UNIVERSITY OF EDINBURGH
SCHOOL OF GEOSCIENCES

THE EFFECT OF A SEMI-NATURAL GRAZING REGIME ON THE VEGETATION OF THE KNEPP CASTLE ESTATE: CAN A WILDLAND BE RESTORED?

BY

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Summary

Frans Vera believes the landscape that existed before human influence consisted of a shifting mosaic of trees, scrub, solitary trees and groups of trees and that large grazing animals were responsible for the regeneration of the vegetation of this landscape (Vera, 2009). These ideas have become very relevant for large-scale conservation schemes, such as The Knepp Castle Estate's Wildland Project. This investigation assessed the impact and role of grazing in re-wilding with regards to Vera's theories. This took place at the Knepp Castle estate where land previously used in agriculture is being allowed to develop naturally. A grazing index was formed, which found the impact of grazing to be moderate and regeneration of woody vegetation to be sufficient to re-wild the land. It is unclear whether grazing animals are responsible for driving this succession; they appear to play a key role. The results of this study indicate that if grazing is maintained at levels of moderate impact a wildland can be restored at The Knepp Castle Estate.

Contents

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List of Abbreviations

- Knepp: The Knepp Castle Estate
- NB2: New Barn 2

1. Introduction

Frans Vera's Theories

It has been widely accepted that the forests which covered much of Europe were closed-canopy woodlands consisting of many mature trees and shrubs. In this system regeneration occurred in gaps that appeared due to the death and decay of trees through natural causes such as wind-blow and disease. This forest system became open only through the influence of humans (Buckland, 2002). More recently consideration has been given to ideas that the forest may have been more open than originally believed. Factors thought to have caused openness include flooding, disease, storms and fire (Kirby, 2004). Alternatively, Frans Vera has put forward controversial ideas that grazing herbivores caused openness and also drove vegetation succession on a landscape scale (Vera, 2000). Vera proposes three main concepts:

- The pre-Neolithic landscape consisted of an open, park like mosaic of wood and grassland.
- The driving force behind this system was large herbivores, which created cyclic vegetation changes from grassland, to shrub then woodland.
- "Re-wilding" is an optimal conservation strategy in Europe for maintaining and restoring biodiversity levels (Vera, 2000).

Vera uses palynological, etymological and historical arguments in order to justify his idea of a "half open" park like landscape having been present in the pre-Neolithic Atlantic era across Europe c7000 years ago (Hodder et al, 2005). He argues that this half open landscape was created by cyclical vegetation dynamics which caused shifting mosaic systems. Vera believes this was driven by a guild of herbivores which would have included Aurochs, Bison and wild horses (Hodder et al, 2005).

Vera describes three stages of cyclical vegetation change. Firstly grassland is present, and within this patches of unpalatable scrub and tree seedlings are also present. The scrub provides protection for the seedlings to establish without being browsed. Following this the groves of trees slowly shade out the scrub and support large grazing animals which prevent regeneration. Lastly comes a "break up" phase where decaying trees within the groves allow light to penetrate the grove and grasses and herbs to re-establish (Vera, 2000).

As can be seen in figure 1 the cycle would probably have worked in the following way:

- Within closed canopy areas of woodland grazing animals shelter, and through trampling and grazing prevent the establishment of seedlings.
- Older trees where grazing animals have sheltered die and decay and open up the canopy. Due to there being no established seedlings at this point trees do not fill in this gap. This is known as the "break up" phase, in which grasses are able to establish. This attracts those species which graze and browse the area and through this continue to prevent tree and shrub establishment.
- The deposition of dung and soil disturbance (from rooting and trampling), begins to provide suitable conditions for non-palatable herbaceous species to establish. Due to their un-palatability, scrub can become established and can expand.
- Expansion of scrub reduced grazing pressure in the area and tree seedlings can become established. Tree seedlings mature and the cycle will begin again (Anon, 2007).

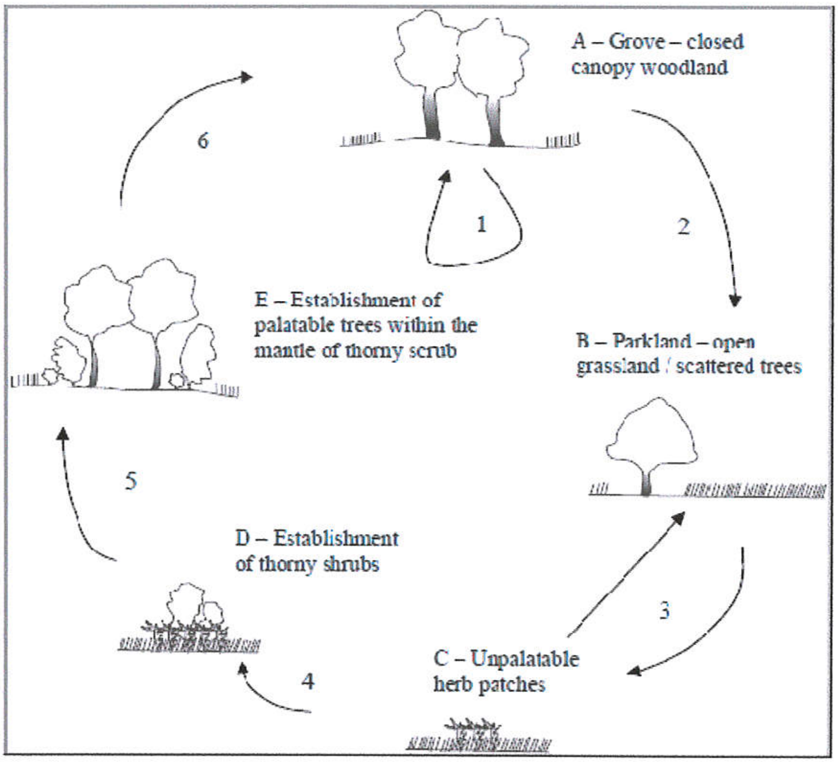


Figure 1: The Vera model of cyclic vegetation succession (Anon, 2007).

In Britain we are mostly concerned with whether herbivores were the dominant mechanism for landscape regeneration and whether this took place on a scale which would have produced a half open, park like landscape (Hodder et al, 2005). Vera's ideas have come about at a time when conservationists, particularly in the UK, are becoming very interested in wood-pastures, landscape-scale nature conservation and allowing natural processes to dominate in nature conservation (Hodder et al, 2005). If Vera's theories are correct, not only do they affect our understanding of how the current ecosystems have evolved, but they could heavily influence the way grazing is used to manage conservation areas (and other areas) in the future, particularly on a landscape scale (Hodder et al, 2005).

Grazing as a management tool

Grazing has only recently been seen as a valuable management tool in conservation (Siebel & Piek, 2002). Studies have found evidence that the influence of grazing facilitates vegetation succession and therefore can be used to restore areas of land that have been ecologically degraded (Van Uytvanck et al, 2008). Herbivores such as deer are able to regulate the balance of vegetation; particularly where agricultural land is no longer in use (Pepin et al, 2006). Cattle, ponies and other herbivores may be able to maintain or develop mosaic landscapes which consist of grasses, shrubs, scattered trees and forests (Vera, 2000, Hodder et al, 2005). There is also evidence that grazing by herbivores can increase biodiversity (Bakker et al, 2006).

The regeneration of woody species in particular is largely affected by grazing herbivores. This interaction is influenced by local variation and grazing conditions (Kramar et al, 2006). Grazing activity such as trampling and uprooting can open up dense herbaceous vegetation reducing its competitive ability. This favours the establishment and germination of woody species (Posada et al, 2000). Woody species establishment in grassland areas is closely associated with species that provide favourable conditions for this to take place; for example unpalatable species such as thorns can provide protection (Smit et al, 2006). Grazing maintains species-rich habitats by controlling species which would otherwise out-compete others and dominate over wide areas. Selection of species that are favoured or more palatable than other species determines the structure and composition of vegetation (English Nature, 2005). Grazing also influences the abundance of species which are more tolerant of grazing than others (Andrews et al, 1999).

Direct impacts of grazing include browsing, trampling and excretion of faeces and urine. In the long-term this can change the productivity, turnover and distribution of species and nutrients in an ecosystem (Wallis de Vries et al, 1998). The concentration of nutrients due to excretion provides enhanced conditions for plants to grow, particularly seedlings (Hobbs, 1996). Indirect effects of grazing can modify the whole structure and function of ecosystems. (Wallis de Vries et al, 1998). Grazing gradually removes plant material which gives more mobile species a greater chance to disperse widely in the habitat (English Nature, 2005). Grazing can also have negative effects on vegetation. Grazing can reduce the abundance of seedlings due to trampling and the height of surviving seedling can be reduced by browsing. Rubbing up against the vegetation and using particular areas for resting can cause damage. If grazing damage is severe this can lead to soil erosion. The highest levels of damage usually occur at grazing levels which are too high for the habitat to support (Adams, 1975).In the past extensive grazing had devastating effects on many half-open landscapes. In the late 1800's keeping grazing animals became much less profitable and people became much more interested in nature preservation. Initially grazing was not considered as management option but it soon became clear that grazing animals had helped to create important landscapes such as heaths, chalk grasslands and dune grasslands. It was not long before grazing was re-introduced in areas that had traditionally been grazed (Siebel & Piek, 2002).

Naturalistic grazing and "re-wilding"

Currently there is much interest in landscape-scale nature conservation and the ways in which it can be promoted (Hodder et al, 2005). A more natural approach to conservation management is gaining momentum and has received increasing support in the UK (Hodder & Bullock, 2009). There is much debate as to whether "re-wilding" the landscape using natural grazing regimes could be one way of achieving such objectives (Hodder et al, 2005).

As a management tool in conservation, grazing is used for two purposes: firstly to preserve, restore or develop landscapes which are characterised by a specific composition of grasses, scrub and woodland. Alternatively grazing is used to facilitate or preserve a particular kind of vegetation or species. In both these cases land managers decide the location and timing of grazing as well as the animals used and the grazing pressure exerted on the land (Siebel & Piek, 2002). In naturalistic grazing regimes natural processes take precedence. The grazing animals are resource limited and therefore there is no specified population density. Grazing drives habitat change and human influence is kept to a minimum (Hodder & Bullock, 2009). The main difference between naturalistic grazing and extensive grazing systems used in conservation management is that instead of management for specific habitat or species composition, direct management through human influence is minimal and the use of natural processes is a primary aim (Hodder et al, 2005).

Vera's work has stimulated much interest in whether natural landscapes can be restored in the UK; with natural grazing regimes playing a role in their creation. Although it is agreed that due to the modification to the British landscape by man we cannot return the land to its pre-Neolithic state; we can work towards a "future-naturalness" where as near natural conditions as possible are reached (Hodder et al, 2009). The idea of re-wilding is that areas of land would be fenced off and natural processes would be left to take place without any human influence. Large herbivores and other animals believed to have been important in contributing to shaping the landscape in the past would be introduced to this area to contribute towards "natural management" eventually leading to a wilderness area. This is something that Frans Vera has instigated in the Netherlands through the Oostvaardersplassen. Vera designed this 6,000ha nature reserve to replicate past landscapes and re-wilded the entire area. The reserve was populated with Konik horses and Heck cattle, analogues of Tarpan and Aurochs respectively and there is also a large Red Deer population. Human intervention is minimal with humans stepping in only to cull animals that are sick or close to death (Marris, 2009). The Oostvaardersplassen is a large experiment partly to test Vera's theories and over time should give answers to many of the questions surrounding his work. There is much interest in the UK to also trial "wilderness" areas and such work is being undertaken at the Knepp Castle Estate in West Sussex.

The idea of wilderness implies that the dynamics of the ecosystems are completely determined by natural processes. For this to be successful species that play a key role in the functioning of these environments should be present; this includes wild predators. (Wallis de Vries et al, 1998). The UK no longer has such predators and so humans would have to interfere to regulate population size, otherwise the population size would become too large and have detrimental effects on the environment due to intensive grazing pressure (Taylor, 2005). Many animals that were present in the past, such as Tarpan and Aurochs no longer exist and so substitutes have to be found (Marris, 2009). Wilderness areas need to be large so that they contain a range of habitats, this allows the grazing animals to disperse across the land and undertake more effective utilisation (Taylor, 2009). In the UK all domestic animals are subject to animal welfare legislation. Animals cannot be left to starve to death, and therefore cannot be resource limited as wilderness objectives imply. In the event of the outbreak of diseases such as foot and mouth or general poor condition of an animal the landowners are obliged to step in under these laws (Kirby, 2009).

The Knepp Castle Estate

The Knepp Castle Estate is a 1400ha estate in West Sussex. Until 2001 the primary land use on the estate was traditional arable and dairy farming, however due to the decline in farming profitability between 1996 and 2006, farming alone was losing the estate money. As a result traditional farming of the land ceased and alternatives were explored. Since then the Knepp Estate has taken an innovative step forward in ecological land management by undertaking many conservation projects, one of which is the "Knepp Wildland Project". The idea behind this is to restore the land to the state it would have been before intensive agriculture took place, allowing grazing animals to instigate the changes in habitat by letting them roam freely with as little human intervention as possible (Anon, 2009).

Knepp Wildland Project

The aims of the project are as follows:

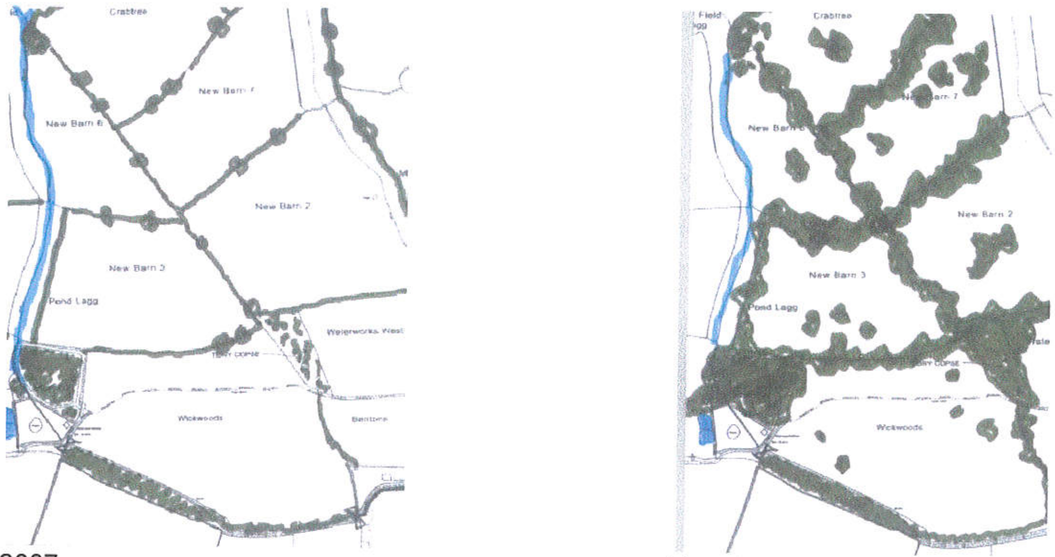
- To improve the biodiversity of the land through the use of natural processes.
- To implement a semi-natural grazing regime which allows animals to lead a more natural existence, whilst meeting the standards of top quality meat production and animal welfare legislation.
- To monitor the changes that take place to transform the land from an agricultural habitat to a more varied landscape containing a variety of habitats and the associated improvements in biodiversity.
- To give a better understanding of conservation and naturalistic grazing through scientific research (Anon, 2009).

The project began by ceasing the use of fertilisers and chemicals as well as discontinuing ploughing and intensive grazing with sheep and cattle. There are currently 3000 acres in the Wildland Project divided into three enclosures (Anon, 2009). Knepp is using a variety of grazing animals in its naturalistic grazing regime, some of which occur naturally, and some that have been introduced by Knepp. Roe deer and rabbits occur naturally on the estate and should not be thought of as being separate from the project. Knepp has introduced Old English Longhorn cattle, Fallow deer, Tamworth pigs and Exmoor ponies. These traditional breeds have been carefully chosen to facilitate natural processes to manage the land. Some of these animals are being used for the production of meat to generate revenue, whereas others are simply part of the project. All the animals live as near to naturally as legislation allows. There are hopes for Elk; Bison and Red Deer to become part of the project in the future (Anon, 2009), and Wild Boar are likely to immigrate naturally due to escaped animals either from the Romney area of Kent or the New Forest. Initially the project will continue for twenty years. The hope is that grazing animals will be free to roam across the entire estate. The internal fences and barriers would be taken away and crossings would be put in place on road barriers. Apart from maintenance of listed parkland and management of weed species where appropriate, the only management in the area would be through the natural grazing regime (Anon, 2007).

