Lessons learnt – Wood pasture and parkland in the UK

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1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to Objective 2 and Deliverable 2.5 which describes the lessons learnt from innovations within agroforestry systems of high natural and cultural value. Within the project, there were ten stakeholder groups focused on such systems (e.g. grazed forests, semi-open pastures, wood pastures, and bocage). This report focuses on a stakeholder group which focussed on wood pasture and parklands in the UK.

2 Background

An initial stakeholder meeting focused on wood pasture and parklands in the UK was held at Epping Forest on the outskirts of London in September 2014 (Upson and Burgess 2014). The UK Biodiversity Steering Group reports that there are 10,000 to 20,000 ha of wood pasture and parklands in "working condition" the UK (Maddock 2008). By contrast Plieninger et al. (2015) using the LUCAS dataset estimated a total wood pasture area in the UK of 799,800 ha, equivalent to 3.3% of the area. From the perspective of the stakeholders present the most important attributes of wood pastures in the UK was their value for biodiversity and as a wildlife habitat (Upson and Burgess 2014). They are particularly valued for the ancient trees and the fauna, flora and fungi that they support (Woodland Trust 2012; Maddock 2011).

The meeting also included a visit to the wood pasture system at Epping Forest where Jeremy Dagley explained the use of the a new barrier-less fencing system termed "invisible fencing" (Dagley et al. 2014). The group also visit an area of wood pasture where the pollarding cycle had been restored to minimise the number of structurally unstable and potentially unsafe trees. Hence another area of interest was research on the reintroduction of the pollarding cycle particularly for the hornbeam trees which tend to respond well to pollarding.

Following the initial meeting, a research and development protocol was developed (Upson and Burgess 2015). Based on the initial discussion, three areas of research were identified. There were:

1) To develop and apply a management tool for assessing the impact of grazing.
2) To develop a web-based platform to allow farmers to interrogate GPS data from cattle collars.
3) To perform a cost benefit analysis of the invisible fencing system

In addition to these, an additional area of research, supported by the AGFORWARD project, focused on the soil carbon content of a wood pasture system is included in Section 6.

3 Management tool

In response to the first objective, a management tool was applied for the wood pasture at Epping Forest. Because the grazing pressure at Epping Forest is low and because of the impact of cattle grazing would be difficult to establish in terms of vegetation, the research focussed on the effects of the wood pasture restoration policy of pollarding. During 2015 Alicia Bernal Lopez completed an MSc thesis with the aim of determining the effects of restoration on the wood pasture and the stability of the tree population. The research is described by Lopez Bernal et al. (2016) but for synthesis purposes the main points are summarised below. The research focused on three main forms of wood pasture (Table 1).

Table 1. Three main types of wood pasture were compared

Wood pasture type	Explanation
Ancient restored wood pasture	Areas with veteran trees where the woodland had been opened up and the trees had been repollarded
Ancient unrestored wood pasture	Areas which used to be pollarded but where there had been no recent management
Secondary wood pasture	Areas with no record of pollarding and where there was no current management. Prior to the study it was assumed that veteran trees were absent

A tree count demonstrated that for each hectare, on average there were 44 oak (*Quercus* spp) trees, 87 beech (*Fagus sylvatica*) trees, 140 hornbeams (*Carpinus betulus*), and 380 holly (*Ilex aquifolium*) trees. However there were large differences in the distribution of tree sizes. In each of the three wood pasture types, the oak trees showed a normal distribution with a mean tree diameter at breast height of 26 cm to 72 cm. By contrast the distribution of beech, hornbeam and holly trees was highly skewed with large numbers of small trees and very few large trees (Figure 1). The beech and holly trees had largely been removed from the restored wood pasture. Hence the tree count in the restored wood pasture was substantially lower than in the unrestored and secondary wood pastures.

