, as the bluebell is an iconic part of British woodland flora. Such fears have also been raised in relation to wild boar rooting in British woodlands (Goulding et al 1998). However, invasive rhododendron has been recorded in many woodlands in the project and these plants can spread and reduce biodiversity (Greenaway 2006), so rooting in woodlands in this case could limit this and aid biodiversity.

It must be remembered though that the aim of the Knepp Wildland Project is to let natural processes predominate (Anon. 2011), therefore one cannot "prescribe in detail what vegetation we will end up with" (Hodder et al 2005, p.118). The establishment of a more natural grazing regime at Knepp lets the natural system drive dynamics and so sometimes inputs into the system (such as rooting) result in the decline of features within this system (like bluebells).

Figure 6.3: The two woodland vegetation survey sites in the North Block (a) and the Middle Block (b) The Middle Block's comparative lack of undergrowth could be caused (at least partially) by the rooting of pigs.

Connell (1978) identified an intermediate level of disturbance as producing the highest levels of diversity. Thus if rooting is too frequent it can destroy plant matter, inhibiting diversity. This could be the case in woodlands at Knepp. Rooting by the same group of pigs was observed in Northern Wood in the South Block (see figure 5.9) over two consecutive days. This rooting was severe, with much R.I. 3 rooting recorded. The undergrowth seemed sparse in this woodland, despite the 2005 baseline survey recording various ground flora here (Greenaway 2006). Therefore perhaps in this woodland the frequency of rooting is too high to maintain diversity and ground flora is being destroyed.

However, rooting that hinders the growth of woodland ground flora could be seen to fit in with Vera's model of cyclical succession. Part of this cycle (outlined in section 3) involves large herbivores disturbing ground beneath tree groves, which prevents regeneration. Pig rooting is a form of such disturbance. Thus rooting in woodlands that removes undergrowth restricts regeneration and so eventually the groves degenerate back into grasslands and the Vera cycle continues (Vera 2000). Therefore the removal of woodland undergrowth by pigs at Knepp could be part of the natural system of shifting vegetation mosaics.

Other evidence of the pigs facilitating such vegetation development was also observed. Vera (2000) says the rooting of wild boar creates suitable conditions for weedy and herbaceous material to establish which then develops into thorny scrub, which protects seedlings from grazing. Figures 5.1 and 5.3 display how the Middle Block and South Block (which both contained pigs at the time of the vegetation survey) old pasture and floodplain sites contain a higher contingent of taller weeds and herbaceous vegetation and (in the case of the South Block old pasture site) woody vegetation than compared to the North Block sites (which do not contain pigs). This indicates that rooting could be aiding the growth of such vegetation.

Observations made (particularly in the South Block) support this. Figure 6.4(a) shows weedy and herbaceous species (including creeping thistle *Ranunculus repens*) colonizing a rooted patch. An increase in such vegetation common on disturbed ground was also recorded in a 2010 survey (Greenaway & Miller 2010). This vegetation is less palatable to herbivores and thus develops into more woody and thorny scrub. Figure 6.4(b) shows this, with hawthorn (*Crataegus monogyna*) scrub occurring in previously rooted areas. This is evidence that rooting is facilitating the spread of scrub that allows regeneration of tree species to take place in the presence of grazers. Observations of young oak saplings growing within scrub are also evidence of such Vera-style regeneration (see figure 6.5).

Figure 6.4: Previously rooted patches containing weedy and herbaceous vegetation (a) and also thorny scrub (b; rooted patches can be seen at the bottom of the picture).

Figure 6.5: A sessile oak (*Quercus petraea*) sapling growing within the protection of brambles in the South Block.

Colonisation of rooted patches by weeds could also be occurring in woodlands in some cases. The Middle Block woodland surveyed for vegetation cover (Swallow's Furzefield) contained patches of pale periscaria (*Polyganum lapathifolium*; see figure 6.6), despite the ground flora of this woodland being sparse (see figure 6.3(b)). These patches seemed to be roughly the same size as rooted patches, so perhaps favourable conditions for germination created by rooting produce these clusters of pale persicaria (however, to establish this with more certainty these patches need to be measured and compared to rooted patches). This has also been observed in the Białowieza Forest with seedlings of trees such as *Tilia cordata* (small-leaved lime) being found in patches that were similar sizes to rooted patches that also seemed to have been rooted (Pigott 1975).