The Knepp Wildland Project and Vera's theories

The vision of the Knepp Wildland Project has been influenced by Frans Vera's theories, and he is a member of the management committee. The project will help to try to answer the questions associated with these theories and at the same time create an interesting and diverse habitat. At the start of the project, previous management was already providing evidence that Vera's hypothesis could possibly be supported. Scrapes that had been dug in grassland were showing signs of scrub invasion and in fields that had not been mown for three seasons and light grazing was present, young oak trees were emerging. These were signs that the natural grazing regime would produce good shrub and tree regeneration (Anon, 2007). There are few studies available to aid the predictions of the outcomes of the project. The Oostvaarderplassen in Holland is a very different site to the Knepp Estate and so relevant knowledge is limited. However, it is expected that the amount of scrub across the estate will increase (Greenaway, 2007).

From other research, predictions have been made as to how the vegetation may change as the project progresses. It is thought that the hedges will become thicker and spread in a clumpy manner. Over a large number of years the hedge structure may disappear altogether from the landscape. In fields and around scrapes it is thought that small areas of scrub and young woodland will establish. In the twenty year period of the project it has been predicted that there will be scrub and small areas of trees within what is now open field and that the hedges will thicken and change but the overall structure in the landscape will remain as it is now; see figure 2. This means that something quite similar to Vera's hypothesis could evolve (Anon, 2007).



2007 Year 20-25

Figure 2: Predicted tree and shrub vegetation change between 2007 and year 20-25 of the project(Anon, 2007).

The need for survey at Knepp

Natural grazing systems are very different from conservation grazing. If the near natural grazing regime at Knepp is successful it will be unique to most other grazing systems and studies in the UK. There are few studies of the impacts of grazing animals on woodlands and no published work to date on natural grazing systems in the UK (Greenaway 2007). It has become clear that a greater knowledge of the effects of grazing animals on vegetation and a better understanding of the changes this could exert on a landscape-scale is needed (Adams, 1975, Armstrong, 1993, Bokdam & Gleichman, 2000). In particular the impact of herbivore-vegetation interactions needs to be understood in depth to give us the ability to make predictions on a long-term scale (Weisberg & Bugmann, 2003). Knowledge of key processes such as vegetation succession will allow effective grazing systems for conservation to be designed (Bokdam & Gleichman, 2000). More knowledge of the effects of grazing on biodiversity and a better understanding of the ecological processes underlying these effects are required if effective grazing systems are to be designed for conservation (Bokdam & Gleichman, 2000). Pioneering projects such as those being undertaken at Knepp (Anon, 2009) provide the perfect opportunity to gain such knowledge.

Field based trials are very important in this research. This is the only way to discover how these systems may be used in the future and how they were in the past. They will also allow us to research the effects on biodiversity these systems have. It is hoped that the Knepp Wildland Project will aid this research (Greenaway, 2007). Monitoring the vegetation changes at Knepp as the project continues is important as the data can contribute towards understanding for future projects, but also to monitor the success of the project. For woody species such as scrub this is particularly important as it includes hedgerows. Monitoring will allow us to discover the benefits as well as the negatives of such systems. For example, it is predicted that scrub will increase and act as a "nursery" for tree species which will then regenerate (Greenaway, 2007).

2. Objectives

There are four main objectives of this investigation:

- To assess the effect of a naturalistic grazing regime on the woody species of the Knepp Castle Estate by investigating the composition of species present and the impacts of grazing that may have occurred.
- To devise a grazing index which can be used to inform not only the Knepp Wildland Project, but also conservation agencies such as Natural England regarding the impacts of natural grazing regimes, and therefore could be used to advise regarding stocking levels and the problems associated with natural grazing regimes.
- To assess whether grazing by large ungulates is the main driver of vegetation succession at the Knepp Castle Estate or whether there are other contributing factors by investigating the composition of woody species present.
- To evaluate whether in the Case of the Knepp Castle Estate re-wilding can realistically be achieved through the use of a naturalistic grazing regime.

Hypothesis

The null hypothesis (H_o): The impact of grazing is too high to allow natural regeneration of woody species to occur. Damage is the major consequence of grazing, and this has negative effects on the composition of woody species. Other factors also contribute to the composition of vegetation present and may be of equal or greater importance to grazing ungulates. Therefore naturalistic grazing regimes are predicted to be unsuitable for re-wilding the landscape.

The first alternative hypothesis (H_1): The impact of grazing is sufficient to allow natural regeneration of woody species to occur which consequently drives vegetation change. Woody species are tolerant of the grazing pressure, indicating the Knepp Castle Estate can be re-wilded using a semi-natural grazing regime.

If H_1 were to be true I would expect to the impact of grazing on woody species to be at a level they can tolerate and survive and that some evidence of substantial regeneration of woody species to be present. If H_0 were to be true I would expect the impact of grazing to be at a level which prevents the regeneration of woody species and to find evidence of damage or degradation.

3. Materials and Methods

The study site

The Knepp Castle Estate is situated south of Horsham in West Sussex, as shown by figure 3. The area included in the Wildland Project is split into three blocks, each having been entered at different stages. This study was undertaken in the southern block (470ha) which has been included in the project since 2005. See figure 6. After commercial agriculture ceased in 2004 the land was left fallow and the vegetation in this area has developed under its own means. It is considered the most interesting in terms of its evolving biodiversity (Anon, 2010). In the spring of 2009 eighty Longhorn cattle and ten Exmoor ponies were released into the southern block. In the autumn of 2009 thirty Tamworth pigs and in February 2010 thirty-five fallow deer were released into this area. It is estimated that there is a wild population of between sixty to one-hundred Roe deer within the southern block, and a large population of wild rabbits.

Selection of survey site

It was decided data collection would be undertaken in field New Barn 2 (NB2), shown in figures 4 and 5. NB2 was last cropped in 2004 and has been fallow since 2005. It is particularly interesting as it has enough tree and shrub regeneration to study and evidence of a wide enough variety of grazing impacts that could contribute to a grazing index.

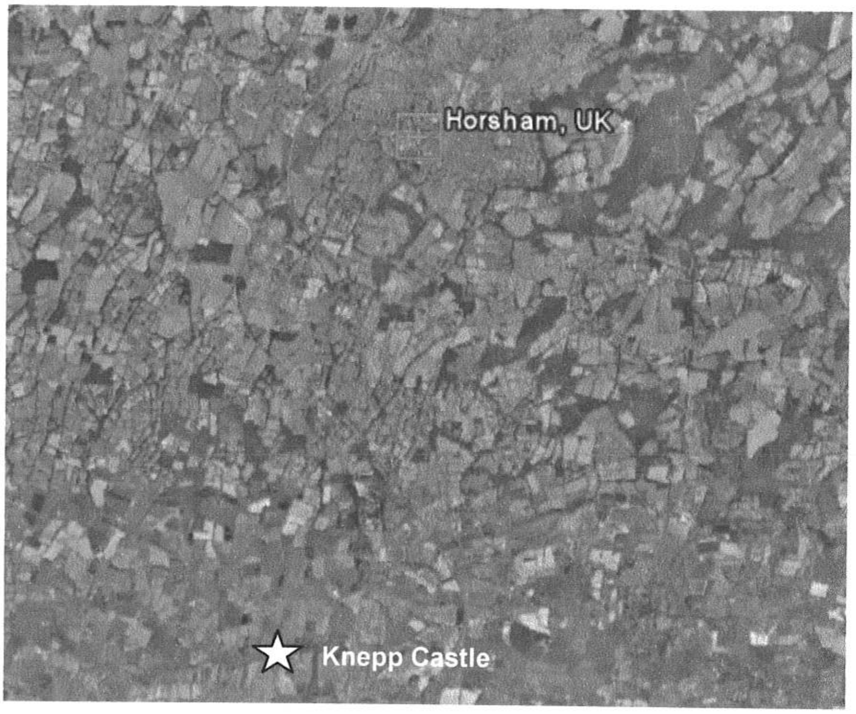


Figure 3: Location of The Knepp Castle Estate, West Sussex (Source: http://maps.google.co.uk)

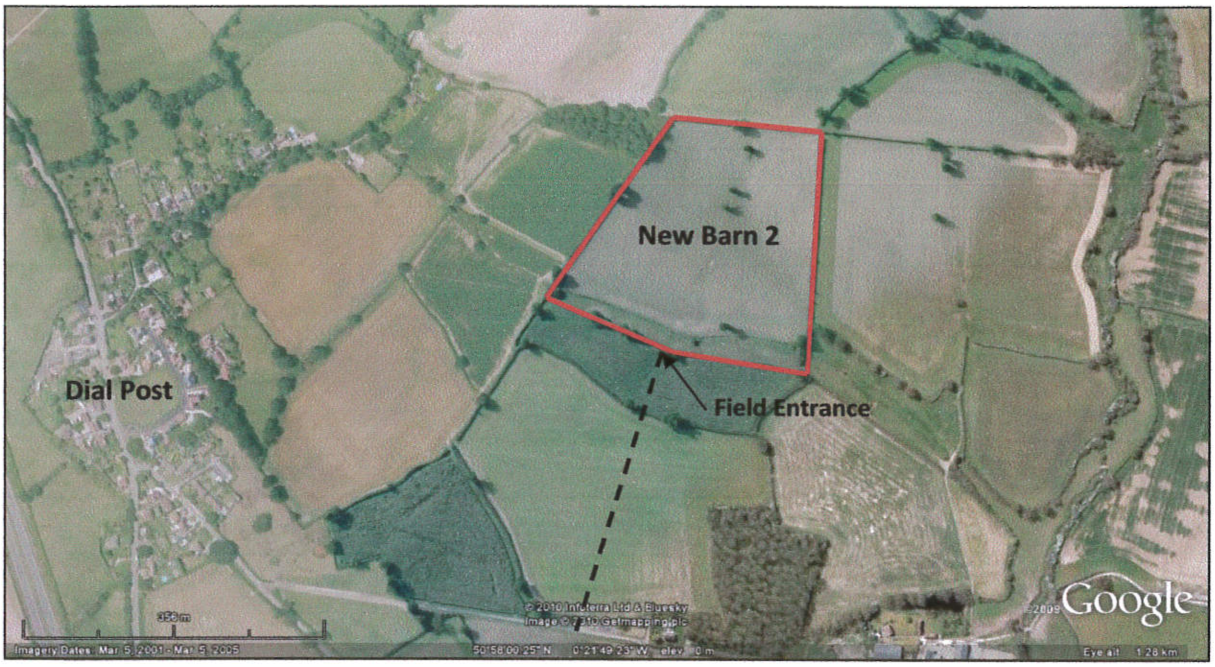


Figure 4: Location of New Barn 2 (Source: Google Earth).

Figure 5: New Barn 2

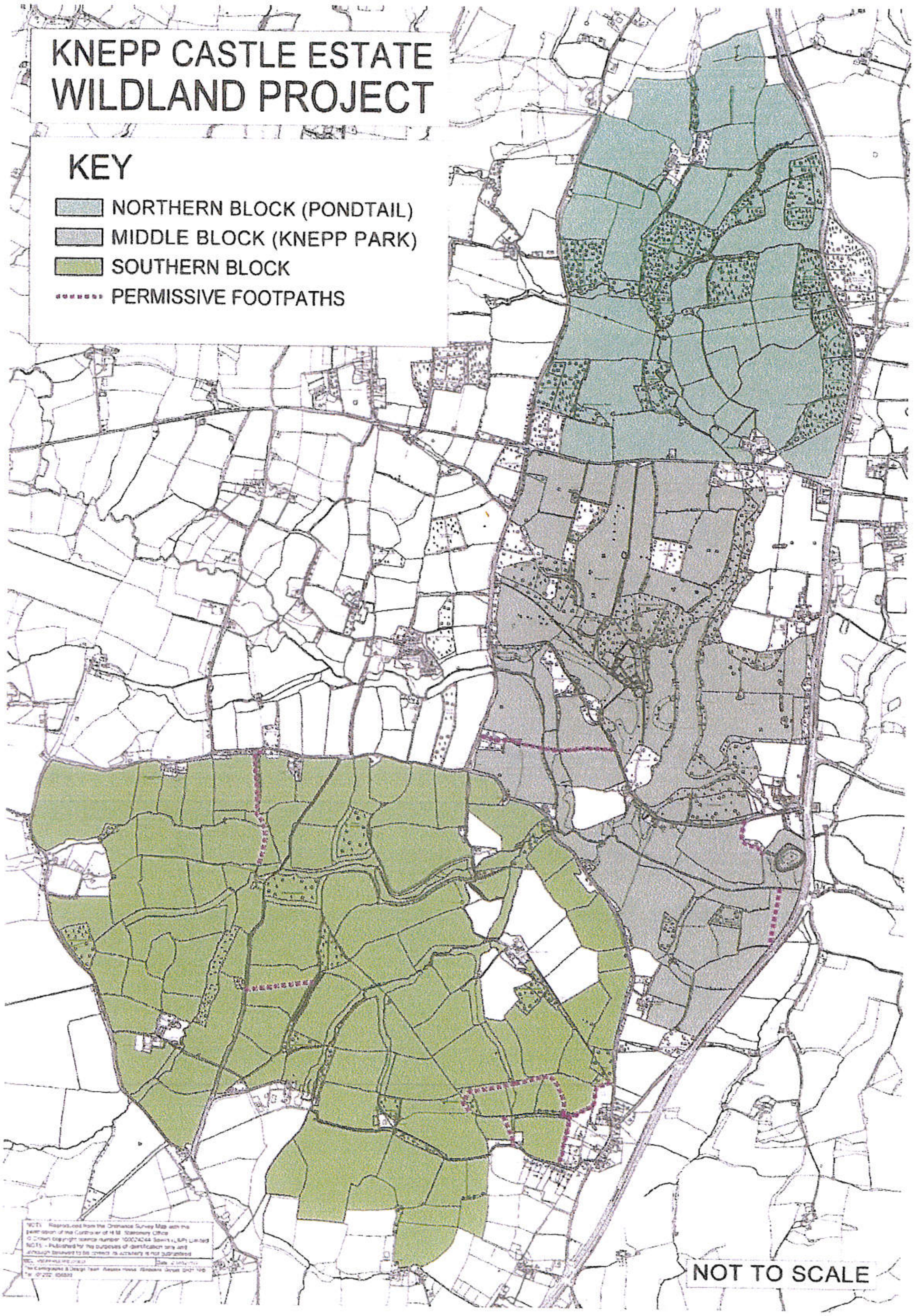


Figure 6: Area of The Knepp Castle Estate included in the Wildland Project (Knepp Castle Estate)

Vegetation mapping

The perimeter of NB2 was measured and a map of the area drawn out. This was checked with images from Google Earth. A 25m by 25m grid was drawn out covering the area of the field and the X and Y axis numbered. Fifteen plots were then chosen at random using a random number generator. See figure 7. This method was chosen to reduce bias and increase the chance of the sample being representative of the area as a whole.

In the field plots were located using a compass and 50m tape measure. In each plot the percentage cover of grasses, thorny/shrub species and tree regeneration was recorded; as well as the percentage of hedgerow and "other" which included bare soil, stream and species such as sedges etc. A simple sketch of the plot was drawn to give an idea of vegetation structure. Notes were taken on the species present, evidence of grazing impacts and other points of interest.

Tree regeneration was surveyed by walking the area of the plot. This was recorded according to species and height classes of 0-10cm, 11-50cm, 51-100cm, 101-200cm, >201cm. A tally was taken of the number of trees in each class.

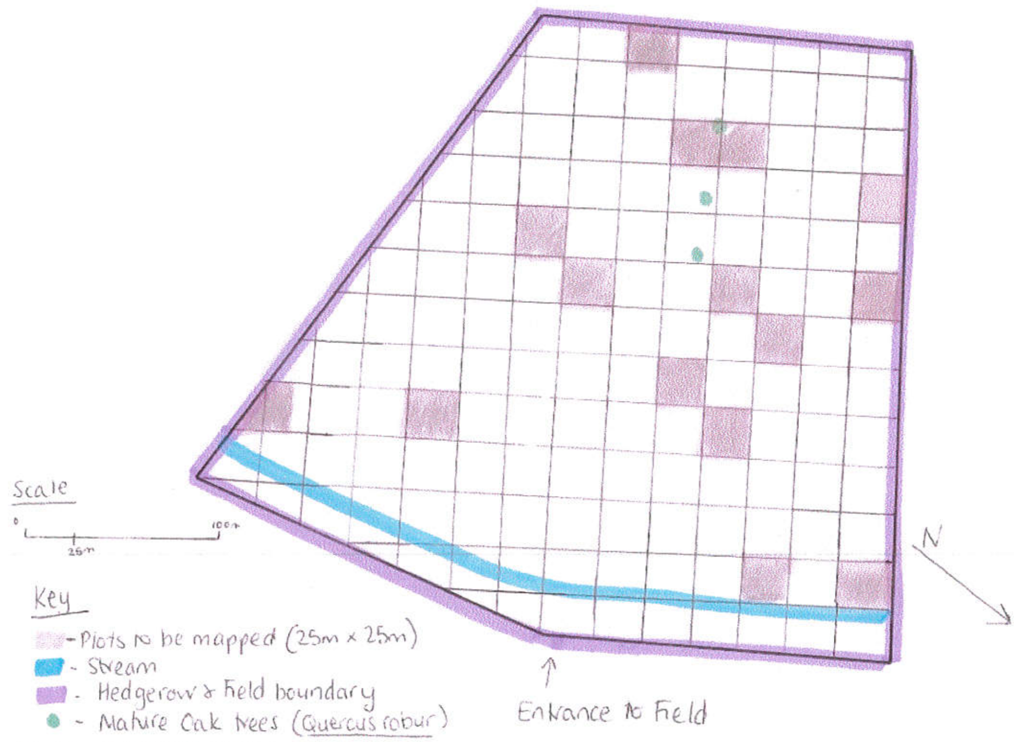


Figure 7: Location of plots surveyed.