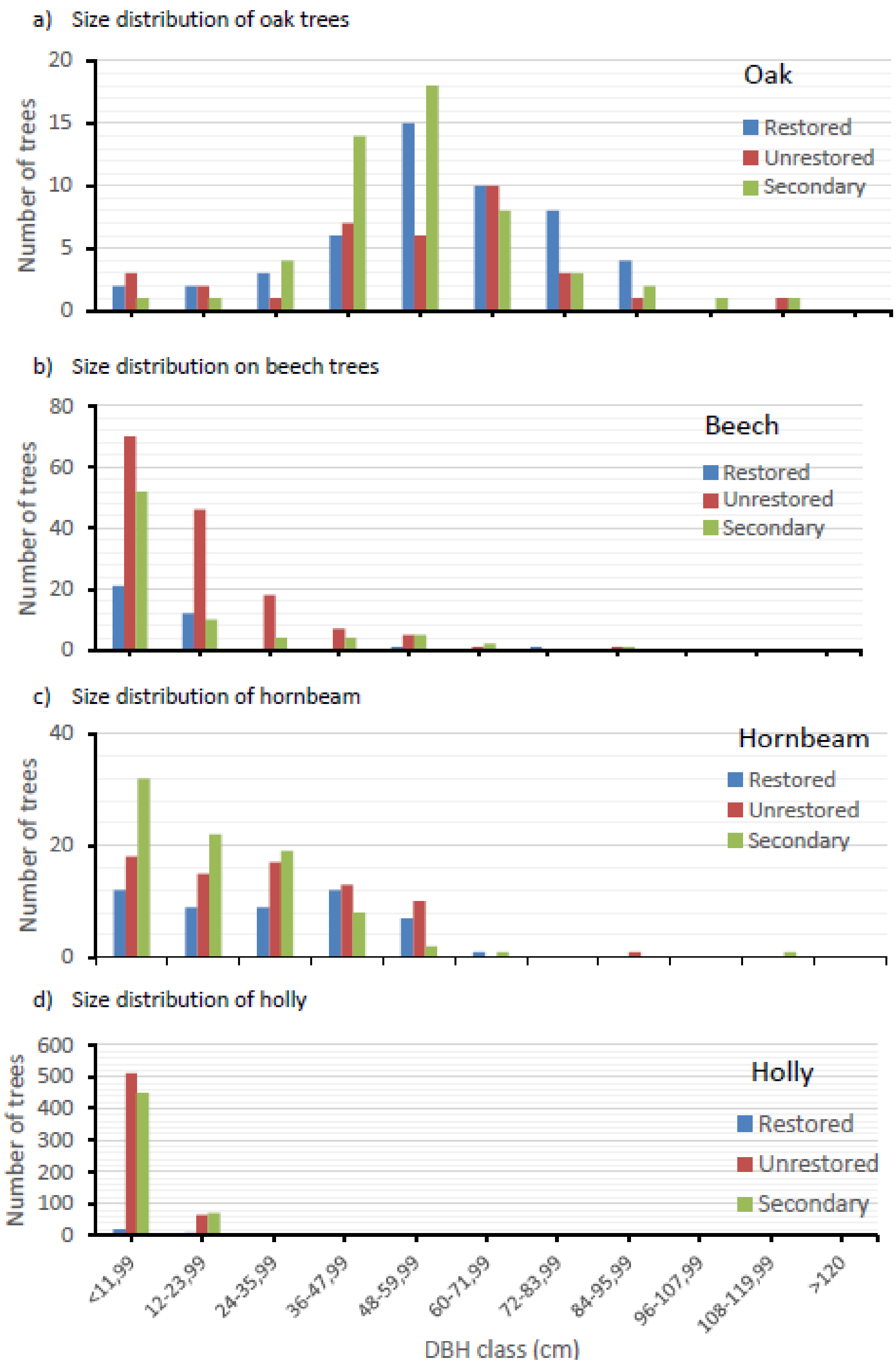

Figure 1. Distributions for each wood pasture type for a) oak, b) beech, c) hornbeam, and d) holly. Note that the vertical scales differ (Bernal Lopez et al. 2016)

An analysis was also completed of the understory. This showed that the number and diversity of understorey species was greater in the restored wood pasture areas than the unrestored and secondary plots (Table 2), but that bracken was becoming dominant. Whilst increasing light levels can benefit oak seedlings (relative to beech and holly seedlings which are more competitive under shade conditions) (Petritan et al. 2014), bracken dominance can be a problem (Table 2) (Mountford et al. 2006).

Table 2. Effect of wood pasture management on the diversity of the understorey layer (modified from Lopez Bernal et al. 2016)

Treatment	Proportion of bareground (%)	Median species richness per plot	Species richness across all plots	Most abundant understorey species
Restored	73	5	22	Bracken (*Pteridium aquilinum*), bramble (*Rubus fruticosus*)
Unrestored	90	2	6	Holly, nettle (*Urtica dioica*)
Secondary	93	2	5	Holly, hornbeam

The last part of the research focused on parameterising and using Kirby's "sustainable" population tree model (Kirby 2014) to estimate the likely evolution of the oaks, beech, hornbeam and holly trees over the next 300 years (Table 3). Although the model has limitations, it was relatively easy to use requiring only three parameters including mortality rate and cohort length. The population of mature beech trees was predicted to increase and the population of mature oak trees appeared to be stable. By contrast the number of mature hornbeams is predicted to increase in the next 70 years and then decline. For further details see Lopez Bernal et al. (2016).

Table 3. Current number of mature oak, beech, and hornbeam trees (of selected age bands) and the predicted future population the Kirby model (modified from Lopez Bernal et al. 2016)

Species	Age of trees (years)	Number of trees in age band in a particular year			
		Present (2015)	2115	2215	2315
Oak	<100	93			
	100-200	52	46		
	200-300		26	23	
	300-400			13	12
	>400				9
		Present: (2015)	2085	2155	2225
Beech	<70	224			
	70-140	32	61		
	140-210	2	17	32	
	210-280		1	5	10
		Present: (2015)	2085	2155	2225
Hornbeam	<70	209			
	70-140	121	12		
	140-210	1	29	3	
	210-280	1	0	3	0

4 Web-based platform

In response to the second objective, during 2015 Matt Upson developed a web-based platform which allowed the investigation of GPS data from the cattle collars and it was possible to map the changing distribution of the cattle over time. There is substantial potential to develop this tool further but following the departure of Matt Upson during the AGFORWARD project this avenue of research was not continued.

5 Financial and economic analysis of invisible fencing

5.1 Overview of the wood pasture system

The use of livestock to manage the understorey is a key feature of the wood pasture systems being managed for biodiversity in the UK. Following the foot and mouth crisis in the UK in 2001, the City of London Corporation reintroduced livestock grazing to Epping Forest in 2002 by contracting a grazier who manages a suckler beef system (Upson and Burgess 2014). The beef cattle are grazed in the wood pasture during the summer; the cattle are typically calved in the autumn and housed indoors during the winter. The cattle are reintroduced to the wood pasture in the spring, although calves normally have to be at least three months old to minimise problems with dogs.

Many wood pasture areas have high recreational value and this is particularly the case for Epping Forest which covers parts of Greater London and the county of Essex. In fact, rights to access common areas, such as Epping Forest, are enshrined in UK law (UK Government 2006). Hence one of the challenges for wood pasture managers is how to constrain the movement of cattle whilst encouraging visitors to enjoy the site.

5.2 Description of wooden and invisible system

A traditional way of restricting cattle to specific areas of the wood pasture is to install wooden fences with stiles or narrow gaps that allow the continued movement of visitors (Figure 2).

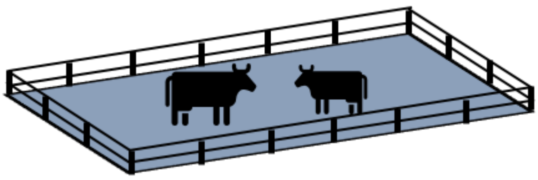

Figure 2. A traditional system to constrain livestock movement in wood-pasture is wooden fencing

In recent years, Epping Forest has also used an ‘invisible’ or ’virtual’ fencing system which does not rely on physical barriers (Anderson 2007; Dagley et al. 2014) (Figure 3). They use the Boviguard® system (Umstatter et al. 2015) which is sold in the UK by Henderson Products. At the time of writing this is the only commercially available invisible fencing system for cattle in the UK. A boundary for the cattle is established by a cable antenna wire-loop which is buried 75-100 mm below the soil surface. The wire loop is connected to a power source which also generates a very shortwave radio signal. This signal is then sensed by transponders worn by the cattle on collars around their necks. The cattle are notified of the presence of the boundary initially through an audible cue, and if the cattle ignores this they then receive a small electric shock (approximately 60 milliJoules) which is set at a lower current that used in a traditional electric fence (Dagley et al. 2014). This is usually sufficient for the cattle to change direction.