Figure 6.6: Patches of pale persicaria (*Polyganum lapathifolium*) in the Middle Block woodland site surveyed for vegetation cover (Swallow's Furzefield). These patches were similar sizes to some observed rooted patches suggesting that the two are possibly related.

The spread of scrub promoted by rooting could provide attractive areas for jays to bury acorns (a process outlined in section 3), as they look for landscape markers, such as bushes in grasslands. It is thought that the lack of such markers has meant that oak regeneration is not as high as it could be at Knepp (Greenaway 2007), however further rooting would increase the amount of bushes in grasslands, providing such landscape markers for acorn burial.

The effects of large herbivores in a more naturalistic system are not evenly spread across the area. Herbivores distribute themselves in the landscape according to vegetation distributions and other factors (Palmer & Hester 2000), meaning their activities are concentrated differently in different areas according to such influences

(Kirby 2004). Due to this, the Tamworth pigs at Knepp preferentially root floodplains and woodlands (see figures 5.9 and 5.11), leading to the removal of ground flora in woodlands and greater levels of structural diversity in vegetation in floodplains (see figure 5.3). However, it is clear the pigs are not the only herbivores creating disturbances which can lead to such structural diversity. The higher level of weeds and herbaceous vegetation in the North Block floodplain and re-seeded sites (where there were no pigs) compared to the same sites in the Middle Block (where there were pigs) suggests that other animals are creating the conditions for such vegetation in the North Block (see figures 5.2 and 5.3). Similarly the 100% cover of short vegetation in the Middle Block re-seeded pasture could show that pigs root this area less, so the uniform short vegetation persists here (see figure 5.2). Despite this, the species diversity of the North Block floodplain site is lower than that of the Middle and South Block. Perhaps it is the lack of rooting that causes this lower diversity.

Overall, it could be said that the Middle and North Blocks are developing in a somewhat similar fashion. The North and Middle Block old and re-seeded pasture sites have similar vegetation trends with high levels of short vegetation cover (see figures 5.1 and 5.2) and the vegetation structures of their floodplain sites is also similar (see figure 5.3). It is the South Block that differs most, with pasture and floodplain sites containing higher levels of weedy, herbaceous and woody vegetation (see figures 5.1 and 5.3). The general appearance of the South Block is also quite different (see figure 6.7). This is interesting as the Middle and South Blocks had the same composition of herbivores at the time of the vegetation survey, while the North Block only had cattle and wild roe deer and rabbits. Most importantly, the North Block has never contained pigs.

Figure 6.7: 'Typical' pastures in the North Block (a), Middle Block (b) and South Block (c). The North and Middle Block pastures are generally similar in appearance, whilst most South Block pastures appear to be more densely vegetated with more scrub.

This leads to the conclusion that other factors apart from the pigs are at work causing this variance. The main difference between the North and Middle and the South Block is that the South Block was left fallow without introduced large herbivores for roughly 5 years before cattle, pigs, ponies and fallow deer were introduced. This time that the South Block was given to recover from intensive agriculture must be the key factor resulting in such differences. Fluctuations of herbivore numbers have been linked with changes in vegetation development (Vera 2000). For example, in the African savanna, grazing and trampling by large herbivores creates good conditions for the establishment of certain species, like acacia. A decline in the herbivore population then allows this young vegetation to grow (Prins & van der Jeugd 1993). The South Block was heavily horse grazed before the implementation of the Wildland Project (Greenaway 2006), so a similar scenario could have taken place here, with the lack of large herbivores for a period of time allowing vegetation to establish more easily, meaning that when large herbivores were introduced, they can (at the right densities) facilitate the cycle without damaging vegetation too much.

This is not to say that the activities of the pigs (and the other large herbivores) are not having an impact. Rooting is affecting vegetation by damaging some woodland ground flora but also facilitating the growth of scrub in grasslands. It could be that these processes are taking more time in the Middle Block and perhaps even more time in the North Block, (where only the cattle component of the system is present), as these areas were not given much resting time after the cessation of agriculture. Yet vegetation structure has still developed in these areas.