Data collection for a Grazing Index

In this study woody vegetation is split in to two types; thorny species such as Blackthorn (*Prunus spinosa*), Hawthorn (*Crataegus* spp.), Dog Rose (*Rosa canina* (agg.)) and Bramble (*Rubus fruticosus* (agg.)) are considered to be "thorny scrub" species. Species, such as Oak (*Quercus* spp.), Willow/Sallow (*Salix* spp.), Ash (*Fraxinus excelsior*) are considered to be trees. A method for assessing the impact of grazing upon the woody species had to be decided. It needed to be quantitative so that it could easily be repeated. The simplest way to investigate the impact of the grazing was to look at how woody species recover from browsing.

Through observations it is apparent that the most recent browsing can clearly be seen by the cut tips of the woody species, broken branches and bark stripping. Grazing and gnawing by rodents and rabbits can be seen at the base of the stem which leaves scaring. When tree species are grazed as seedlings it can lead to the individual becoming multi-stemmed. Trampling and brushing against the trees and shrubs can break branches; this is considered to have the same effect as browsing as it is another process by which material is cut back. Particularly on tree species, it is easy to see where the individual has recovered from browsing as a node and scar is visible and the tree branches out from that point rather than continuing to grow through a single stem. This acts as a good reference of how many times the individual has been browsed or broken in its lifetime. It was decided that nodes would be used to assess grazing impact. At Knepp it is difficult to determine what can be classed as "damage" caused by grazing as it is an experiment to find out what will happen to the vegetation. I therefore decided to focus on the impact or amount of grazing rather than damage.

Three transects, 75m apart from the SW side of the field were marked out, shown by figure 8. A compass was used to gain a bearing to ensure transects were equally spaced in the irregularly shaped field. All trees and thorny shrubs one metre either side of the transect line were assessed for grazing/browsing. For each individual the following were recorded:

- Species name
- The number of grazing nodes present: These are given the name grazing points as they represent the number of points of grazing/browsing. Evidence of rabbit and rodent damage at the base of the tree was counted as one point. Figure 9 below shows a grazing point.
- Single/ Multi-stemmed. Multi-stemmed was regarded as a number of shoots coming from a single base point. When a tree species was multi-stemmed this was counted as one point as it is not in their nature to establish in this way. However, where a thorn species was multi-stemmed this did not count as one point as these species can grow this way naturally.
- Height in centimetres.
- Comments/ features of interest.

Photos were taken of features of interest, including evidence of trees growing within thorny patches of shrub, and the effects of browsing.

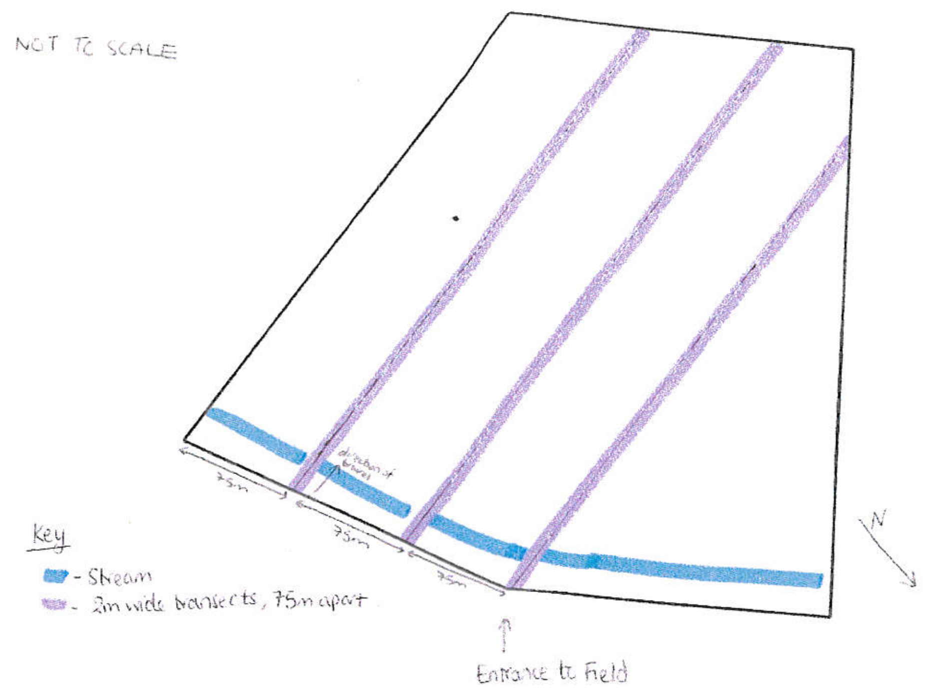


Figure 8: Location of transects.

Figure 9: The red arrow points towards the grazing point, a node and number of emerging shoots as a result of browsing.

Data Analysis

Vegetation data

The data was displayed as a number of histograms of percentage cover of different vegetation types and the frequency of sapling heights.

Grazing index data

Basic statistics (mean, standard error, frequency distributions and tests for normality) were carried out to test the suitability of the data for further analysis. Correlation analysis was then undertaken to test for an association between the number of grazing points and the height of the individuals. Firstly scatter plots were created to visually display whether positive, negative or no association could be seen. Pearson Correlation analysis was then applied and the results recorded in a table. Finally, regression analysis was carried out to define a line of best fit for associations found and ANOVA was undertaken to test the significance of the regression line

4. Results

Impacts of Grazing

Impacts of grazing are provided in Table 1. Figures 1-12 in Appendix I provide evidence of these impacts in NB2.

Table 1: Observed impacts of grazing animals within New Barn 2.

Observed impact of grazing	Animals involved	Description	Photo evidence (Appendix I)
Bark Rubbing	Deer, Cattle, Ponies	Animals rub up against the tree/shrub wearing away the bark	
Bark stripping	Deer, Rabbits	Bark is stripped from the stem. In some cases all bark was removed.	Figure 1-3
Browsing of tips of branches and shoots	Cattle, Deer, Ponies	Tips of the branches/ shoots are nipped off; this can be neat or cause the shoot to fray at the tip. Results in multiple shoots growing from this point (used for grazing points)	Figure 4-6
Gnawing at base of tree/shrub	Rabbits, Mice, Voles	Bark at the base of the tree/shrub is gnawed away.	Figure 7 & 8
Poaching of soil	Cattle, Ponies, Pigs, Deer	Trampling and uprooting causes soil to become exposed.	Figure 9
Root damage	Pigs, Rabbits, Mice, Voles	Seen where the roots have been grazed or uprooted.	
Snapped branches, broken tips	Cattle, Deer, Ponies	Animals brush against the trees causing breakages.	Figure 10
Trampling of woody material	Cattle, Ponies, Pigs and Deer	Vegetation is flattened, may cause damage or the vegetation to grow in a different direction.	Figure 11
Uprooting	Pigs	Material is pulled out causing the soil to become exposed.	

Grazing Index Data

Basic statistics: Mean, Standard Error, frequency distributions and tests for normality

361 trees were surveyed in this investigation; 185 "tree" and 169 "thorny" species. Tree species recorded were Oak (*Quercus* spp.), Willow (*Salix* spp.) and Ash (*Fraxinus excelsior*). Thorny species recorded were Blackthorn (*Prunus spinosa*), Dog rose (*Rosa canina* (agg.)), Bramble (*Rubus fruticosus*) and Hawthorn (*Crataegus* spp.). The mean height of each thorny species exceeds the mean height of each tree species in all cases. Dog rose had the highest mean height of all species at 119.8cm, whilst Ash had the lowest at 39.5cm. See figure 10.

Oak had the highest mean number of grazing points of all the woody species surveyed with an average of 3.6 grazing points. Bramble had the lowest mean number of grazing points with an average of 1.1. Excluding Hawthorn, all thorny species had mean number of grazing points lower than that of tree species. See figure 11.

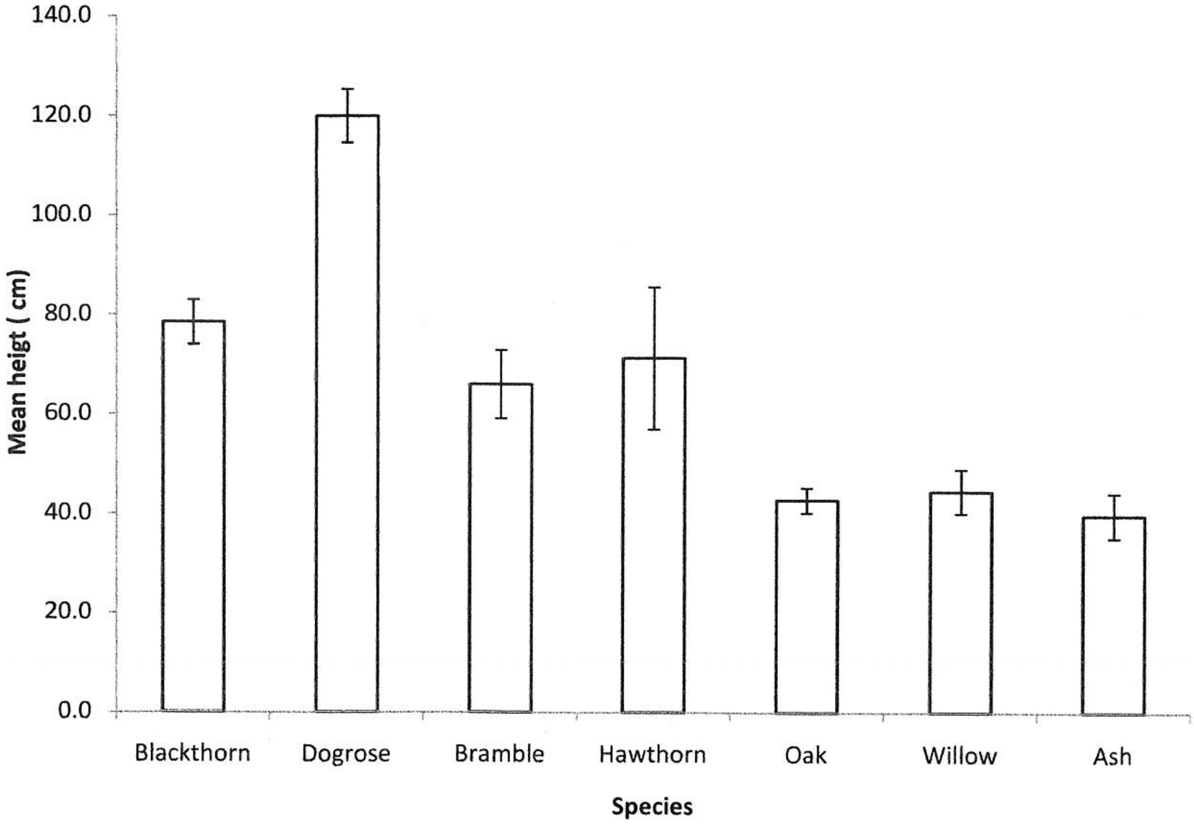


Figure 10: The mean (±S.E) height of all woody species surveyed (2010). N= 361

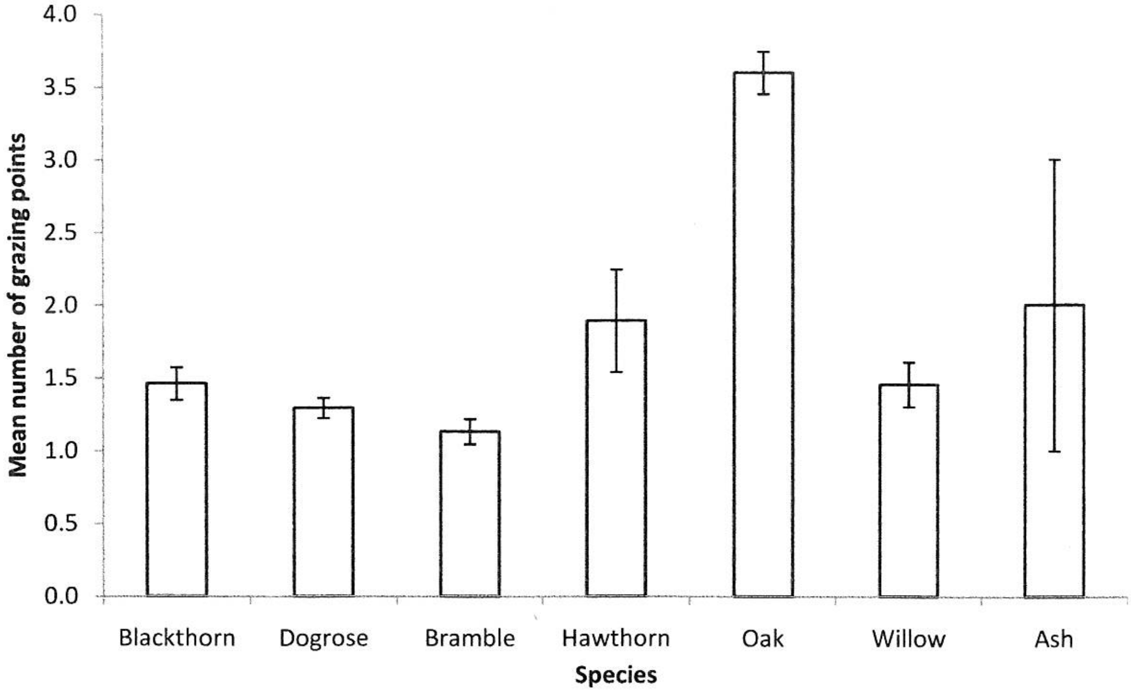


Figure 11: Mean (±S.E) number of grazing points of all woody species surveyed (2010). N= 361

In 2009 95% of the tree species surveyed had been grazed/ browsed as shown by figure 12. 584 trees were included in the survey; thorny species were not surveyed. Willow (83.7cm) and Birch (76.3cm) had the greatest mean heights, whilst Ash (47.5) had the lowest as shown by shown by figure 13.
The mean height of each species for 2009 is higher than in 2010. The highest change is seen for willow, with a reduction of 39.3cm (~50%). Field Maple (*Acer campestre*) and Birch (*Betula spp.*) were recorded in 2009 but were not recorded in the transect survey. See figure 14.

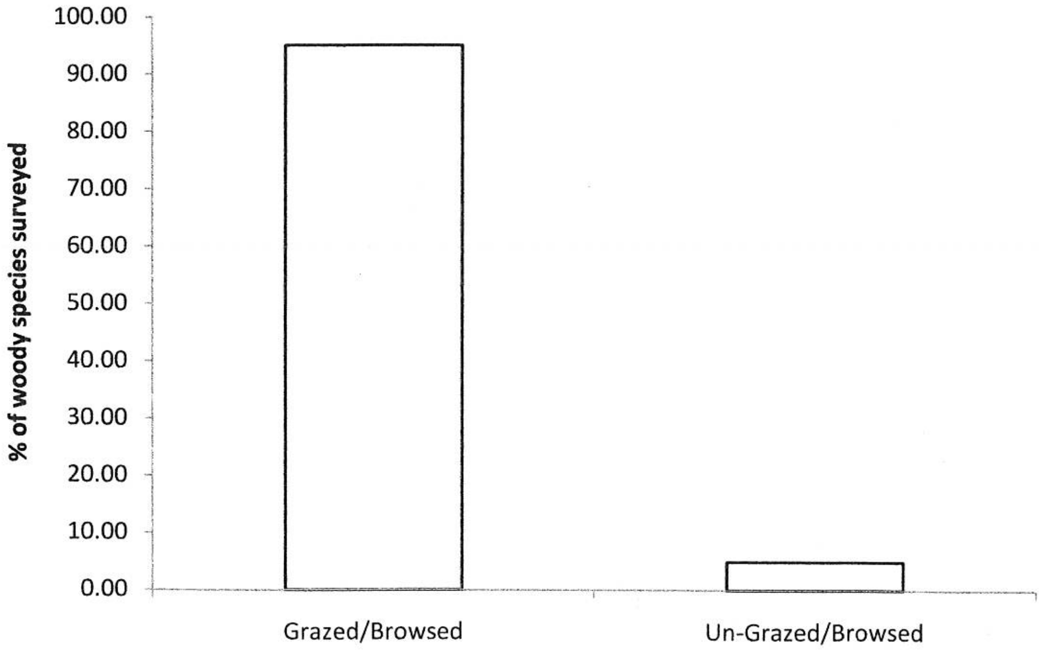


Figure 12: The percent of tree species grazed/ browsed and un-grazed/browsed before the introduction of The Wildland Project animals. N= 584. Thorny species were not included in this survey.