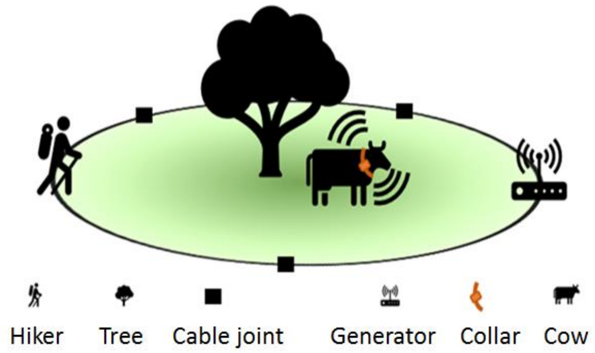

Figure 3. An alternative method to constrain cattle movement is ”invisible” or ”virtual” fencing where the cattle wear a collar which senses the output from a buried wire

In some situations, it is possible to dispense with the wire as the location of the boundary can be programmed into a Global Positioning System (GPS) unit located on the collar. These systems, which are being used in rangelands in the United States, can allow the grazing zone to be shifted day by day (Umstatter 2011; Anderson et al. 2014; Anderson 2007; Umstatter et al. 2015). This can allow flexible and fast responses to spatial differences in grass growth, changing needs to protect certain areas. However in this case of a wood pasture system, where cattle are often under trees, the satellite signal can be lost and the system is therefore impractical.

In the system at Epping Forest, although the boundary is not established using GPS, the cattle do wear GPS sensors on the collar. This can be useful for identifying their location within a large wood pasture and the data can provide useful insights for wood pasture management.

An example of the system used in Epping Forest is shown in Figure 4. An area of 140 ha is enclosed by a combination of wooden and invisible fencing. Assuming a simple case of 140 ha as a square, the perimeter is about 4700 m. Because the maximum length of an individual buried cable is 2000 m, for perimeters greater than 2000 m it is necessary to install the cables as ”double loops”. In the example in Figure 4, the perimeter is demarcated by six double loops of invisible fencing (700-1300 m) providing a length of 3000 m, and two lengths of wooden fence with a length of about 2000 m.

The area that can be encompassed by an invisible fence depends on whether a single loop or a double loop is used (Figure 5). Because the maximum length of a loop is 2000 m, assuming a square field the maximum area that can be encompassed by a single loop is 25 ha. Whilst smaller units are often recommended to encourage more even grazing, the emphasis in Epping Forest in on biodiversity enhancement and conservation rather than maximising cattle or understorey productivity. Using adjoining double loops it is possible to possible to encompass larger areas. The area encompassed increases as a square function of the perimeter.

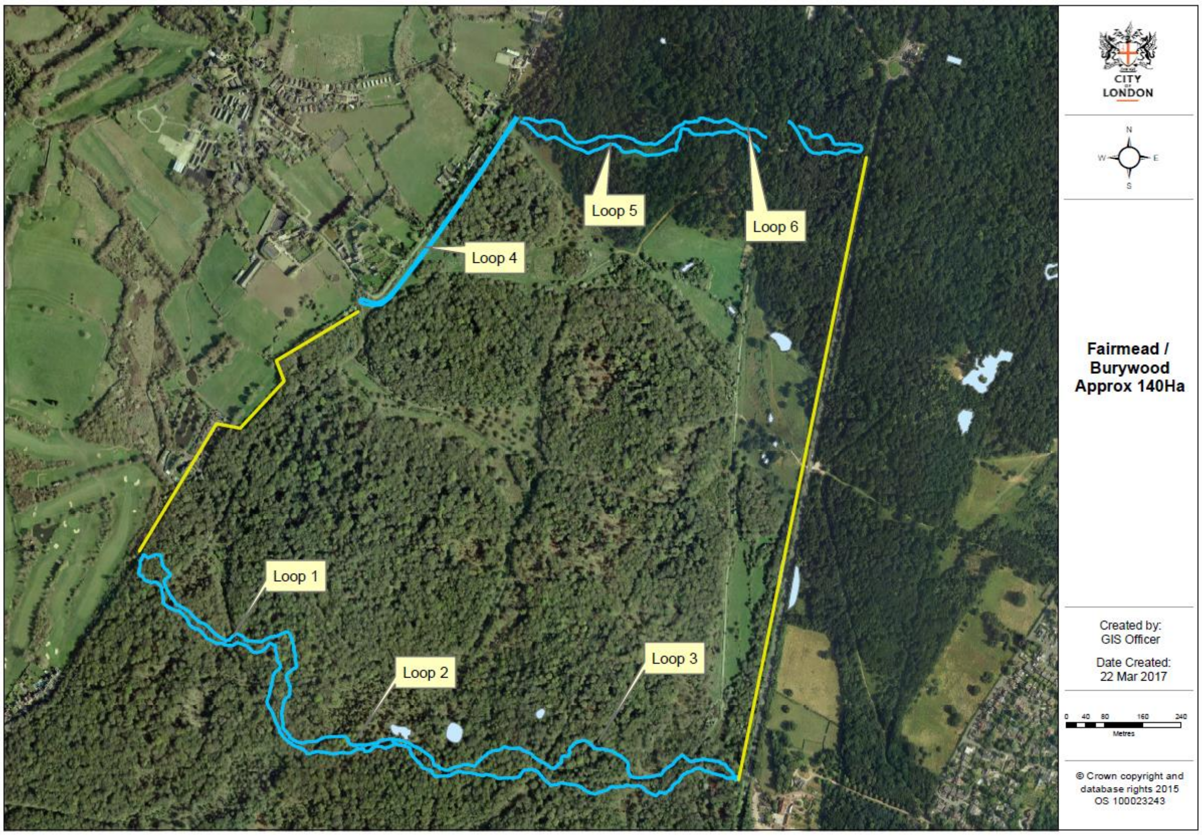

Figure 4. The actual fencing area includes a combination of invisible fencing (indicated in blue) and wooden fences (indicated in yellow). The lengths of the loops are: 1: 1300 m; 2: 1000 m; 3: 1000 m; 4: 1100 m; 5: 700 m, and 6: 800 m (Crown Copyright; produced by the City of London 2017)