Digitised vegetation maps of the estate (see Appendix IV) have shown the composition of the landscape during agriculture and now that the Wildland Project is in place (from Hodder et al, in press). Before the start of the Wildland Project, the majority of the area was arable, with some semi-improved grassland, woodland and wood pasture. Since the area was entered into the Wildland Project, arable is no longer present, wood pasture has increased and large areas of acid grassland that are interspersed with significant areas of scrub have appeared. Thus stark changes in landscape composition have occurred in many areas already, even though the project is only 10 years old, with some areas only being taken out of intensive agriculture as little as 6 years ago. Therefore the landscape developments that were expected by years 20-25 of the project (see figure 3.6) are already being seen to some degree. Such transitions in vegetation structure are said to take long periods of time. Studies have shown that it can take 30-45 years for woody vegetation to dominate formerly arable areas (Smit & Olff 1998), so the progression of landscape development at Knepp could be seen to be happening at an appropriate rate.

Implications for the effects of wild boar in Britain

Tamworth pigs proved to be a suitable analogue for wild boar, as they demonstrated similar patterns of activity, such as higher frequencies and severities of rooting during winter and spatial preferences for rooting in woodlands, riparian environments and in more densely vegetated grasslands (eg. Cahill et al 2003; Bueno et al 2009; Welander 2000). Despite this, Tamworth pigs remain just an analogue for wild boar; they are not identical. Domestic breeds chosen as analogues can adapt to behaving in a more 'wild' manner, so that they become 'untame', however it is usually undesirable for such animals to be so wild that they are 'savage' (Koene 2002), thus their status as wild animals is always restricted. The Tamworths displayed this as they were unafraid of human presence, which would drastically alter the behaviour of wild boar. This leads to them spending more time in open areas than wild boar might do, which influences the spatial patterns of their effects.

Despite this, pigs did seem to utilise marginal areas in human presence, which is a trait wild boar display in areas they experience hunting pressures (eg. Thurfjell et al 2009). This could have implications in British landscapes, with wild boar affecting these marginal areas more. Also, the damage to woodland undergrowth that the Tamworth pigs caused echoes concerns raised about such effects of wild boar (eg. Defra 2005).

However, the pigs preferential rooting of riparian areas could help a riparian species: the Black Poplar tree (*Populus nigra*). Only 7,000 specimens are thought to be present in the U.K., and one of the reasons thought to cause its decline is a lack of open riparian ground for germination (Anon. 2005). Perhaps the rooting of pigs (and wild boar where they are present) could provide this open ground on floodplains once again (Anon. 2011). Also, the spread of protective scrub that is facilitated by rooting that breaks up dominant vegetation could aid regeneration of trees in British ecosystems, as has been observed in this study. This benefit is difficult to predict though and would not be seen everywhere.

Suggestions for further research

In the process of conducting this study, many issues have been encountered along the way that require further research. Firstly, a detailed study into the vegetation dynamics of rooted and non rooted patches at Knepp would give a more definite view of how this disturbance affects vegetation and it's facilitation of the development of protective scrub. A study into whether the pale persicaria observed in the Middle Block woodland is actually a result of pig rooting could aid such studies of rooting-vegetation interactions as well. Also, researching how variances in oak mast richness between years can affect rooting patterns would be insightful, as this has been seen to affect wild boar rooting (eg. Groot Bruinderink & Hazebroek 1996). Finally, with climate perturbations becoming ever increasingly important in studies of natural landscapes, investigating how changes in temperature and precipitation influences rooting patterns would produce interesting data. Higher precipitation rates could result in higher levels of rooting as ground would be wetter. Conversely, cold winters and hot, dry summers could freeze or dry-up ground, which would decrease the amount of rooting that could occur.

7. Conclusions

Seasonal activity patterns displayed by the Tamworth pigs included a concentration of rooting at increased severities in winter, with more grazing as well as other activities in summer. Pigs were also found to concentrate rooting spatially in densely vegetated grasslands, floodplains and other riparian areas, as well as woodlands, despite this habitat covering a small percentage of the Knepp Wildland Project. This is similar to many patterns seen in wild boar activity (eg. Welander 2000; Cahill et al 2003; Bueno et al 2009). The pigs also focused more rooting in the South Block of Knepp as this area has greater structural diversity and denser vegetation.

Effects of such activities include the damage of woodland ground flora (such as bluebells) which could be seen as negative. Concerns have been raised about this in relation to wild boar in British woodlands (Defra 2005). Despite this, beneficial effects of pig activity seemed to occur at Knepp, such as the break-up of dominant species in grasslands which leads to the spread of herbaceous and scrubby vegetation. This is facilitating regeneration as it provides protection for young trees against grazing (in line with Vera's theories, 2000).