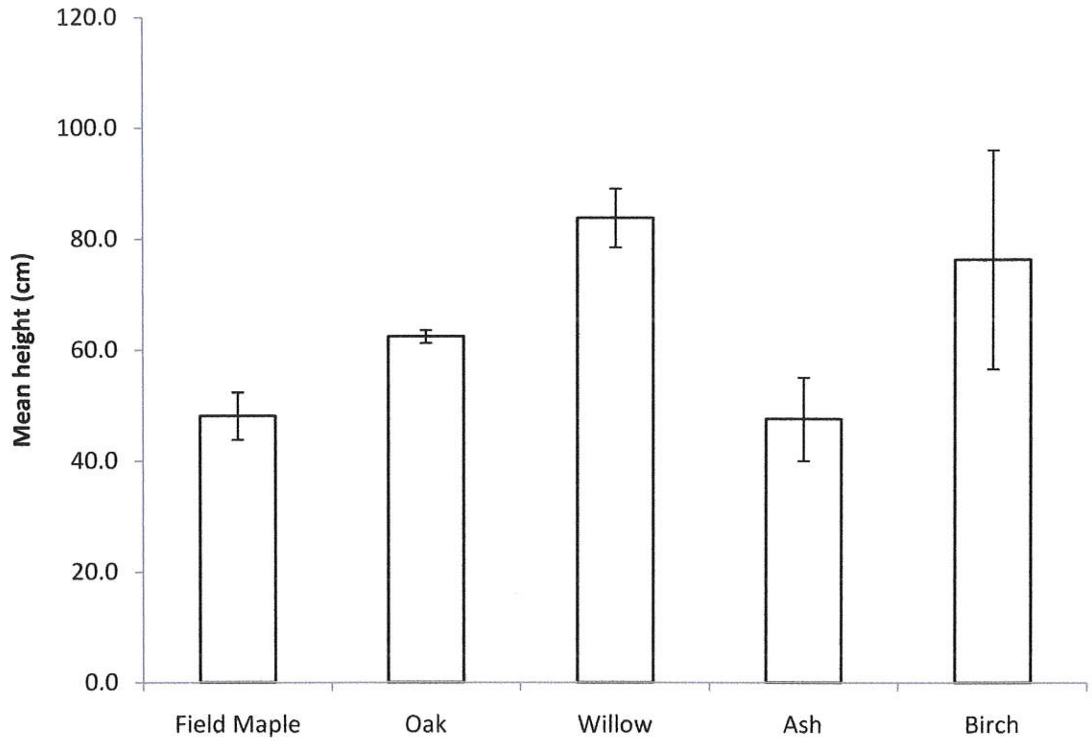


Figure 13: The mean (±S.E) height of all tree species surveyed in 2009. N= 584.

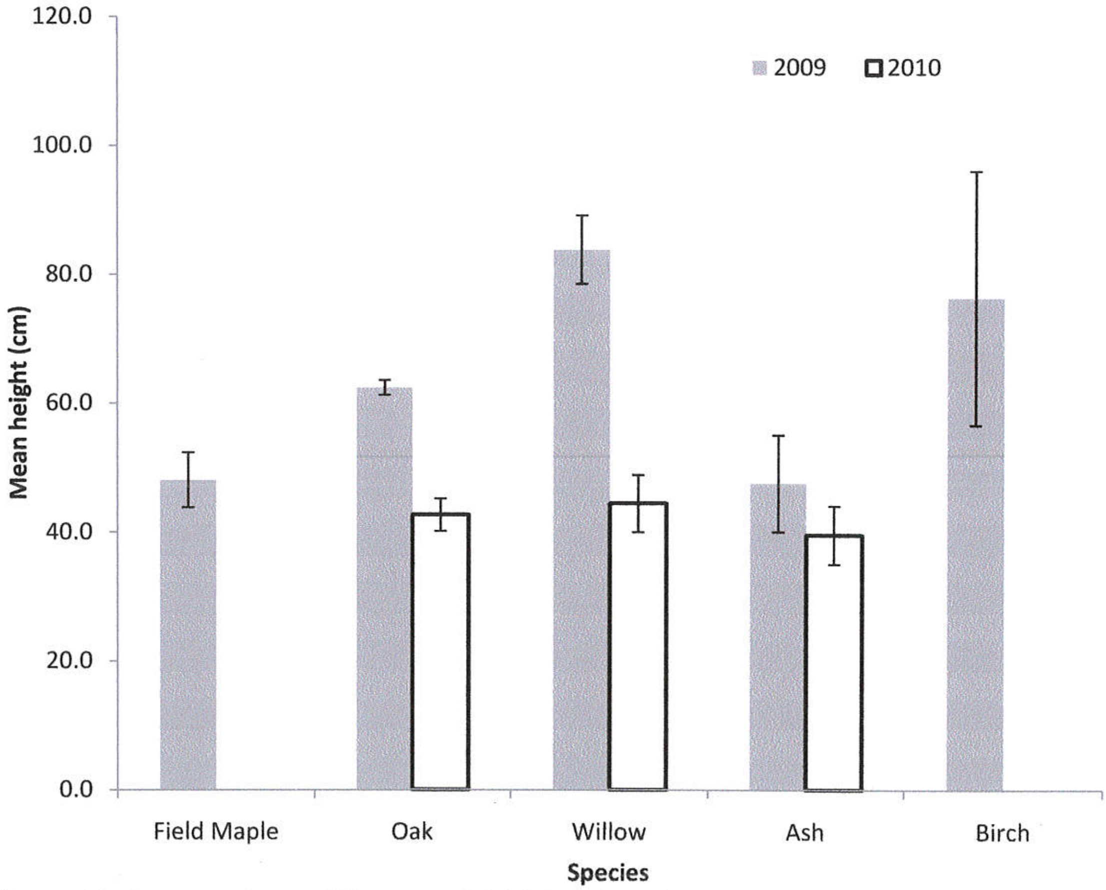


Figure 14: A comparison of the mean (±S.E) heights of tree species between 2009 and 2010. Field Maple and Birch were not found in 2010. Thorny scrub species were not recorded in 2009.

The majority of woody species surveyed in 2010 fall in to the 0-75cm height class, as shown by figure 15. As shown by figure 16, the distribution of height frequency is skewed to the left for tree species, whereas the distribution for thorny species is only slightly skewed to the left, showing a more normal distribution. A greater number of thorny individuals are in each of the height classes from 76cm to 250cm. When compared with 2009, as shown by figure 17, it can be seen that the distribution for tree species has become more skewed to the left with the majority of individuals now in the lower height categories.

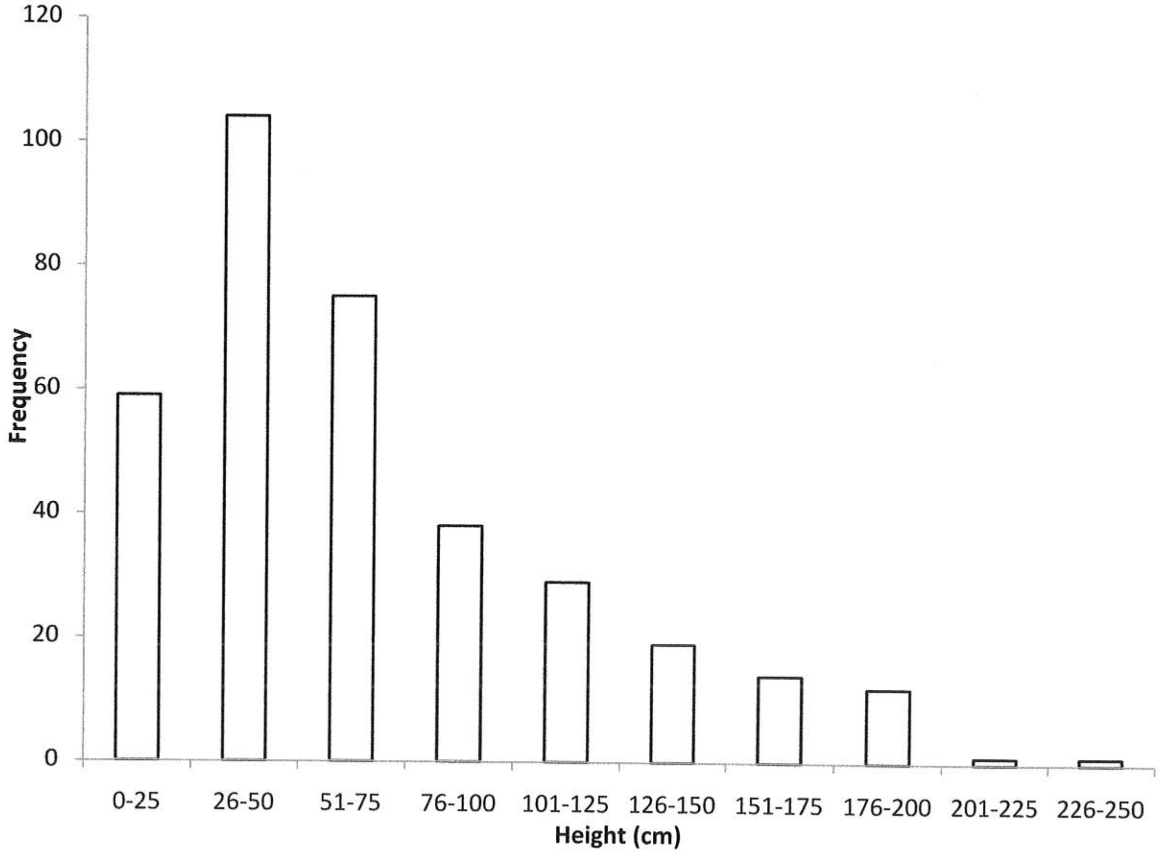


Figure 15: Frequency distribution of the heights of all woody species surveyed (2010). N= 361

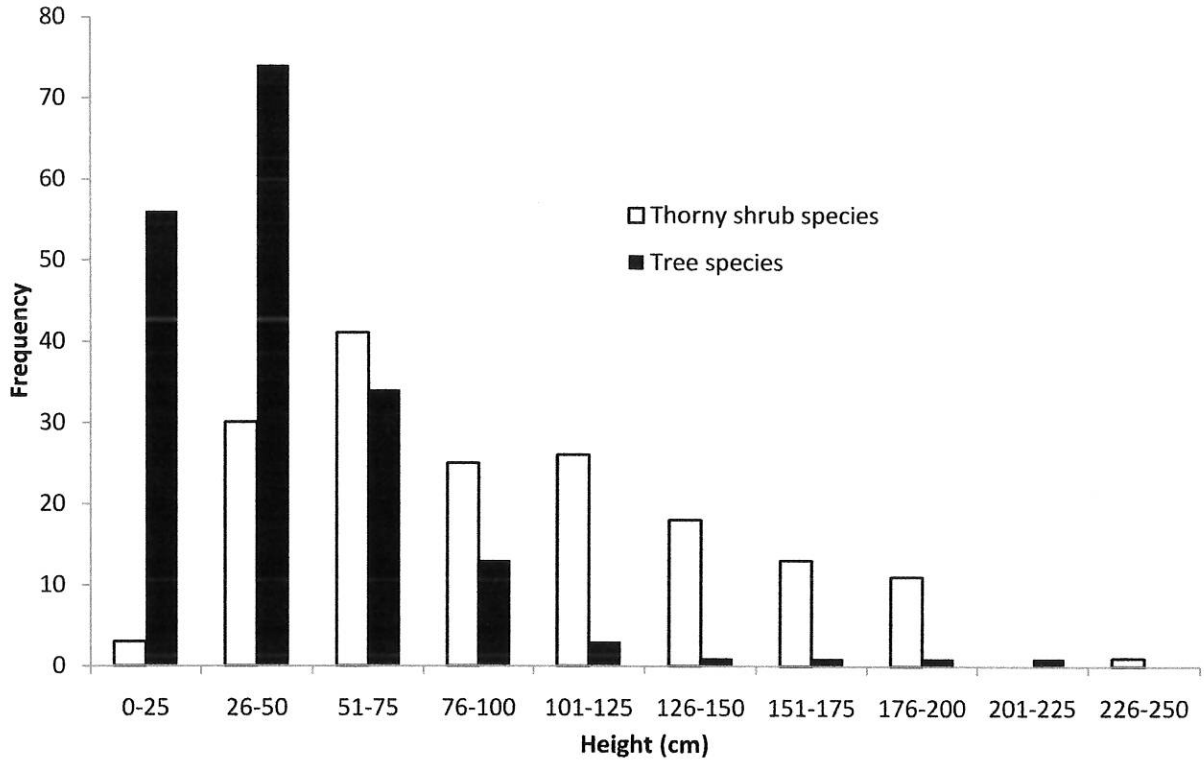


Figure 16: A comparison of the frequency distribution of tree (n=185) and thorny species (n=169) height (2010).

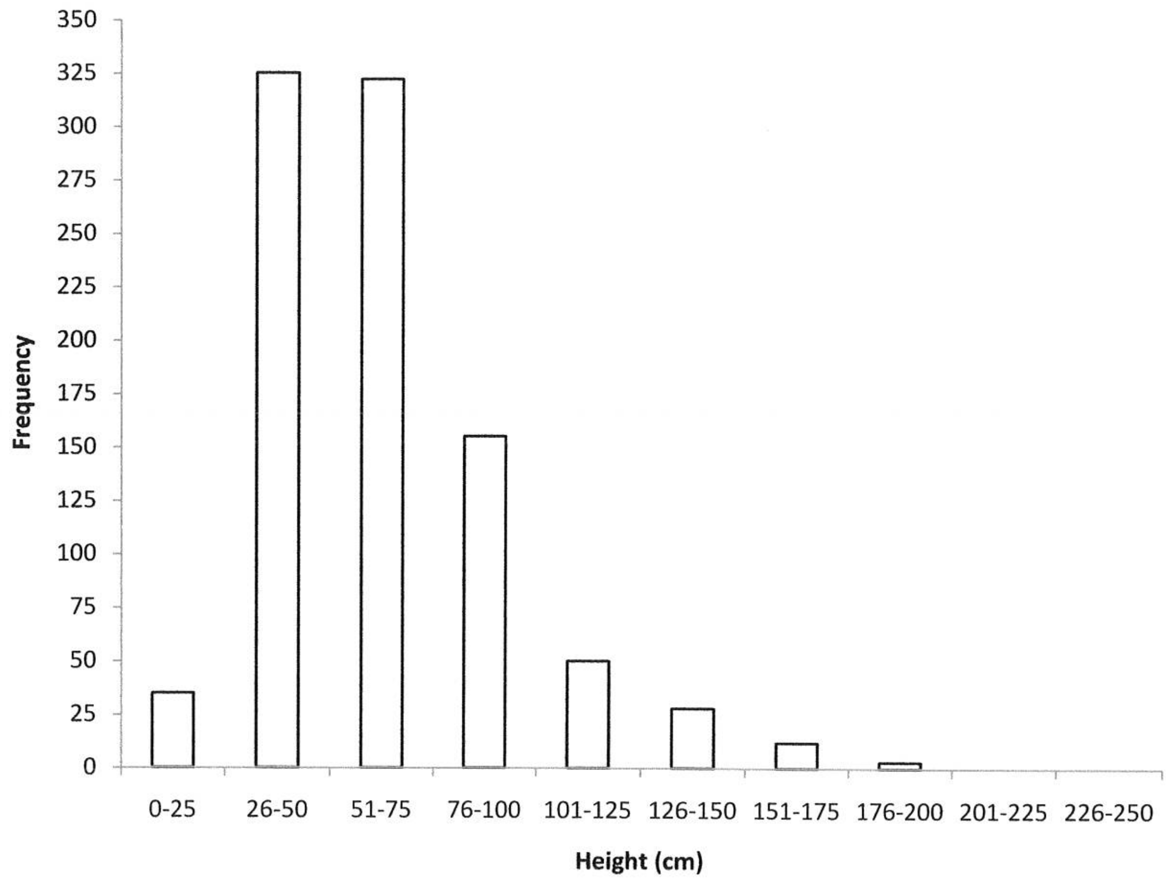


Figure 17: Frequency distribution of the heights of all tree species surveyed in 2009. Thorny scrub species were not recorded in 2009.

The frequency distribution of the number of grazing points for all woody species surveyed is skewed to the left with the majority of individuals in the 2-4 point classes. See figure 18. For thorny species the distribution is slightly skewed to the left, and all individuals have between 0 and 4 grazing points. The distribution for tree species follows a normal distribution and individuals have between 0 and 8 grazing points as shown by figure 19.

Results for normality tests (Histograms with fit and Probability Plots) can be found in Appendix II. All data was normally distributed and suitable for correlation and regression analysis.