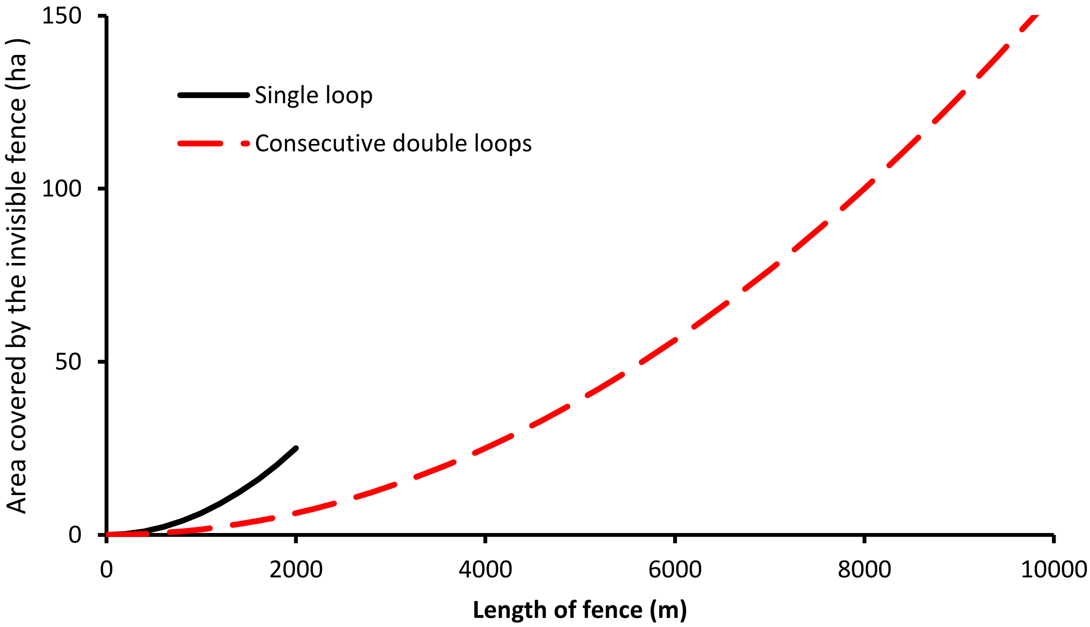

Figure 5. The area (assuming a square shape) that can be contained by fence increases as a square of the fence length. Because the maximum length of a single loop is 2000 m, the maximum area contained by a single loop fence is 25 ha. Consecutive double loops can encompass larger areas.

5.3 Methodology

A financial and economic comparison of invisible fencing, relative to wooden fencing, was undertaken during 2016 by Francesca Chinery, Georg Eriksson, Erica Pershagen, Cristina Pérez-Casenave, Paul Burgess and Silvestre Garcia de Jalon. Graves et al. (2005) provides a useful framework to describe the objectives and nature of financial modelling (Table 4).

Table 4. Criteria established for the economic model categorised using the framework based on Graves et al. (2005)

Characteristic		Criteria for the economic model. The model should be able:
1. Background	1.1	To operate as a “open” format model
2. Systems modelled	2.1	To model an ’invisible’ fencing and a ”wooden” fence system
3. Objectives of economic analysis	3.1	To under a financial marginal cost benefit analysis using discount rates
	3.2	To examine sensitivity to changes in input values
4. Viewpoint of analysis	4.1	To simulate a financial view-point from the perspective of a landowner
5. Spatial scale	5.1	To operate for a range of sizes (6.25-100 ha)
6. Temporal scale	6.1	To use a yearly time-step
	6.2	To use a maximum rotation of 30 years
7. Platform	7.1	To be a spreadsheet ‘workbook” model
8. Inputs and outputs	8.1	To enter inputs directly into the spreadsheet
	8.2.	To produce both tabular and graphical output

The team undertook a literature review and sites visits were made to see and discuss the system with Dr Jeremy Dagley (Head of Conservation at Epping Forest) and John Phillips (the Grazing and Landscape Project Manager). A financial model of the invisible fencing system, relative to a wooden system, was developed in Microsoft Excel.

5.3.1 Form of financial analysis

The financial analysis was based on a marginal cost benefit analysis of the invisible fencing relative to a ‘default’ wooden fence system with two horizontal wooden beams. Because the focus is on the marginal change in costs, the model did not address revenue streams such as beef production or costs such as feed, winter housing and veterinary medicines as these were assumed to be the same in both cases.

The financial analysis tool was developed in Microsoft Excel which means that it is easy to change the model to tailor different circumstances. Possible changes include technical assumptions such as stocking density and fence length, and financial assumptions such as changes in the discount rate and the presence or absence of grants.

5.3.2 Technical assumptions

The technical assumptions covered i) the type of terrain and the grazing period, ii) the type of wooden fence, iii) the nature of the invisible fence and the length, iv) the stocking rate, and v) the life of the fence.

Type of terrain and grazing period: it is assumed that the area is flat with no water features or structures. It is assumed that the cattle are grazed for seven months each year, between April and October, in both systems.

Type of wooden fence: the counterfactual system was assumed be wooden fencing comprising two horizontal beams held between upright posts and including wire mesh-netting (See Figure 2). The fence is 1.1 m high.

Type of invisible fence: to allow scaling to large areas, it was assumed that the fence could be a single-loop or a double-loop arrangement. The default analysis assumed 2000 m of fence, as 2000 m is maximum length that can be managed by one Boviguard generator. Hence assuming a square shape, 2000 m in a single would result in a square with 500 m sides and an area of 25 ha.

Stocking rate: in 2014, the suckler beef herd comprised 35 red poll cattle (Upson and Burgess 2014). If there were 35 cattle in the system in Figure 4, then the cattle population density would only be 0.25 cows per hectare. If the number of cattle, as planned, was increased to 150, then the density would be 1.07 cows per hectare. The default stocking rate assumed in the model was **0.4 cows ha^{-1};** this is substantially lower than an intensive stocking rate of about 2 cows ha^{-1} on a lowland dairy farm (Natural England 2009). Hence assuming a fence length of 2000 m and a square field would cover **25 ha**, and a density of 0.4 cows ha^{-1} would correspond to 10 cows per 2000 m of fence.

Fence lifetime: based on the discussions with staff at Epping Forest, it was anticipated that the collars for the Boviguard system will last 15 years and the underground cable will need to be replaced every 10 years. Staff at Epping Forest indicated that wooden fences would last 5-20 years depending on the type of wood. For the financial analysis, it was assumed that a new fence was needed every 15 years with an allowance for annual maintenance.

5.3.3 Cost assumptions for the wooden fence

The cost assumptions for the wooden fence are provided in Table 5.

Table 5. Assumed costs for the wooden fencing

Costs	Value	Unit
Fence construction[1]	6.11	£ m^{-1}
Age of fence at replacement	15	years
Maintenance input required[2]	0.1	hours animal^{-1} month^{-1}
Period when cow is in the field	7	months
Maintenance labour cost[3]	10.35	£ h^{-1}
Annual increase in labour cost[3]	2	%

1. Fence erection includes labour and material costs (posts, two horizontal wooden beams and mesh netting) derived from Redman (2016).
2. It is assumed that fence maintenance required 0.1 hrs month cow^{-1} during the period that the cow was in the field (i.e. 7 months).
3. Labour costs derived from Redman (2016) are adapted from average values for farm labour in 2016 and includes 10 hours overtime each week, a 2% annual wage increase and insurance obligations.