However, it is difficult to single out pig activity at Knepp, as there are other large herbivores affecting the landscape, as well as other factors. One such factor is the longer time the South Block was left fallow before a grazing regime was introduced, which could be the main reason for the structural differences seen in its vegetation compared to the other blocks. Fluctuations in herbivore numbers have been found to allow the establishment of vegetation in other natural systems (eg. Smit & Olff 1998), so perhaps similar processes are taking place at Knepp. The combinations of many factors and long time-scales involved mean that more detailed study is required at Knepp to unpick these complex processes.

Knepp's Wildland Project is unique. A more dynamic system is allowed to operate here, with broader limits set. This allows internal processes to dictate outcomes

(Hodder et al 2005), thus the role of the pigs is allowed to be carried out in a fuller sense. Many natural areas are not given these broad limits, thus dynamic changes are not tolerated or desired. Revolutionary projects like Knepp are changing such conservation philosophy though and are challenging contentions that “Nature is now in danger of becoming subservient to Nature Conservation” (Oates 2006, p.89). Thus, within these alternative conservation scenarios, the role that pigs and wild boar can play in their ecosystems can be understood and appreciated more fully.

This transition in ideas about nature and conservation makes the return of wild boar to Britain timely. Projects such as the Oostvaardersplassen and indeed Knepp are showing that there is another way. Dynamic natural systems driven by herbivores could allow wild boar to reclaim their place in British environments, meaning that perhaps soon analogues of them are not needed. Hopefully their example will lead to the return of more lost species.

Appendices

Appendix I

Figure 1: Map of the sites sampled in the vegetation survey
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Appendix II

Figure 1: An example of 'Rooting Index' (R.I.) 1 rooting

Figure 2: An example of 'Rooting Index' (R.I.) 2 rooting.

Figure 3: An example of 'Rooting Index' (R.I.) 3 rooting.

Appendix III

Plant name	Scientific name	Locations found
Creeping buttercup	*Ranunculus repens*	North Block: floodplain (50%), Middle Block: floodplain (40%) and old pasture (10%), South Block: floodplain (3%) and woodland (5%)
Creeping thistle	*Cirsium arvense*	North Block: floodplain (20%), old pasture (10%) and re-seeded pasture (20%), Middle Block: floodplain (10%) and old pasture (20%), South Block: floodplain (3%)
White clover	*Trifolium repens*	North Block: old pasture (70%), Middle Block: re-seeded pasture (60%), South Block: woodland (70%)
Common ragwort	*Senecio jacobaea*	North Block: re-seeded pasture (5%), South Block: old pasture (45%), exclosure (5%)
Brambles	*Rubus fructicosus (agg.)*	North Block: woodland (40%), Middle Block: woodland (20%), South Block: exclosure (40%)
Greater plantain	*Plantago major*	North Block woodland (15%)
Fern	*Dryopteris filix-mas*	North Block woodland (5%)
Broad-leaved dock	*Rumex obtusifolius*	Middle Block: floodplain (2.5%)
Mouse-eared hawkweed	*Pilosella officinarum*	Middle Block: floodplain (2.5%)
Pale persicaria	*Polyganum lapathifolium*	Middle Block: woodland (20%), South Block: floodplain (20%)
Nettles	*Urtica dioica*	Middle Block: woodland (5%)
Silverweed	*Potentilla anserina*	South Block: floodplain (60%)
Dandelion	*Taraxacum agg.*	South Block: floodplain (3%), old pasture (2.5%), exclosure (5%)
Common Fleabane	*Pulicaria dysenterica*	South Block: old pasture (5%)
Sessile Oak seedling	*Quercus petraea*	South Block: old pasture (2.5%)
Grasses		North Block: floodplain (30%), old pasture (20%), re-seeded pasture (75%), woodland (30%), Middle Block: floodplain (45%), old pasture (70%), re-seeded pasture (40%), woodland (30%), South Block: exclosure (50%), woodland (70%)
Mosses		South Block: woodland (10%)

Table 1: The plant species recorded in the vegetation surveys. The species important to the pigs are *Trifolium repens* (white clover) and grasses. These are the species that the pigs preferentially graze on and the only ones that pigs were observed to be grazing on. Percentages refer to the percentage cover of each species at each sample site