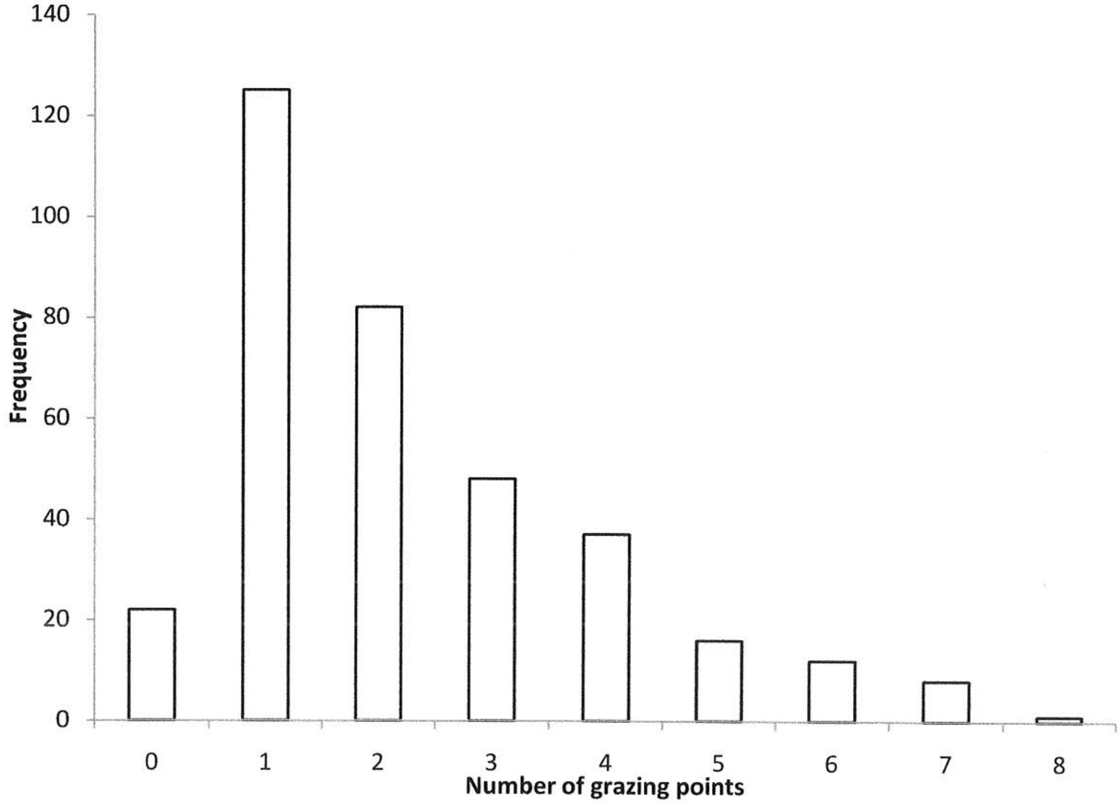


Figure 18: Frequency distribution of the number of grazing points recorded for all woody species (2010) N= 361.

Figure 19: A comparison of frequency distribution of number of grazing points for tree (n=185) and thorny (n=169) species (2010).

Correlation Analysis

Pearson's Correlation analysis, shown in table 2, found a slight positive relationship between the number of grazing points and the height of tree species to be significant. For all woody species surveyed a slightly negative relationship is significant. A slightly negative relationship for thorny species was found to be insignificant.

Table 2: Correlation Analysis of the association between the number of grazing points and height for i.) All woody species surveyed; ii.) All tree species surveyed and iii.) All thorny species surveyed (2010). R is the Pearson Correlation coefficient (-1 = perfect negative correlation; 0 = no correlation, and +1 = perfect positive correlation), P is the significance probability of R being equal or greater than the critical value if the null hypothesis were to be true (If P is <0.05 the R value is said to be significant; * highly significant (<0.001), *significant (<0.05), n/s not significant (>0.05)).**

	R	P	Significance
All woody species	-0.199	0.000	***
Tree species	0.300	0.000	***
Thorny Species	-0.123	0.119	n/s

Regression Analysis

Regression analysis of all woody species shows slight negative association as shown by figure 20. 95% confidence intervals are narrow; however the 95% prediction intervals are wide. R^2 is 4.0%, therefore 96% of variation is not accounted for by the regression line. Analysis of variance (ANOVA) shown by table 3, found the regression line is significantly different from 0.

For all tree species surveyed the regression line shows a slightly positive association. 95% confidence intervals are narrow; however 95% prediction intervals are wide. R^2 is 9.0%, therefore 91% of variation is not accounted for by the regression line. See figure 21. The ANOVA for tree species regression analysis, shown by table 4, illustrates that the slope of the regression line is significantly different from 0.

Regression analysis for thorny species data shows a slightly negative relationship, see figure 22. 95% confidence intervals are not as narrow as for tree species and all woody species and 95% prediction intervals are very wide. R^2 is 1.9% which is very low; therefore 98.1% of variation in the data is not accounted for by the regression line. ANOVA confirms that the regression line is not significantly different from 0, see table 5.

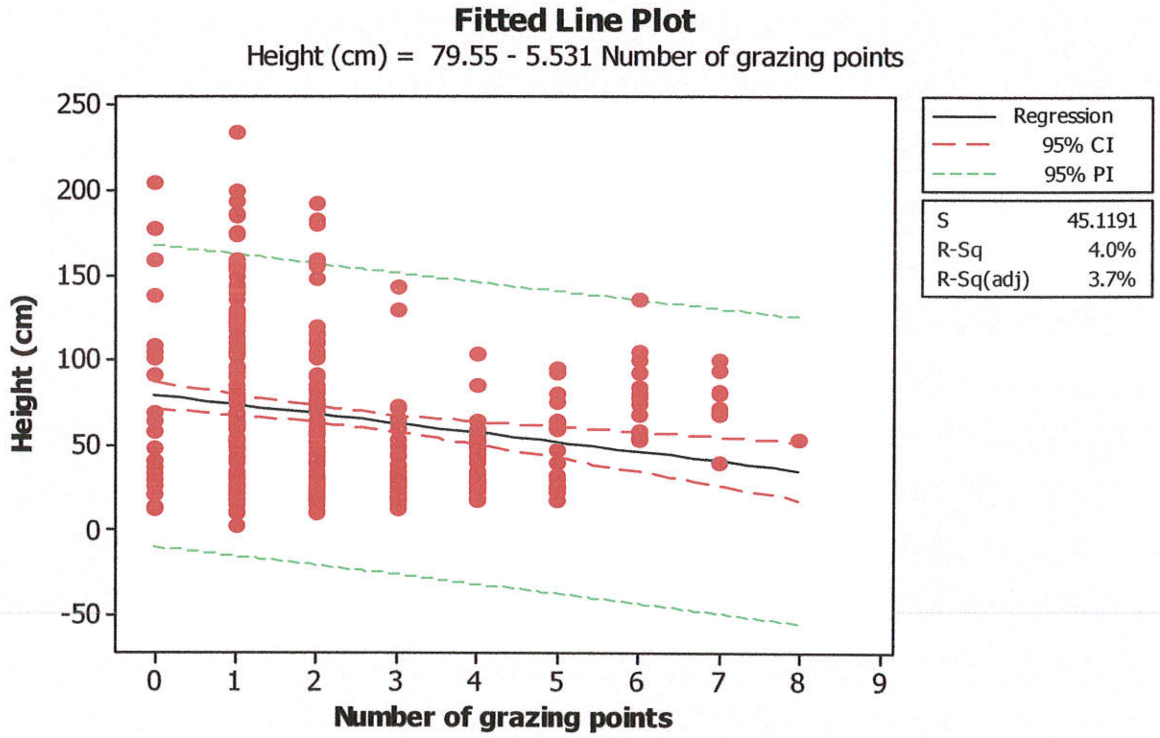


Figure 20: Regression analysis number of grazing points vs height of all woody species surveyed (2010). The regression equation is y= 79.55+5.531x. 95% confidence intervals are given by the red dashed line; 95% prediction intervals are given by the green dashed line. R-Sq (r^2) is the percent of variation in the data that is accounted for by the regression line.

Table 3: Analysis of variance (ANOVA) for regression analysis of the association between number of grazing points and height of all woody species surveyed. ANOVA gives a comparison of the variation explained by the regression line and the variation due to error, therefore telling us whether the slope of the line is significantly different from 0. D.F= degrees of freedom; SS= sum of squares; MS= Mean squares; F= test statistic; P= the probability that the absolute value of the test statistic would be greater or equal to F if the null hypothesis were to be true. If P<0.05 then the null hypothesis is rejected, i.e. then the slope is significantly different to 0.

Source of variation	DF	SS	MS	F	P
Regression	1	29160	29160.2	14.32	0.000
Error	348	708435	2035.7		
Total	349	737595			

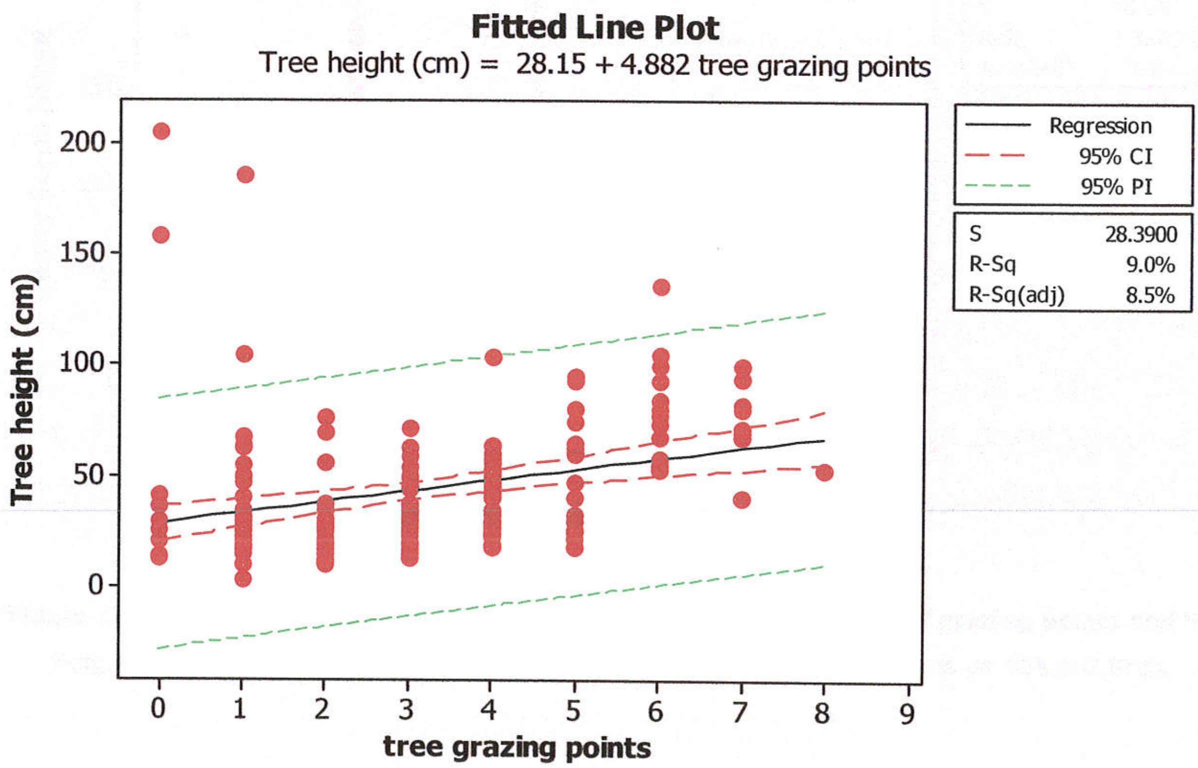


Figure 21: Regression analysis of the association between the number of grazing points and the height of all tree species surveyed (2010). The regression equation is y= 28.15+4.882x.

Table 5: Analysis of variance (ANOVA) for regression analysis of the association between number of grazing points and height of all thorny species surveyed.

Source of variation	DF	SS	MS	F	P
Regression	1	5230	5229.92	2.46	0.119
Error	161	342790	2129.13		
Total	162	348020			

Plot % Cover data

Thorny scrub and tree cover are not evenly distributed across New Barn 2; see figure 23. Scrub regeneration is highest in plots 3, 4 and 5. Tree regeneration is highest in plots 1, 6 and 14. Plots 1, 9 and 12 contain similar amounts of tree and thorn. Plots 3, 7 12 and 15 contain little or no tree regeneration. Percent cover of grass is high in all plots. Mature trees were present in plots 1, 13 and 14. Hedgerow is present in plots 1, 3, 12 and 15, see figure 24. Plot one has a large number of trees of 0-50cm, whilst the tallest trees are found in plots 11, 13 and 14. Overall the majority of trees are in the 11-50cm height class; see figure 25.

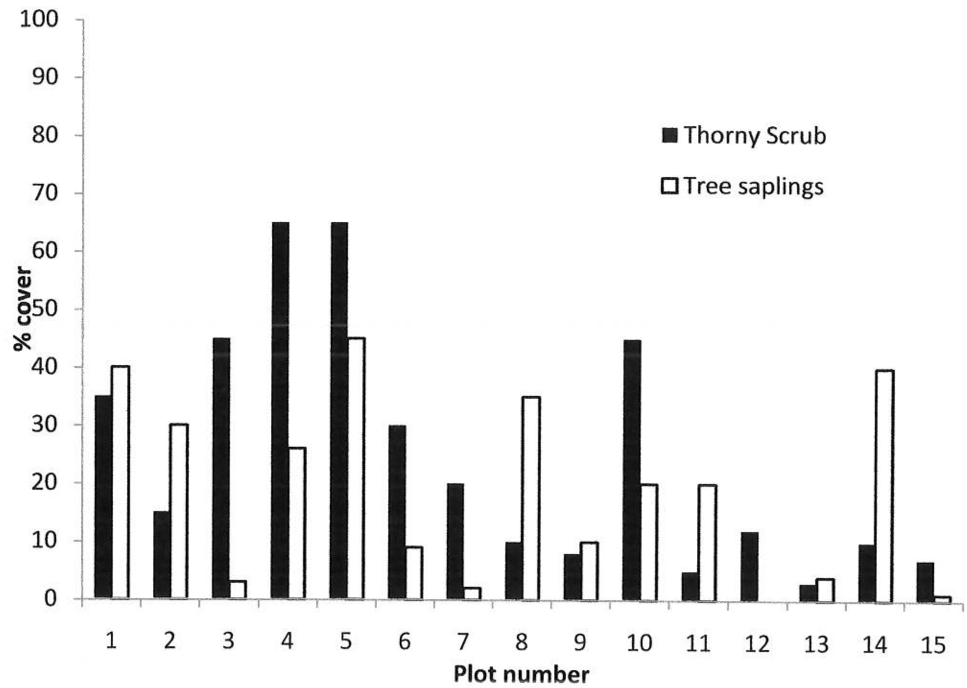


Figure 23: A comparison of the % cover thorny and tree species in each plot surveyed (2010).

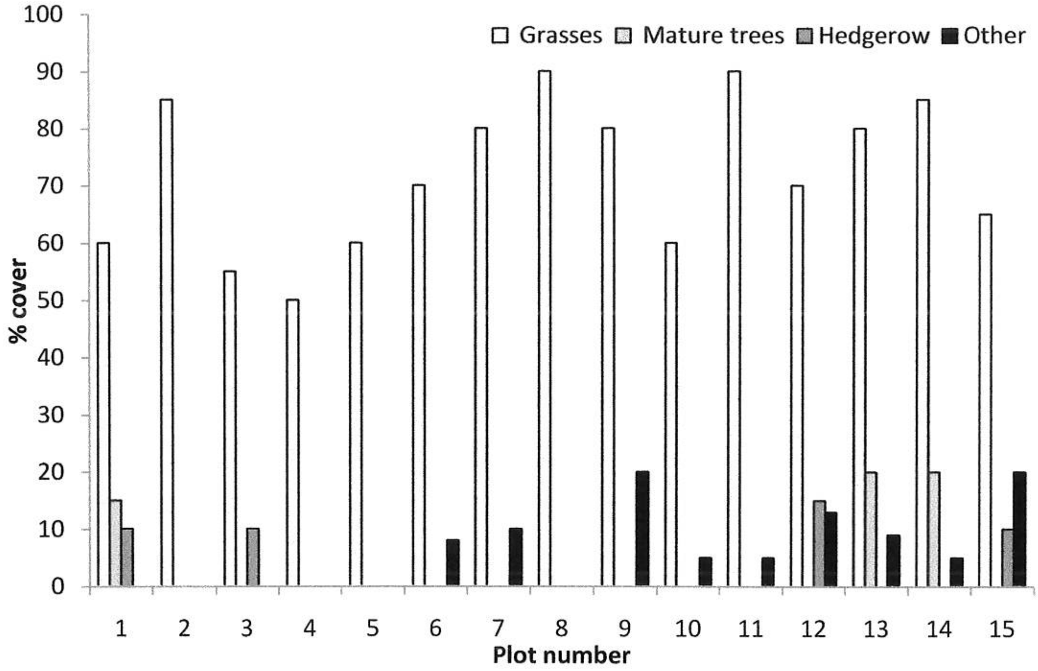


Figure 24: The percent cover of grass, mature trees, hedgerow and other for each 25mx25m plot surveyed.