5.3.4 Cost assumptions for invisible fencing

The costs in Table 6 were largely derived from staff at Epping Forest. Similar to wooden fencing, it was assumed that there were 0.4 cows ha^{-1}, and thus 10 cows per 2000 m of single loop fence.

Table 6. Assumed costs for the invisible fencing system at Epping Forest. Data derived from interviews

	Value	Unit
Invisible line/cable[1]	0.994	£ m^{-1}
Cable joints[2]	0.054	£ m^{-1}
Cable lifetime	10	years
Contractor labour[3]	10	hrs 2000 m^{-1}
Assumed increase in labour	2	%
Contractors[3]	25	£ hr^{-1}
Signal generator[4]	633	£ $unit^{-1}$
Lifetime for generator[4]	10	years
Generator batteries[5]	109.95	£ $battery^{-1}$
Batteries per generator[5]	3	
Lifetime for batteries[5]	5	years
Maintenance labour[6]	10.35	£ hr^{-1}
Default maintenance requirement[6]	10	hr $season^{-1}$
Length dependent maintenance[6]	0.0125	hr m^{-1}
Annual breakdown costs[7]	51-180	£ $(2000\ m)^{-1}$
Collars[8]	438	£ $unit^{-1}$
Collar lifetime[8]	15	years
Annual collar battery cost (4 x AA)[9]	5.18	£ $collar^{-1}$

1. The invisible fence line is available in sizes of 500 m at a cost of £497 i.e. £0.99 m^{-1} of line.
2. Three cable joints costing £36 each are required for every 2000 m loop i.e. £0.054 m^{-1}.
3. Installation of 2000 m of cable is assumed to take 10 hours, i.e. 0.005 hours m^{-1}. A 2% annual increase is assumed.
4. One signal generator (£633) is required for every 2000 m of fence, with a life of 10 years.
5. The generator is powered by a 12-volt rechargeable battery. It is assumed that three batteries (with a life time of 5 years) are rotated for every 2000 m of cable, so that the batteries can be changed on a rolling basis. Labour costs are included in maintenance.
6. Maintenance applies annually and includes battery changing and charging, and loop and cable checks. Annual increase in labour charge was assumed to be 2%. Based on data at Epping Forest the maintenance time comprises a fixed rate of 10 hours regardless of length plus 0.0125 hrs m^{-1}. It was assumed that the cost of labour increases at an annual rate of 2%, (Redman 2016).
7. Breakdowns refer to the mending, for example, of a single cable joint and/or a generator or transponder. Breakdowns are unpredictable. The lowest value (£51) was assumed to comprise a single cable joint fault costing of £31 $season^{-1}$, 2 hours labour and £10 for tools/materials). The worst-case was a cut/broken estimated to cost £180 $season^{-1}$ (9 hours labour and £90 for tools/materials). £110 is the mean value (for 2000 m) from the range of Monte Carlo results. The Monte Carlo analysis generated random variables.
8. The cattle wear special collars which consist of a transponder, batteries, and a neck strap. A collar, including the strap and transponder, is assumed to have a 15-year lifetime.
9. The collar transponders are powered by four AA-batteries. They last over the entire 7-month grazing season and must therefore be changed once per year. Labour costs for this activity are included in maintenance.

5.3.5 Grants

The default analysis assumed that no grants were available. Within the wooden fence, a grant equal to £4 m^{-1} is available but only for the first year. The grants for invisible fencing in the UK are currently on-hold as official invisible fencing guidelines are produced, but staff at Epping Forest assumed that a grant of £1.80 m^{-1} could be available in the future (Table 7). In the ”with grant” scenarios, it was assumed that this grant was only available in year 1.

Table 7. Assumed grants[1] for the invisible and wooden fencing systems

Costs	Value	Unit	Reference
Invisible fencing grants[1]	1.8	£ m^{-1}	Natural England 2017a
Wooden fence grants[2]	4.0	£ m^{-1}	Natural England 2017b

5.3.6 Discount rate

Annual total costs were discounted using a discount rate of 4%. The UK Government typically applies a 3.5% discount rate to all government projects (HM Treasury 2013). Given that this investment is likely to be riskier than a government project, as it is from the perspective of a landowner, a higher rate of 4% has been applied.

5.3.7 Sensitivity analysis

Sensitivity analysis was applied in the worksheet to determine how the net present value (NPV) of each system responds to changes to i) stocking density and ii) fence length.

5.4 Financial results

5.4.1 Effect of cattle density on the cost

The results from the cost-benefit analysis model at the reference point (10 cows in 25 ha, comprising either 2000 m of wooden or single loop invisible fence, or 4000 m of double loop fencing with 10 cows) are shown in Table 8. For the default system (0.4 cows per hectare), the undiscounted cost of the single-loop invisible fence system over 30 years (£39400) is 44% greater than the undiscounted cost of the wooden fencing system (£27380). The cost of the double loop system (£64140) is 134% greater than the wooden fence system (Figure 6).

Table 8. Effect of the livestock density on the 30 year cost in undiscounted and net present value (NPV) terms of a) wooden fencing, b) a single-loop and c) a double loop invisible fencing system covering 25 ha assuming no grants (assuming both a zero and a 4% discount rate)

	Assumed fence length (m)	Cow density (ha^{-1})				
		0	0.2	**0.4**	0.6	0.8
a) Wooden fence						
Undiscounted (£)	2000	24440	25910	**27380**	28850	30320
NPV (*i* = 0.04) (£)	2000	19000	19840	20670	21500	22330
b) Single-loop invisible fence						
Undiscounted (£)	2000	29070	34240	**39400**	44560	49720
NPV (*i* = 0.04) (£)	2000	18050	21920	25880	29680	33550
c) Double-loop invisible fence						
Undiscounted (£)	4000	53820	58980	**64140**	69300	74460
NPV (*i* = 0.04) (£)	4000	33660	37540	41410	45290	49160