Appendix IIV

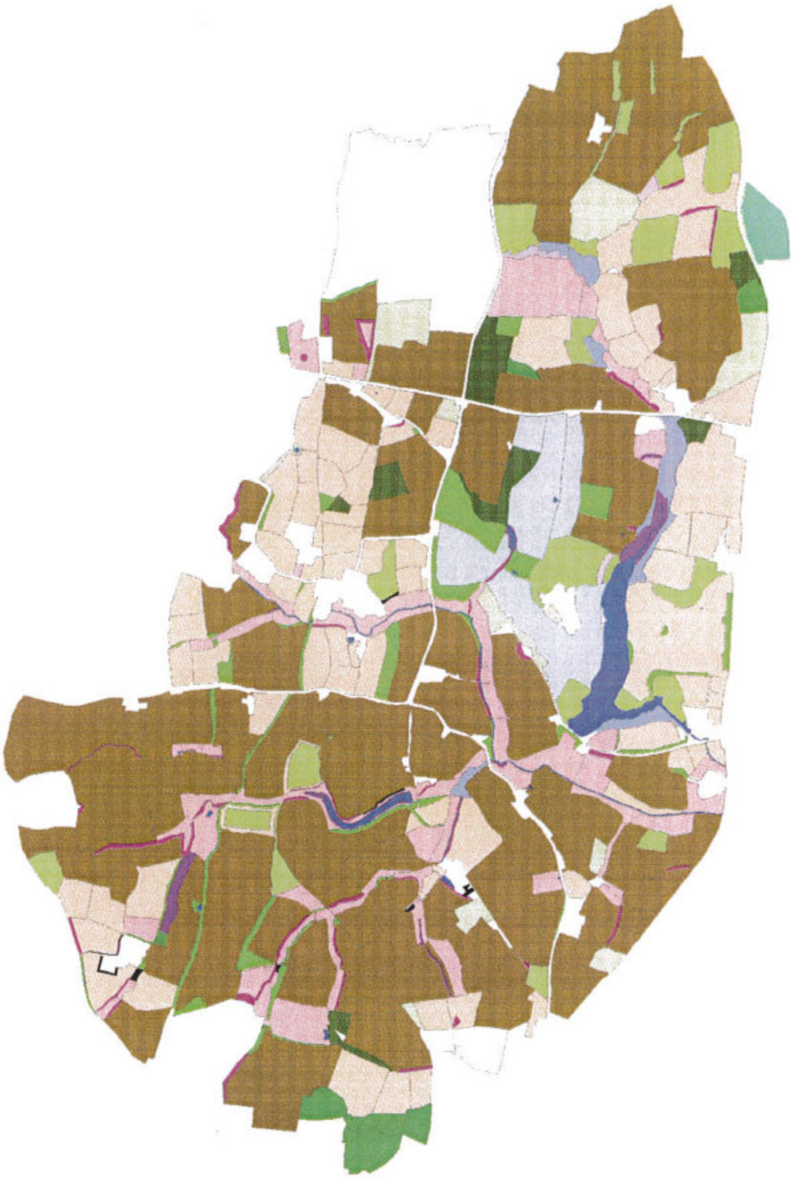

Figure 1: A digitised scenario map of the Knepp Castle Estate showing landscape-type before the Wildland Project was implemented
(from Hodder, K. H.; Douglas S.; Newton, A. C.; Bullock, J. M.; Scholefield, P.; Vaughan, R.; Cantarello, E.; Beer, S.; Birch, J. (in press) 'Analysis of the costs and benefits of alternative solutions for restoring biodiversity' Final report to Defra.