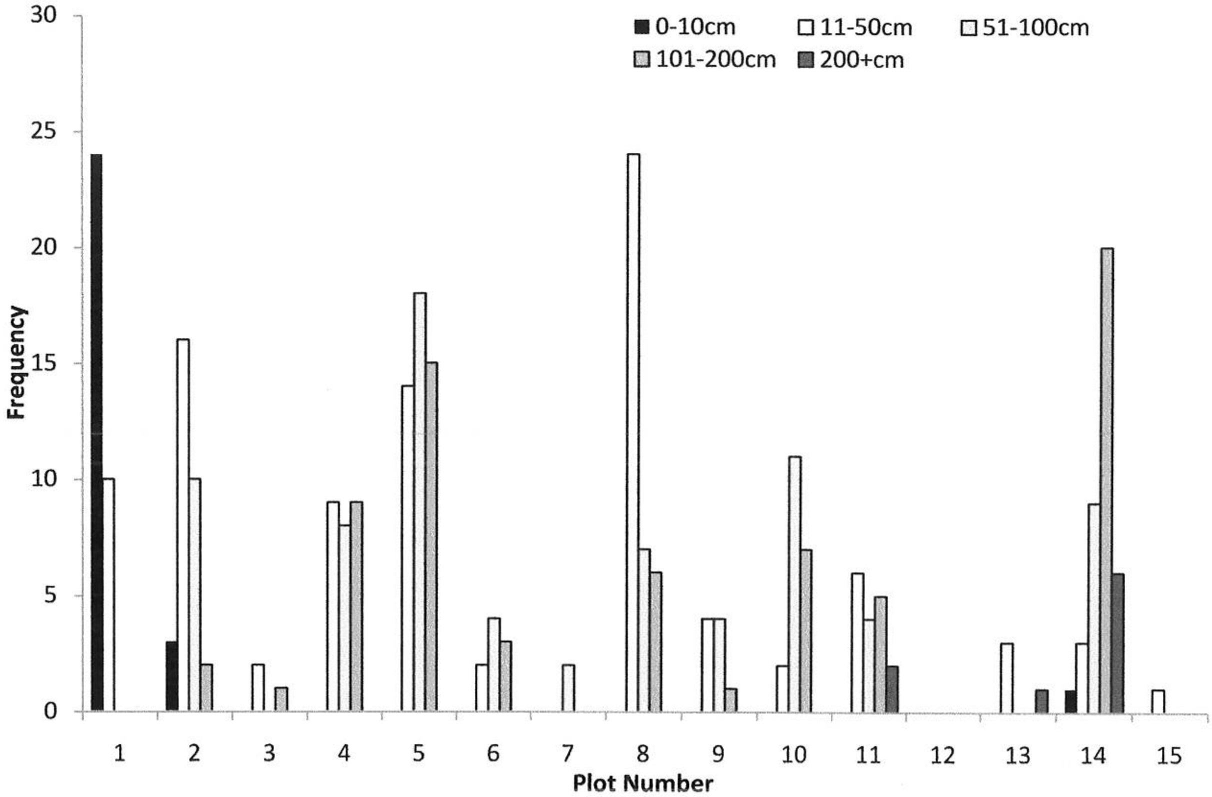


Figure 25: The number of tree saplings recorded in each plot according to height class.

5. Discussion

Impact of a semi-natural grazing regime on the Knepp Castle Estate

Impacts of grazing observed in NB2, are shown in table 1. Browsing the tips of branches has been found to restrict the growth of woody species to small, severely bitten down shrubs (Peterken, 1996) and trampling can destroy seedlings revealing those previously covered so they become susceptible to browsing (Mitchell & Kirby, 1990). Impacts are not always negative, for example trampling can expose the soil and create regeneration niches for tree seedlings enabling numerous tree seedlings to become established. Debarking has been found to have little impact on the survival of woody species (Peterken, 1996).

Since 2009, the mean height of tree species has reduced significantly, see figure 14. The proportion of trees in the lower height classes (0-50cm) has increased and has decreased in the taller height classes; see figures 16 and 17. This suggests grazing has reduced the height of trees in NB2. However, the 2010 results in figure 16 show trees have been recorded in the 201-225cm height class when there were none previously. Some individuals may have become taller despite the increased grazing level. The larger proportion of smaller trees could indicate a higher amount of seedling establishment, perhaps due to an increase in suitable sites due to trampling or protection from presence of thorny scrub.

Field Maple and Birch were not found in the transect survey although, small numbers were noted in the plot survey. Their abundance may have declined since the Wildland Project grazing animals were introduced. Studies such as that by Harding and Rose (1986) have found repeated browsing damage to trees can remove many typical woodland species from an area. The impact of grazing, perhaps due to their palatability may have been greater on Field Maple and Birch and in time they could become absent, reducing the diversity of tree species at Knepp.

The grazing index suggests that the impact of grazing is less on thorny species than on tree species, see figures 11 and 19. This is supported by evidence that thorny species surveyed had greater mean heights than tree species; see figure 10. The un-palatability of thorn, in comparison with other species present may account for this. Species such as Bramble (*Rubus fructicosus)* and Hawthorn (*Crataegus* spp.) have been found in the diets of deer, particularly Roe (Mountford & Peterken, 2003) this explains why thorny species have some grazing points. Woody species differ in their susceptibility to damage, and individual species are most vulnerable in specific age and size classes (Flowerdew & Ellwood, 2001). The age of the woody species in NB2 may be contributing to the effect of grazing, as they mature they may become more tolerant of grazing or less palatable.

Although introduced grazers have only been present for one year, wild populations of Roe deer and rabbits would have been grazing the area before this; it is assumed since the field was left fallow in 2005. In 2009 ~95% of trees in NB2 had been grazed. See figure 12. Comparing the 2009 and 2010 data gives an idea of the impact of grazing above the "truly wild level".

The 2009 survey included all trees in NB2 whereas in 2010 a sample was taken. This difference in sample size must be taken into consideration. If the 2010 survey had covered all trees and thorns in NB2 the error in the data may have been greatly reduced and the results may have been different. Sample size is a likely cause of error in the data; where error is high there were very few individuals included in the standard error calculation.

Formation of a Grazing Index: The Grazing Points Index

Correlation and regression analysis found no relationship between height and number of grazing points for thorny species. The index may not work for thorny species because the nature of their growth makes grazing points less obvious and measuring height accurately was made difficult by their structure. For example Bramble is a sprawling shrub, producing shoots from its root stock which die in the autumn of their second year. New shoots grow over the dead ones increasing the height of the shrub eventually forming a thicket (Harmer *et al,* 2010). This makes it difficult to decide where the highest point is and removes signs of browsing as the material dies. It is also possible the sample size was too small, and given more data a clearer relationship might be found.

A relationship between the number of grazing points and height was found for combined woody and tree species. There is a less that 0.01% probability that the results are due to chance therefore predictions can be made as to how this index could be used in the future. A larger sample size may have strengthened this relationship. I suggest the index is used in the following way:

- If the regression line is similar to that in figure 26b, the impact of grazing is low. As the number of grazing points increases the height increases. Although woody species are being grazed they are still becoming taller and must be tolerant to the grazing level.
- If the regression line is similar to that in figure 26a, the impact of grazing is high. As the number of grazing points increases the height decreases. Although there are tall individuals with few grazing points there must also be many individuals which are short with a high number of grazing points.
- The slope of the regression line indicates the extent of grazing impact, see figure 27a-c. Grazing may be different degrees of "moderate"; positive (+), when close to low; or negative (-) when close to high impact.
- If P is greater than 0.05, i.e. the slope of the regression line is not significantly different from 0, a particular height level may be being maintained (see figure 26c). This might be found in a grazing regime which aims to meet a specific outcome in terms of vegetation structure.
- A regression line at 90^0 would suggest a range of tree heights where individuals have the same (± ~1) number of grazing points, this may be due to a specific grazing level being maintained, see figure 26d.

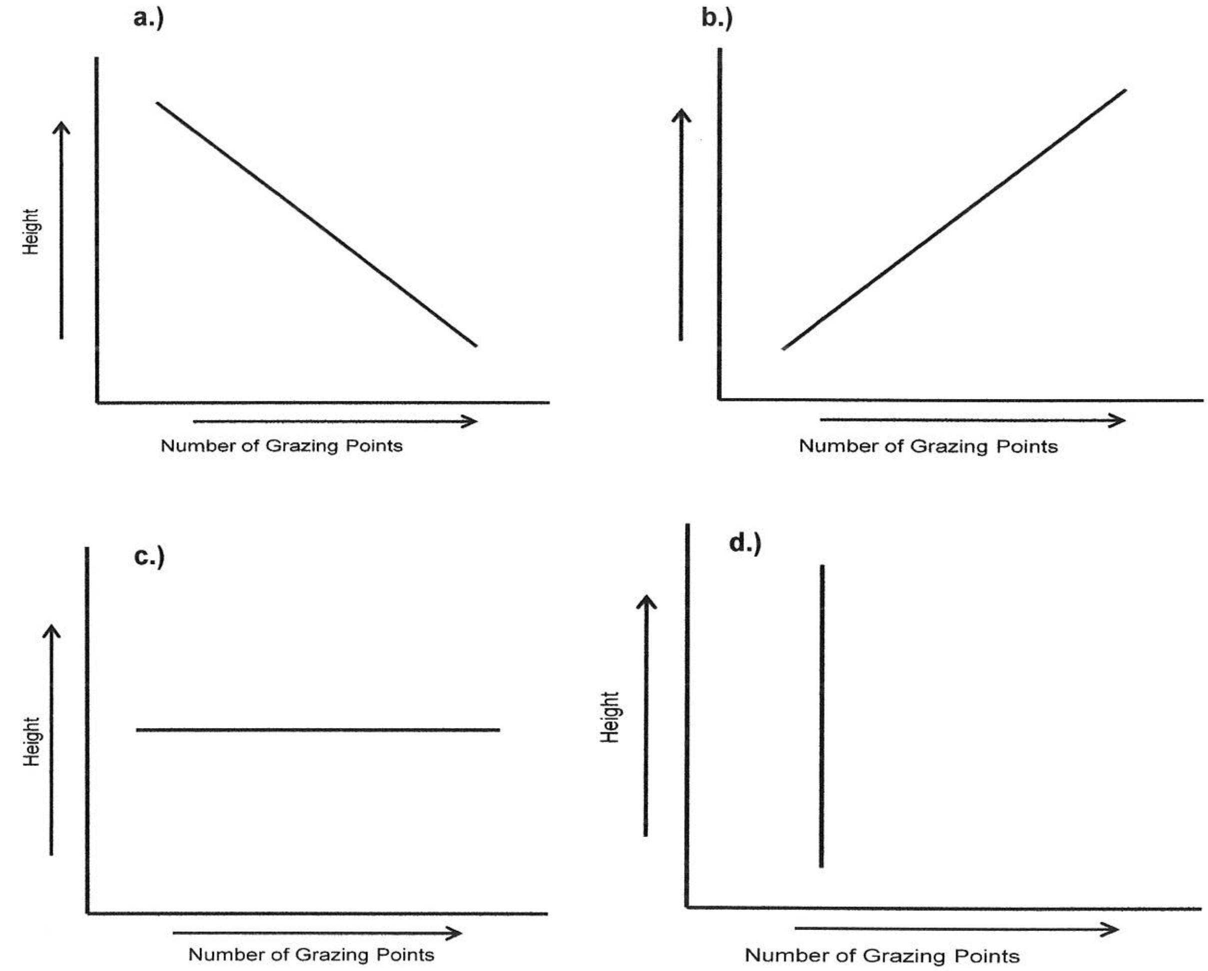
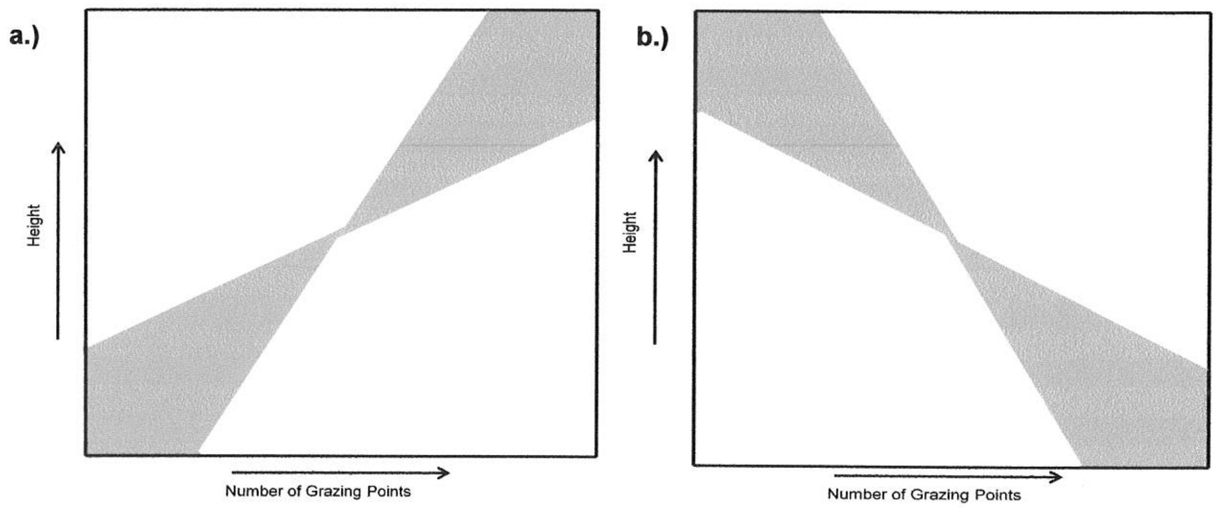


Figure 26 a-d: The regression analysis of number of grazing points vs. height of indicates whether the impact of grazing is a.) High, b.) Low, c.) maintaining a specific height structure or d.) maintaining a specific grazing level



c.)

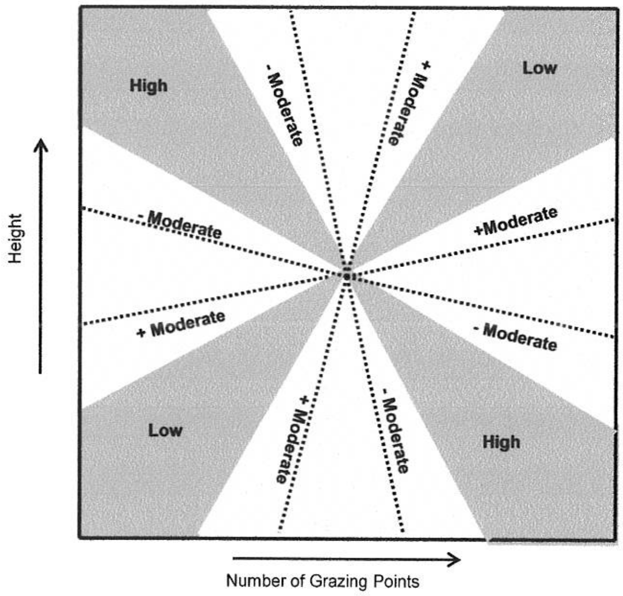


Figure 27 a-c: The slope of the regression line indicates grazing impact: if the regression line falls in the area shown in a, grazing impact is low; if the regression line falls in the area shown in b grazing impact is high. Outside of these areas grazing impact is thought to be moderate (+ moderate to low, - moderate to high), as shown by c.

The X and Y scales are important. Once the height of the trees is above the browse line (around 2.5m- trees in wood pastures were pollarded at a height of 2-3m (Peterken, 1996)), I would expect density dependant factors and other non-grazing related factors to control height. It should be taken into account that the height of the browse line is specific to each grazing animal. When the number of grazing points is low, the slope of the regression line should be referred to.

Time scale is important. If high impact occurs after a short amount of time, grazing may lead to damage or degradation. If high impact is reached after a long time period, damage is less likely as the vegetation may be more tolerant. Other checks must also be undertaken to prevent damage occurring.

When applied to the data collected in this investigation; (figures N, O, P), the impact of grazing on all woody species is -moderate. For trees, grazing impact is +moderate. This is because the data for thorny species on its own was found to be insignificant, and also because taller individuals cause the regression line to tilt to -moderate. This highlights how easily the slope is changed and indicates that this index is more appropriate when looking at species or families individually. The frequency distribution of individuals in each height class and number of grazing points should be taken into account as a large proportion of taller individuals or a minority of individuals taller than the browse line could affect the data.

The moderate classification given by this index is supported by other work such as that done by Mitchell & Kirby (1990), given in table 6. According to Mitchell and Kirby (1990) the moderate grazing level is likely to be of the highest conservation value, therefore the grazing at Knepp could be successful.

Table 6: Grazing level indicators (Mitchell & Kirby, 1990)

Excessive grazing — No shrub layer; barking of mature trees; stripping of bark from branches on the ground; extensive bare patches and soil disturbance; invasion of weed species such as *Rumex* spp., *Poa annua*.

High grazing — Shrub layer normally lacking; predominantly grass, bryophyte or bracken dominated vegetation; ground vegetation low in stature (20 cm); no tree regeneration greater than 20 cm even under canopy gaps; some bare patches; the more palatable, grazing-sensitive shrubs and herbs (e.g. *Lonicera periclymenum*, *Rubus fruticosus*, *Luzula sylvatica*, *Vaccinium myrtillus*) confined to inaccessible areas or at least noticeably more abundant there; pronounced browse line on shrubs and trees.