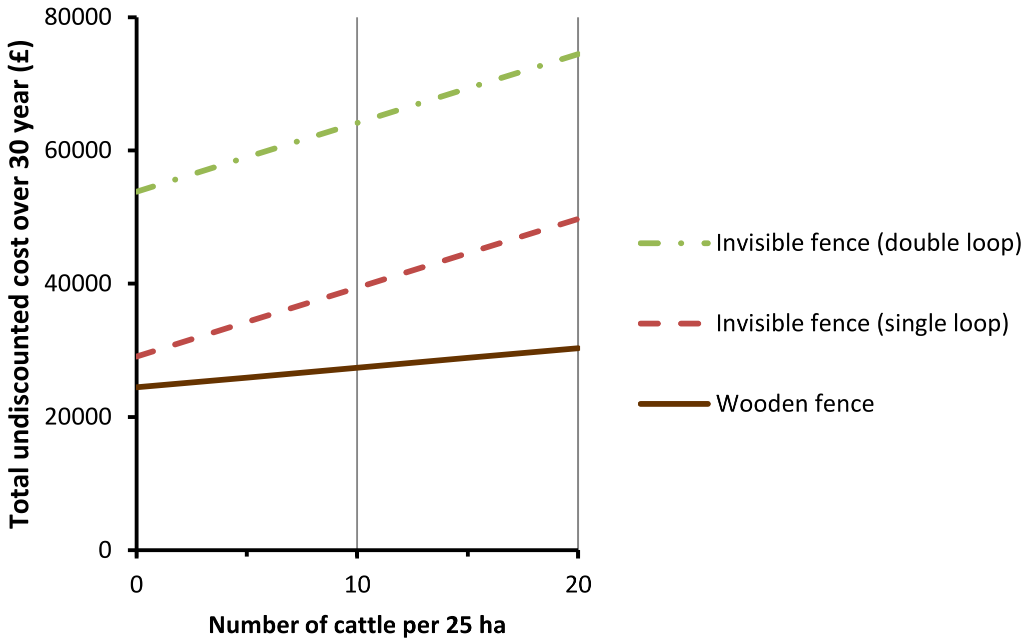

Figure 6. Effect of the number of cattle per 25 ha on the assumed 30 year cost of a wooden fence system (2000 m) or an invisible fence system with a single loop (2000 m) or double loop (2 x 2000 m)

The wooden fence costs increase slightly as cow density increases as it was assumed that the monthly maintenance requirement was equivalent to 0.1 hours per cow (Figure 6). By contrast the invisible fencing system cost increases more sharply as cow density increases as an increased number of cows increases the number of collars required. Hence at a density of 20 cows per 25 hectares (i.e. 0.8 cows ha^{-1}) the cost of the single-loop fencing system (£49720) was 64% higher than for the wooden fencing (£30315) compared to 44% higher at 10 cows per 25 hectares. Hence the invisible fencing system tends to be more advantageous when the stocking density is low.

5.4.2 Cash flow

The wooden fencing system is dominated by the construction of the wooden fence (£12200 for 2000 m) every 15 years and the annual maintenance cost (£145 to £257) is relatively low (Figure 7a). By contrast the assumed phasing of costs for the invisible fencing system is dominated by the replacement of the cable every ten years, the collars every 15 years, and an annual maintenance and breakdown repair cost (Figure 7b). The maintenance costs are assumed to increase over time because of an annual increase in labour costs relative to other costs.

5.4.3 Proportional costs

Over 30 years, the capital costs of the invisible (£21420) and the wooden fencing (£24440) are similar (Figure 8). However the invisible fencing system has substantially higher maintenance costs which was assumed to be 35 hours per year.

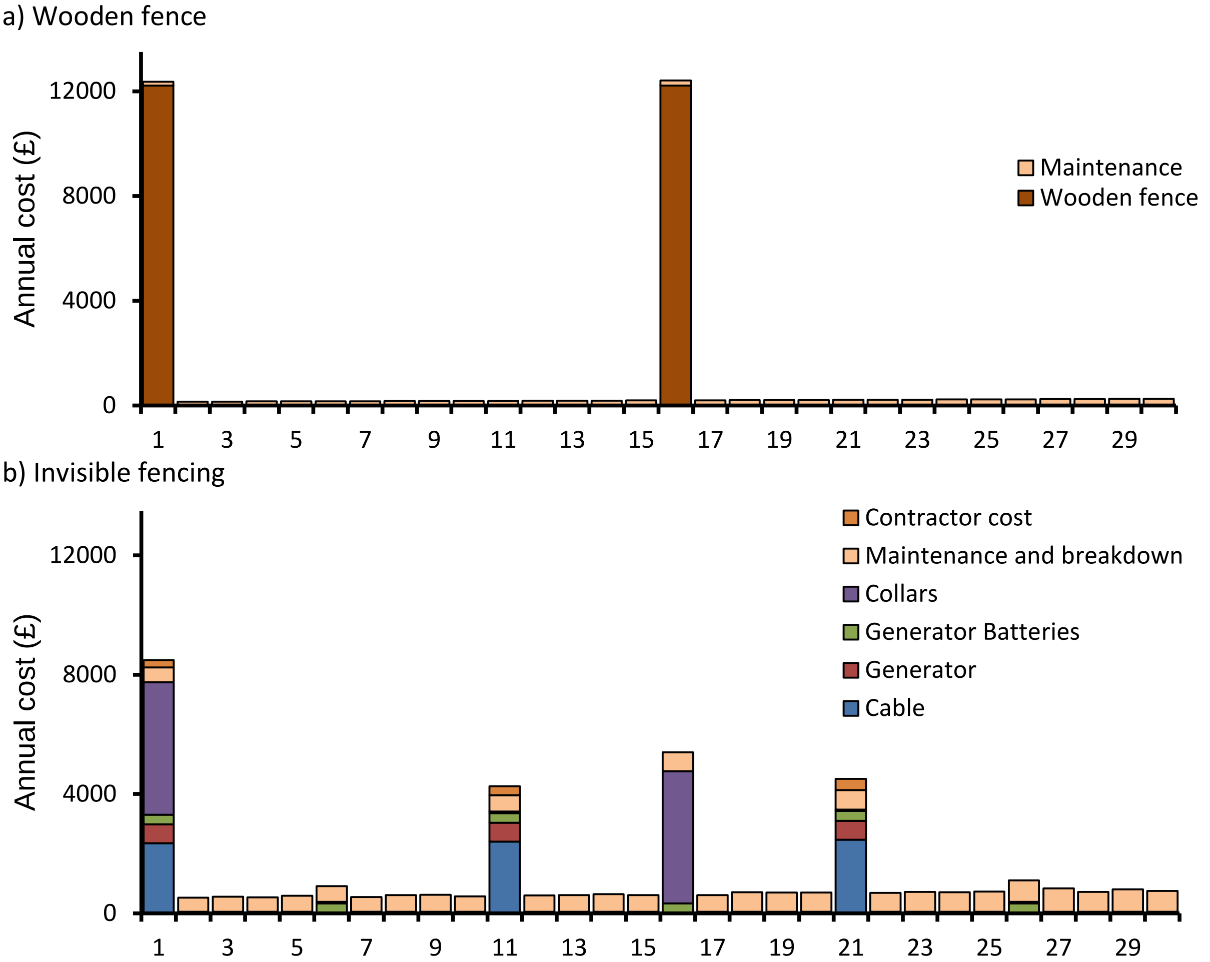

Figure 7. Annual undiscounted costs of a) the wooden fence (2000 m) and b) the invisible fence (2000 m in a single loop) over 30 years for the default system (25 ha and 10 cows)