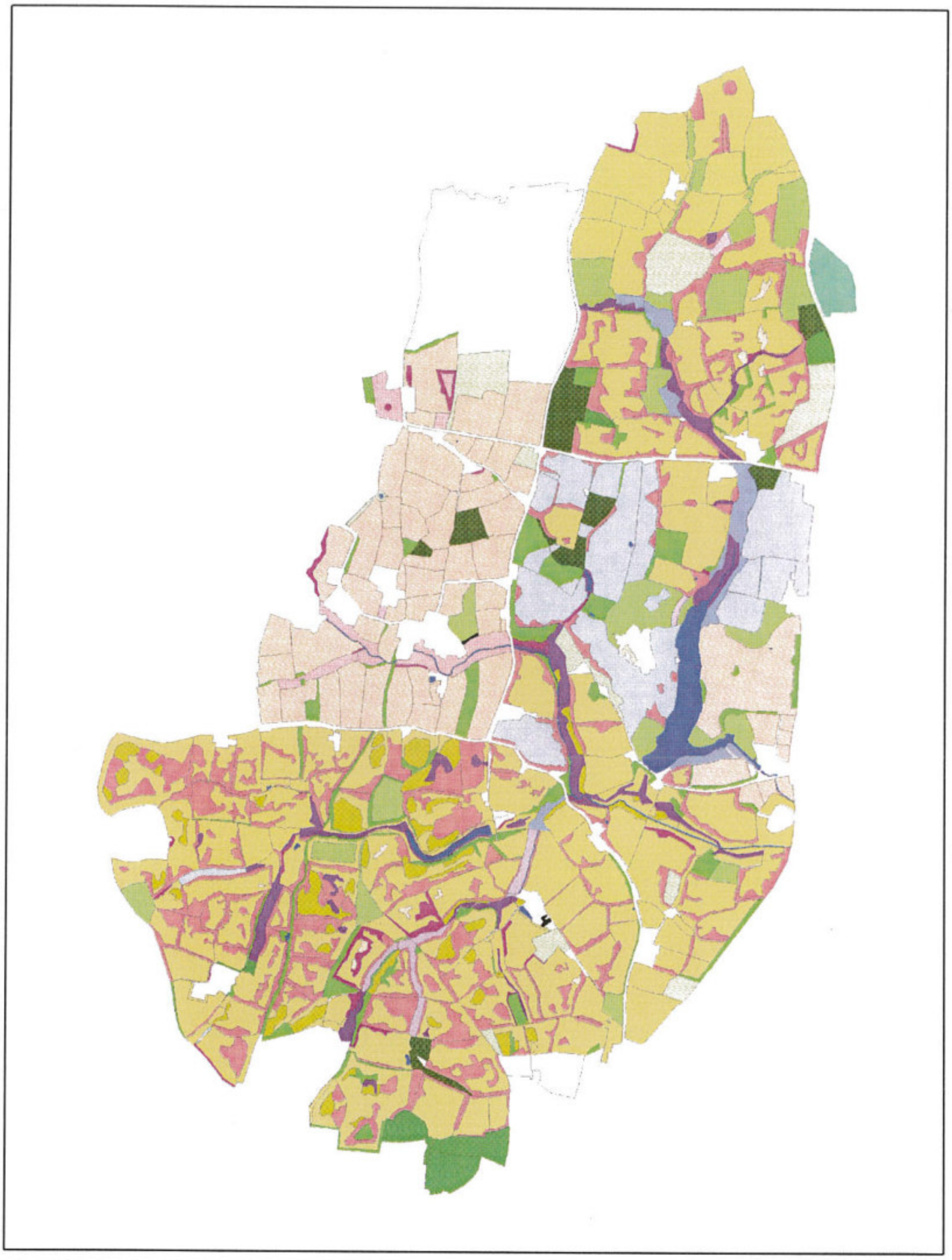

Figure 2: A digitised scenario map of the Knepp Castle Estate showing landscape-type now that the Wildland Project has been implemented
(from Hodder, K. H.; Douglas S.; Newton, A. C.; Bullock, J. M.; Scholefield, P.; Vaughan, R.; Cantarello, E.; Beer, S.; Birch, J. (in press) 'Analysis of the costs and benefits of alternative solutions for restoring biodiversity' Final report to Defra.

Acid grassland
Arable
BAP ancient semi-natural woodland
BAP wet woodland
Broadleaved plantation
Broadleaved woodland
Conifer plantation
Excluded
Excluded area - tenanted land
Fen vegetation
Fen vegetation and sallow scrub
Gorse
Improved grassland
Mature or over-mature tree
Mixed plantation
Open water
Orchard
Plantation and ancient semi-natural mosaic
Rank vegetation
Sallow scrub
Scrub
Scrub and broadleaved trees
Semi-improved grassland
Semi-natural woodland
Species-rich grassland
Wet semi-improved grassland
Wood pasture and parkland

Figure 3: Key for digitised Knepp scenario maps in figure 1 and 2
(from Hodder, K. H.; Douglas S.; Newton, A. C.; Bullock, J. M.; Scholefield, P.; Vaughan, R.; Cantarello, E.; Beer, S.; Birch, J. (in press) 'Analysis of the costs and benefits of alternative solutions for restoring biodiversity' Final report to Defra).

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