Moderate grazing — Mixture of grass/herbaceous/dwarf heath vegetation but signs of grazing or browsing on plants; few bare soil patches; saplings present although sometimes localized; ground vegetation greater than 30 cm high; shrub layer developed in parts.

Low grazing — Saplings generally frequent wherever there are canopy gaps; shrub layer well-developed with no obvious browse line; *Hedera helix* present; ground vegetation may be dominated by grazing-sensitive species (*Rubus fruticosus*, *Luzula periclymenum* or limited by the density of the shrub layer; extensive monospecific mats of *Deschampsia flexuosa* may also occur in base-poor sites.

Critique of the Grazing Points Index

It was difficult to devise an index which combined all impacts of grazing; however this system allows the majority to be included. Impact upon the soil and roots, as well as uprooting and trampling had to be excluded. A method of assessment of this damage needs to be found. Identifying grazing points on tree species is a simple and effective way of assessing the impact of grazing, however it is less appropriate for species where past browsing is not clear. This index is specific to the tree species recorded and future research is needed as to improve its generality. When tree species were multi-stemmed this counted as one grazing point, however species such as willow can be multi-stemmed due to suckering. These problems indicate individual species may need unique indexes. A disadvantage of this system is that "points" could occur due wind, frost or other damage; however regression analysis and ANOVA give some indication of error which may take this into account. The index site specific and should be tested over multiple areas and grazing regimes to improve its validity. It should be tested under different grazing densities to assess its effect and further improve the index.

The index is based on the majority of individuals being below the browse line in height. Above the browse line impacts such as bark rubbing or stripping can still occur. A method which assesses this impact could be devised. The method is simple to carry out in the field as it requires little equipment. Points can easily be identified which is an advantage when volunteers survey. The data is easy to analyse and interpret and clearly indicates whether the impact of grazing is low or high.

Vegetation Succession

The vegetation survey revealed a range of vegetation compositions and an uneven distribution of trees and scrub. A mosaic could be developing, as some areas largely consist of grass, some of a large amount of woody species regeneration and some mixed. Patches of thorn nursing establishing trees were observed, shown by figures 28 and 29.

Figure 28: Oak thriving under the protection of thorny scrub.

Figure 29: Oak thriving under the protection of thorny scrub.

Vera's cyclic vegetation may be beginning to take place; however, as shown by figure 25, the tallest trees (200cm+) are found in plots which have a low percentage of thorny scrub (11, 13 and 14). These were not mature trees. This contradicts Vera's theories, which predict trees survive and become taller when surrounded by protective cover (Vera, 2000). I would have expected to find taller trees in plots with the highest percentage of scrub (3, 4, 5 and 10), yet the maximum height here is 200cm. When only roe deer and rabbits were present these trees may have been able to survive the grazing/browsing pressure and have continued to thrive since other animals have been introduced.

The distribution and composition observed may be caused by impacts being greater in some areas than others because of grazing preferences. Peterken (1996) discusses how the impacts of grazing are unevenly distributed; individual grazing animals have different impacts on different species and selective browsing enhances the representation of some species over others. Table 7 gives a classification of the potential impact of different herbivores (Mitchell & Kirby, 1990), and supports observations made in this study (table 1). Individual feeding methods, density, diet preference, selectivity, trampling, seasonal variation and habitat use also cause different effects. (Mountford & Peterken, 2003) Grazing/browsing influences species composition. Species present are usually those that are unpalatable, grazing intolerant species form small groves and palatable species are uncommon (Peterken, 1966). Preferences of animals change seasonally, for example rooting peaks in spring, whereas in winter the emphasis is on browsing. According to Peterken, herbivores have little effect structurally as gap phase regeneration is hindered rather than prevented (Peterken, 1996). When these effects are combined you would expect to see a mosaic of impacts on the vegetation, this is becoming evident at Knepp.

NB2 has only been fallow since 2005 therefore it is difficult to attribute the present vegetation composition and distribution to grazing or other processes. This study indicates the overall height of woody species and the number of trees in the lower height classes has reduced, suggesting that the amount of regeneration in NB2 has declined due to grazing. Other studies, particularly those on wood-pastures, have found that grazing and browsing makes the regeneration difficult, hence in wood pastures pollarding and periods of low-intensity grazing were used to allow regeneration to occur (Peterken, 1996).

Table 7: Classification of herbivores and their potential impact on vegetation (Mitchell & Kirby, 1990)

Herbivore	Type	Impact
Cattle	Grazer	Low selective herbaceous bulk feeder, trampling damage may be considerable in regenerating woodland, will browse unselectively.
Horse	Grazer	Low selective herbaceous bulk feeder, creates large mosaics in grassland, tendency to strip bark, will browse unselectively.
Sheep	Grazer	Highly selective herbaceous feeder, inclined to browse especially when the quantity and quality of available herbage is low.
Red deer	Grazer/Browser	Highly selective grazer, more inclined to browse especially when the quantity and quality of available herbage is low; bark stripper.
Goat	Browser/Grazer	Highly selective browser, will graze herbage when quality is high, bark stripper, destructive to saplings.

There was a substantial amount of Bramble (*Rubus fructicosus)* in NB2. Bramble is known to be abundant when grazing is absent as it is quite sensitive to grazing (Kirby, 2001). Deer browse on Bramble and other thorny species are commonly reported in their diet. Favourable conditions for Bramble growth occur in clearings. (Harmer *et al,* 2010). Before 2009, the grazing level may have been low enough for

Bramble to thrive and regenerate in the open conditions. This may indicate grazing has not driven succession, but in fact the conditions present and other factors such as competition for space, light and nutrients. Watkinson *et al* discuss the factors determining the structure and composition of woodlands. On a regional scale the influence of climate and geology overrides all factors however on smaller scales species interactions, topography, management, soil properties (in particular pH) and grazing are all involved (Watkinson *et al,* 2001). Other animals can affect the survival of tree seedlings. Squirrels, mice and voles can significantly impact woodland vegetation and regeneration. This may be related to grazing by large herbivores; a reduction in grazing by large herbivores can lead to greater vegetation cover which in turn leads to more small mammals which can have effects such as bark stripping, redistribution and consumption of seeds and through eating emerging seedlings (Mitchell & Kirby, 1990). Evidence of small herbivore impacts were observed in NB2. The increase in vegetation cover since 2005 may have increased small herbivore numbers. This could have contributed to the distribution of woody species. Past land use may have affected distribution, for example the use of pesticides or ploughing. Strips of land along the western and southern field boundaries had been set aside since 1999; establishment of vegetation may have begun in these areas then.

The level of their impact may define whether grazing animals drive succession. At low levels competition may drive succession, whereas at high levels grazing drives succession through preferences such as suggested by Vera (Vera, 2000). A number of studies suggest grazing is maintained at moderate or fluctuating levels as this allows regeneration to occur without preventing trees maturing. Grazed woodlands and wood-pastures often have age structures which suggest they survived by periodic flushes of regeneration when grazing pressures have been low (Rackham, 2001, McVean, 1964, Peterken &Tubbs, 1965, Peterken, 1986). At present it is not clear whether grazing is controlling succession at Knepp; however given that much succession had taken place before the introduction of grazing animals, other processes may have a large influence.

Suggestions for future research

It is difficult to decide what can be considered damage; however it is important that the point at which damage and/or degradation is defined so that it can be prevented. It is also difficult to define what impact individual animal species. Work needs to be undertaken to define these factors. Future research could investigate the effect of removing one species if grazing is high, for example if cattle are removed does the impact decrease? If pigs are removed does the amount of seedling establishment decrease? More research is needed on the effects of grazing on individual tree and thorn species and their tolerance. Research is needed to develop the grazing points index as discussed in the critique. This will increase its value for future conservation projects. Research in to how the main drivers of succession can be defined would be useful. In terms of the Knepp Wildland Project, it would be interesting to find out what the other influences are on succession, for example soil quality and whether this has been affected by past use of fertilisers; topography, geology; seed dispersal mechanisms and sources; proximity to the river and the effects of the floodplain etc. Effects of small herbivores such as squirrels, rodents and rabbits could be looked into in more detail.

Can the re-wilding of the Knepp Castle Estate realistically be achieved through the use of a naturalistic grazing regime?

This investigation shows that there is a moderate effect of grazing and that there is evidence that woody species are regenerating and forming a natural woodland/scrubland. According to Mitchell and Kirby (1990) a moderate level of grazing is thought to have the highest value for conservation, this is supported by studies such as that done by Mountford and Peterken (2003) which suggest that continuous grazing at low density is thought to be the most sustainable for maintaining high diversity of vegetation and habitats in wood pastures. A moderate level of grazing should be used in the conservation of semi natural woods as it minimises disadvantageous changes in the ground vegetation and creates regeneration niches. This creates a diverse stand structure and allows the succession of trees to take place (Mitchell & Kirby 1990). This suggests a wildland could be restored at Knepp. However, it is known that in wood-pastures grazing had to be controlled if damage was to be prevented. Grazing was seen as a threat to the under-wood (Peterken, 1993). A study of the long term changes caused by grazing in the New Forest found that high numbers of livestock prevented tree regeneration for decades, even where thorny scrub provided protection. This study suggests that herbivore numbers are maintained at moderate levels of 0.15 or 0.3 cattle per hectare and to fluctuate the levels of grazing (Mountford & Peterken, 2003). Wood pasture in Britain is thought to best represent Vera's model of original natural woodland and wood-pastures were often formed on areas of wasteland (Harding & Rose, 1986) so these studies are useful in assessing whether The Knepp Wildland Project will be successful and add validity to Vera's theories. The results of this study, when compared with past studies indicate that a wildland could be restored using the current semi-natural grazing regime. However, it has become clear that to be successful the grazing pressure will have to be carefully maintained. It is possible that Knepp could revert to wildland within a century, but if other factors, such as land use and topography have a significant effect on the ability of the land to regenerate re-wilding could be prevented. Evidence of past management will most likely remain after a century and can take up to two hundred years to fade (Peterken, 1996).

Implications of this study for future conservation management and re-wilding projects

The findings of this study could inform other conservation and semi-natural grazing regimes of appropriate stocking densities and herbivores used and to prevent damage and degradation of natural environments. Once improved the grazing index could be used to monitor grazing regimes and to test the impact of grazing on different habitats or environments. The results of this study suggest that natural grazing regimes can be used to re-wild areas and could be referred to in development of wildland areas in the future. There is evidence to suggest that Vera's cyclic vegetation theory may be correct given the similarity between wood-pastures and the Vera theory as well as field evidence at Knepp, therefore this work could be used to develop this further and act as a baseline for further conservation management and research. The findings of this investigation can be used in the development of the Knepp Wildland project and act as a baseline for monitoring the changes in vegetation cover and the impact of grazing over time.

6. Conclusions

The null hypothesis; grazing impact is too high to allow natural regeneration to occur and therefore re-wilding cannot be achieved, can be rejected. There are a range of effects of grazing on woody vegetation, some having positive impacts and some negative. Overall the impact of the semi-natural grazing regime at Knepp was found to be moderate, thus allowing sufficient regeneration to occur to re-wild the landscape.

The grazing index devised was successful. With further investigation to improve its validity and accuracy it could be of great use to inform regarding both re-wilding projects and conservation grazing regimes.

Evidence was found that both supported and contradicted Vera's theories. It is unclear whether grazing by large ungulates is the main driver of vegetation succession. Much research is needed on other factors which could affect succession, such as past land use, other animals and soil quality before the main drivers of succession can be determined.

This study has found evidence to suggest that re-wilding could be achieved through the use of a semi-natural grazing regime, although grazing pressure needs to be carefully monitored. The devised index should allow this monitoring to be easily undertaken.

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Appendix I

Figure 1: An example of bark stripping

Figure 2: An Ash sapling after having been stripped of all its bark and browsed at the tip

Figure 3: Bark has been stripped back on this Oak sapling

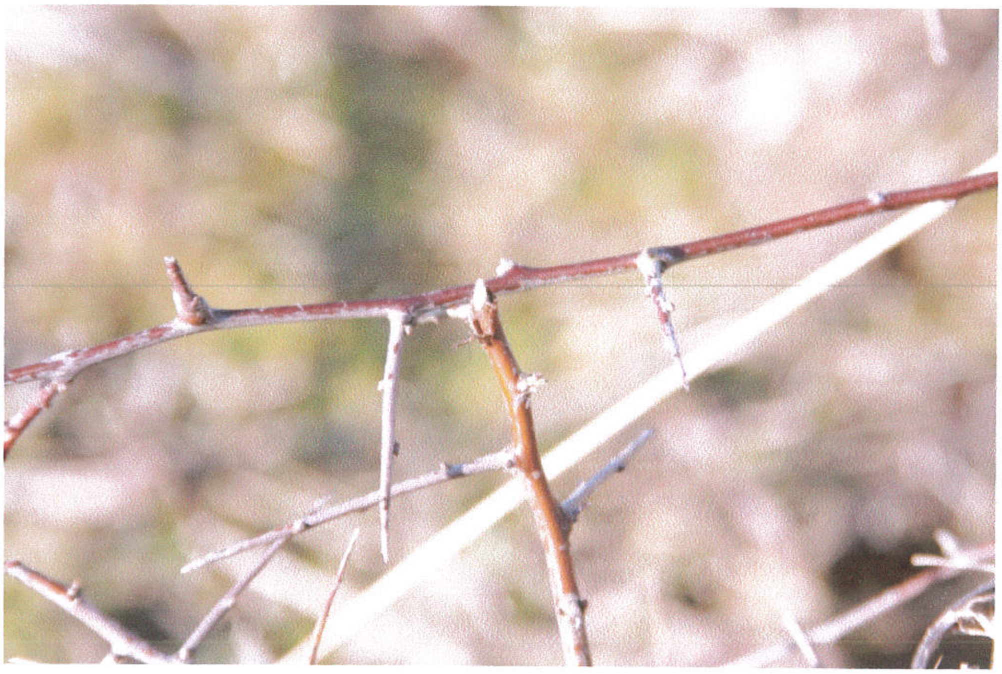


Figure 4: Blackthorn browsed at the tip by deer

Figure 5: Willow browsed at the tip by cattle or horses

Figure 6: Browsing of the tips of a Willow

Figure 7: Bark stripping and gnawing at the base of an Oak caused by rabbits and other small herbivores.

Figure 8: An example of scarring left by the removal of bark at the base of the tree.

Figure 9: Poaching and uprooting of the soil caused by pigs and trampling of other large herbivores

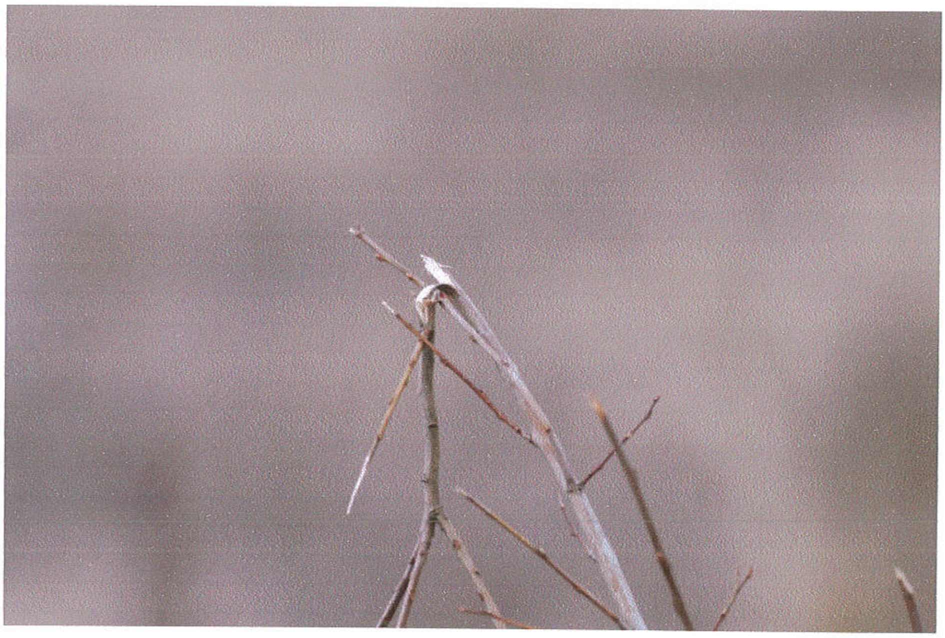


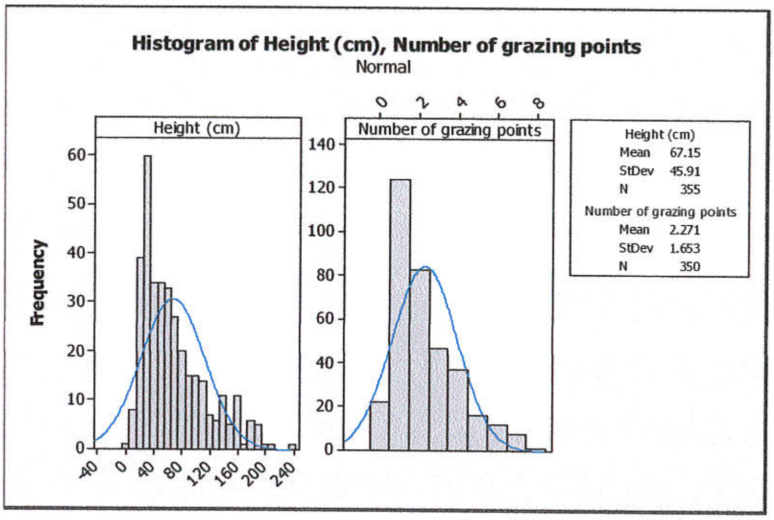
Figure 10: Example of breakage to the tips of branches caused by animals brushing against the trees.