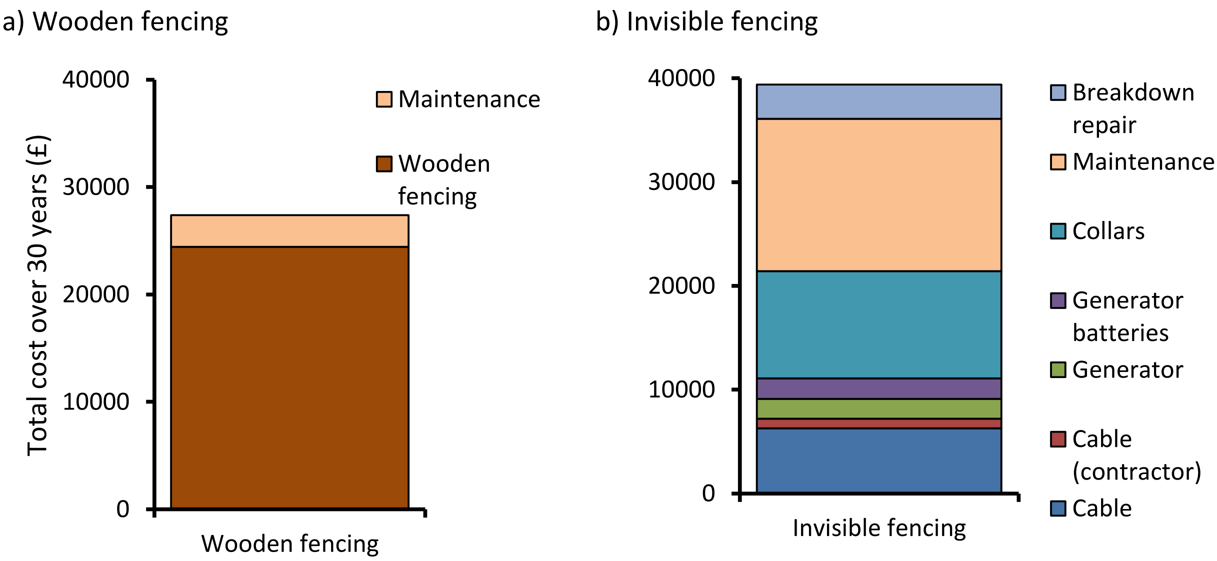

Figure 8. Breakdown of the costs (over 30 years) for a) wooden fencing system (2000 m) and b) the invisible fencing single loop (2000 m) for the default system of 25 ha and 10 cows

5.4.4 Effect of system size

The maximum size of a single loop invisible fencing system is currently 25 ha; above this size a double loop system is needed. The effect of the size of the system is shown in Table 9. For an area of 25 ha and assuming ten cows, the undiscounted cost of the invisible single loop system was 143% of that for the wooden fencing. However as the field size becomes smaller, the relative cost of the invisible fencing becomes greater; hence for a field of 6.25 ha and 2.5 cows, the invisible fencing cost is 169% of that for the wooden fencing. This is because, below a distance of 2000 m, the fixed costs of the generator and batteries are spread over a lower area. Because smaller grazing blocks than 25 ha are often recommended in commercial grazing management (to help managers maintain an even grass sward), invisible fencing is likely to more attractive where the focus of cattle management is to encourage a diverse habitat rather than high grass utilisation.

Table 9. Effect of the area of the system on the net cost of the wooden and invisible fencing systems (stocking density is maintained at 0.4 cows per hectare)

		Area (ha)				
		6.25	**12.5**	**25.0**	**50.0**	**100**
Number of cows		2.5	5	**10**	20	40
Wooden fencing	Assumed fence length (m)	1000	1414	2000	2828	4000
	Undiscounted (£)	12950	18750	**27380**	40440	60640
	Undiscounted (£ cow^{-1} a^{-1})	173	125	91	67	50
Invisible single loop fencing	Assumed fence length (m)	1000	1414	2000		
	Undiscounted (£)	21920	28350	**39400**		
	Undiscounted (£ cow^{-1} a^{-1})	292	189	131		
Invisible double loop Fencing	Assumed fence length (m)	2000	2828	4000	5656	8000
	Undiscounted (£)	31650	47220	**64140**	95510	144120
	Undiscounted (£ cow^{-1} a^{-1})	422	314	213	159	120

Above an area of 25 ha, it is necessary to start using the invisible fencing in a double loop arrangement (See Figure 4 and Figure 5). Because a double loop requires twice the length of cable and number of generators, and we assumed twice the maintenance, the relative costs of the invisible fencing are substantially greater (Figure 9). Hence for the default system of 25 ha and 10 cows, over a period of 30 years, the double loop system is estimated to be £24740 more expensive than the single loop system (Table 9). Because of the need to use a double loop system for areas greater than 25 ha, the relative cost of invisible fencing jumps once the area is above 25 ha (Figure 10). However for a particular type of invisible fencing system (i.e. single-loop or double-loop), the relative cost of invisible fencing relative to wooden fencing stays broadly consistent as most costs are directly related to the length of the fence.

Another way to express the cost of fencing is an amount per cow per year. The values of £50-£422 per cow per year are high, and are very much higher than the fencing costs that would be considered for a commercial beef suckler enterprise, where the cull value of a cow may only be £550-£600 (Redman 2016). Table 9 demonstrates that as the area increases, so the relative cost of fencing per unit area or per cow decreases, an observation that is, for example well-established in fencing calculations within forestry projects.