Figure 11: Broken branch of an Oak, caused by trampling or rubbing against the tree.

Appendix II

Tests for normality:

a.)



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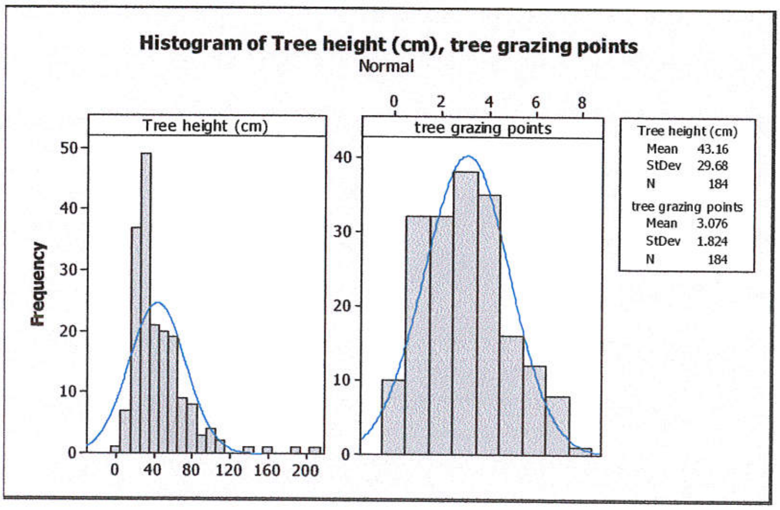


c.)

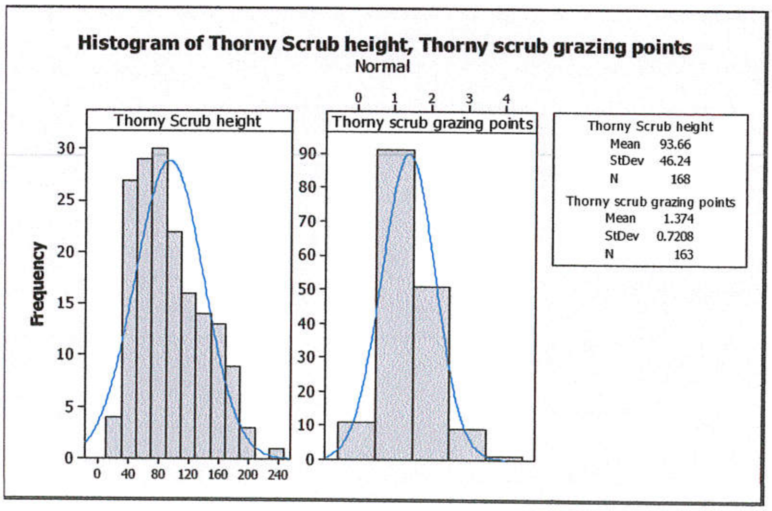
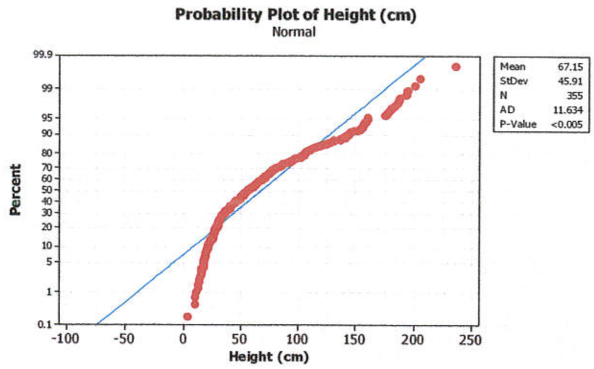


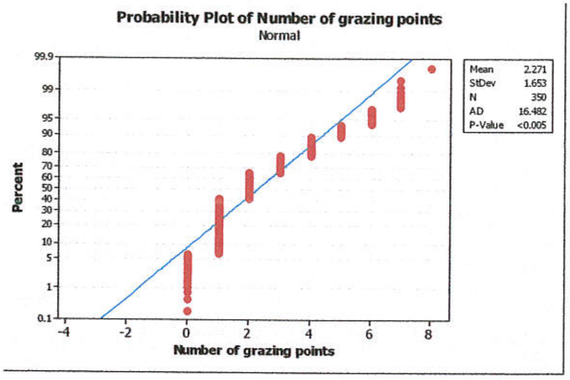
Figure 1a-c: Histograms with fit of height and number of grazing points for a.) all woody species, b.) tree species and c.) thorny scrub species.

Probability plots

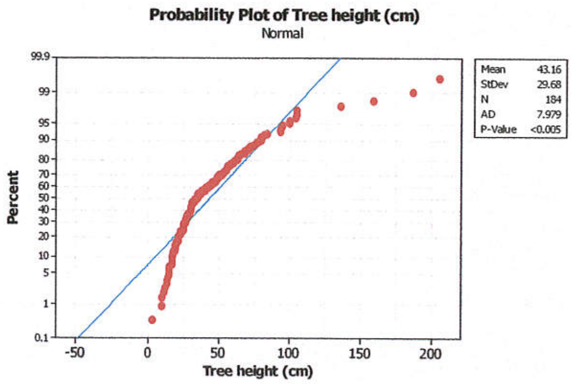
a.)i



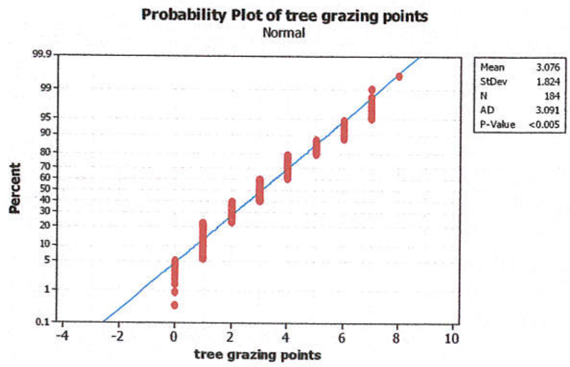
a.)ii



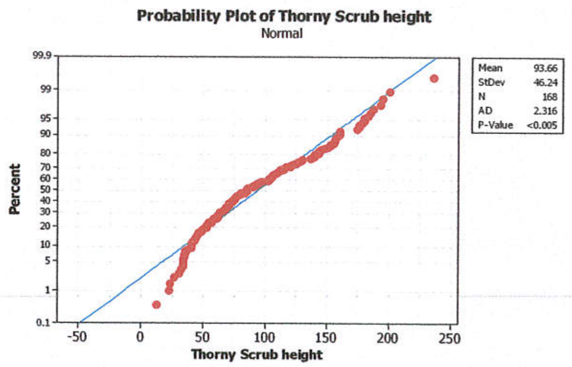
b.)i



b.)ii



c.)i



c.)ii

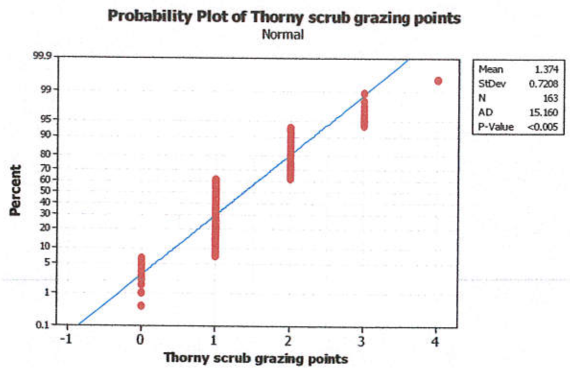


Figure 2 a-f: Probability plots for height (i) and number of grazing points (ii) for a.) all woody species, b.) tree species and c.) thorny scrub species.

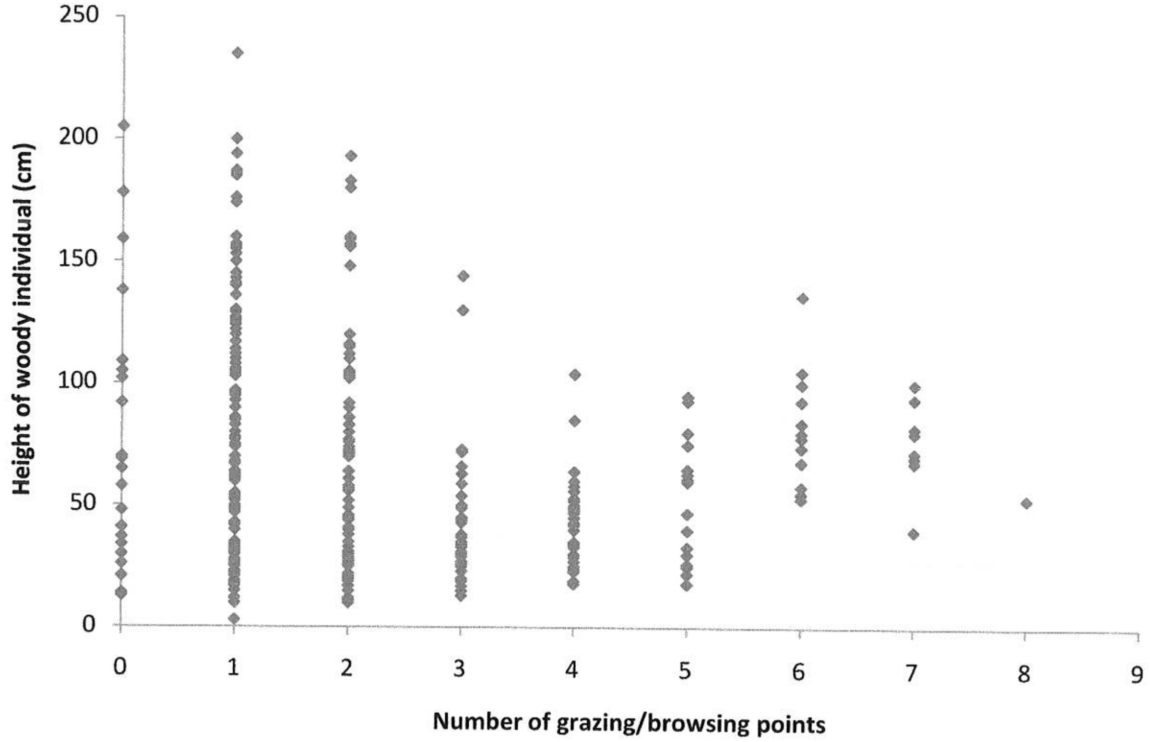


Figure 3: Scatter plot displaying the relationship between the number of grazing points and the height of all woody species surveyed (2010) N= 361.

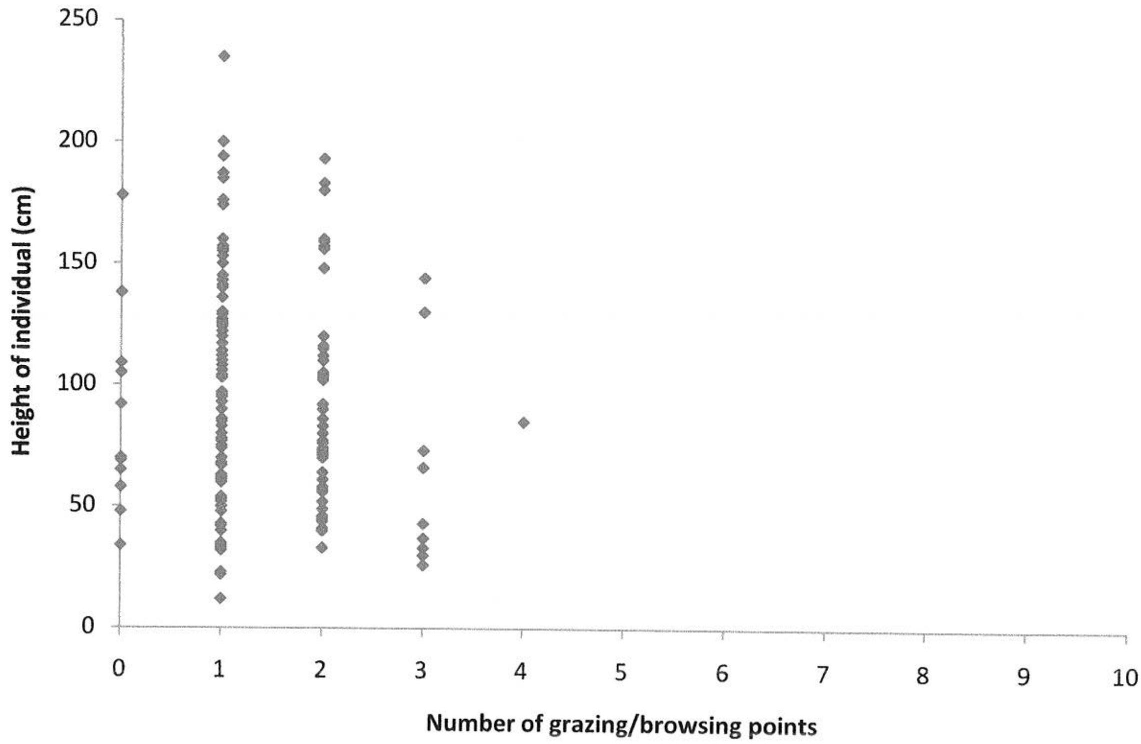


Figure 4: Scatter plot displaying the relationship between the number of grazing points and height of the Thorny species surveyed (2010). n= 169

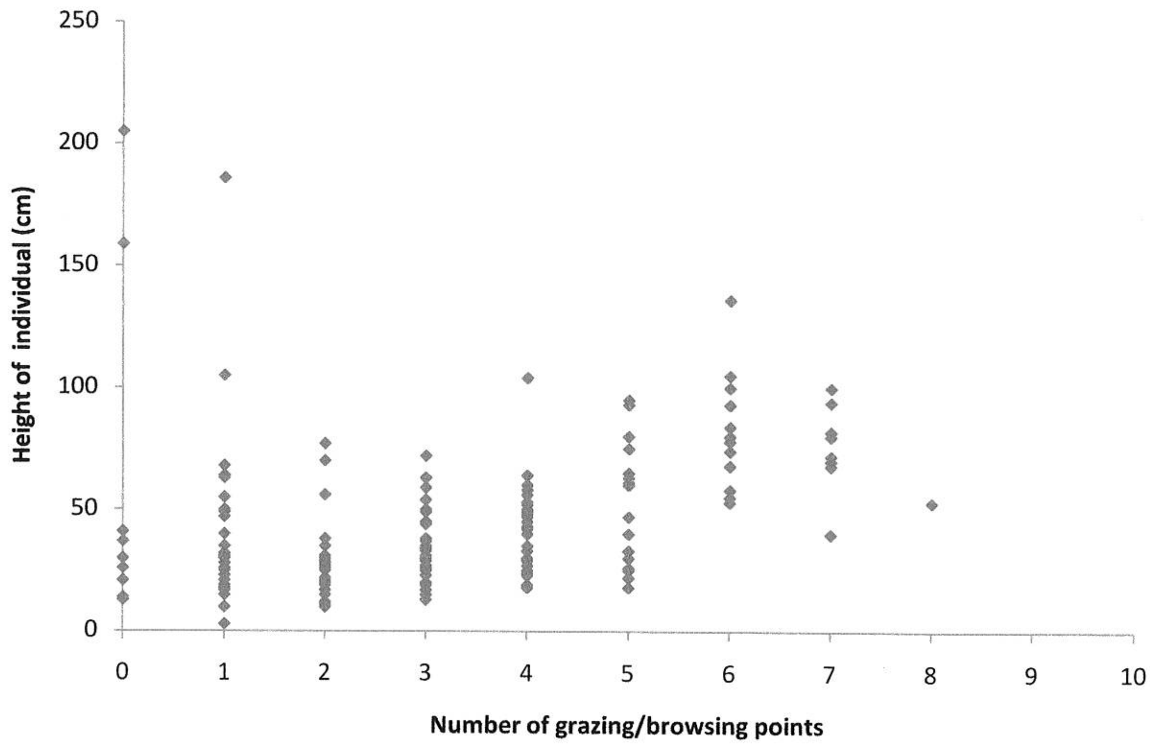


Figure 5: Scatter plot displaying the relationship between the number of grazing points and the height of all Tree species surveyed (2010). N=185