5.4.5 Effect of grants

The assumption regarding grants was that the wooden fence would receive a payment of £4 per metre of fence in year 1. Hence the addition of grants for 2000 m, reduced the net cost by £8000 (Figure 10). It was assumed that the invisible fencing could result in a payment of £1.80 per metre of cable in year 1 only. Hence for the 2000 m system, the net fencing cost was reduced by £3600. Because the invisible fencing is more expensive, and the cost per metre of fence or double cable is similar, the grants cause a greater relative reduction with the wooden fencing system (Figure 10).

a) Invisible fencing single loop

b) Invisible fencing double loop

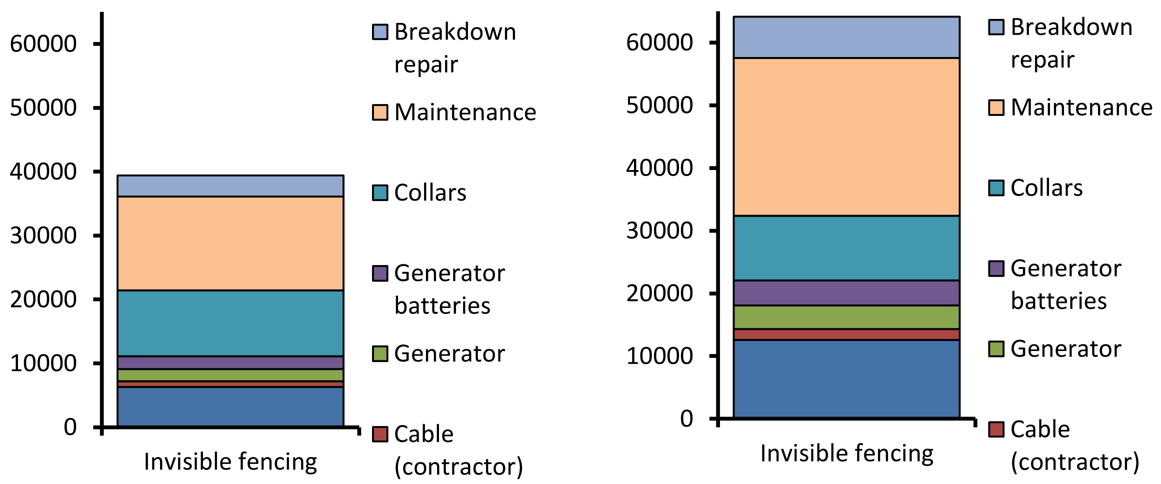

Figure 9. Proportional breakdown of the costs (over 30 years) for a) the invisible fencing single loop (2000 m) sufficient to encompass 25 ha, and b) a double loop system.

a) Wooden fencing

b) Invisible fencing

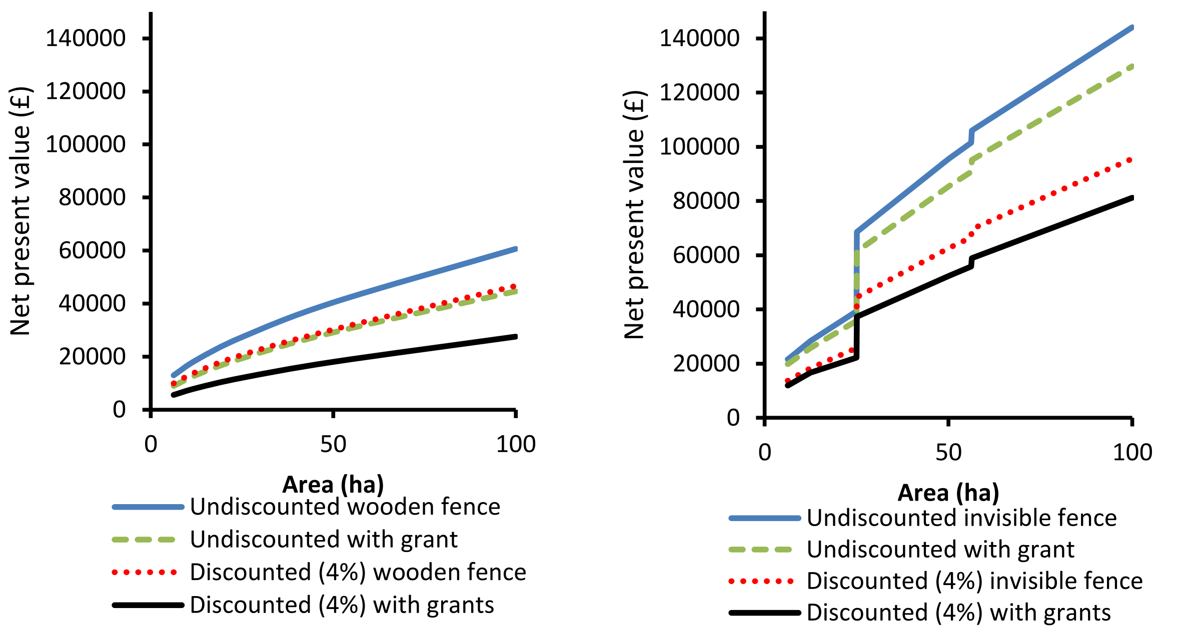

Figure 10. Effect of grants and discount rate on the net present value of the total costs over 30 years for different size areas for a) wooden fencing and b) single loop (< 25 ha) and double loop (> 25 ha) invisible fencing. The need to incorporate a double loop above 25 ha was assumed to result in a step change in costs.

5.5 Wider considerations

The preceding analysis focused solely on the financial analysis of "invisible" fencing relative to a default wood fencing system. The non-market qualitative benefits of each system can also be analysed using the ecosystem services framework (Defra 2007). The ecosystem service framework used by de Groot et al. (2002) categorises the wider societal benefits and costs of an ecological system in terms of production, regulation, information, and habitat services.

Grazing in woodland pastures provides a diverse range of ecosystem service benefits. The production benefits of grazed wood pasture include food from beef production, but the benefits are the same for both the wooden and the invisible fence systems (Table 10). The regulation services provided a grazed wood pasture include carbon sequestration (Sharrow and Ismail 2004; Kirby and Potvin 2007), reduced soil erosion (Smith et al. 2011; Forestry Commission 2011), regulation of surface water (Nisbet et al. 2011), improvement of air quality (Beckett et al. 1998; Jose, 2009; Tyndall and Colletti 2007), and improved nutrient cycling (Sharrow and Ismail 2004). However again, the levels of these services from the wooden and invisible fence systems are likely to be the same.

Table 10. Estimates of the impact on invisible fencing, relative to wooden fencing, in a wood pasture area on selected ecosystem services

Category	Wooden fencing system	Invisible fencing system	Change	Reference
Provisioning				
Food	+	+	0	Anderson (2007)
Regulating				
C sequestration	+	+	0	Sharrow & Ismail (2004); Kirby & Potvin (2007)
Flood control	+	+	0	Nisbet *et al.* (2011); Umstatter (2011)
Air quality	+	+	0	Beckett *et al.* (1998); Jose (2009); Tyndall & Colletti (2007)
Nutrient cycling	++	++	0	Sharrow & Ismail (2004)
Erosion control	+	+	0	Smith (2011); Quine (2011); Forestry Commission (2011)
Cultural				
Recreation/ Tourism	+	++	+	Forestry Commission (2004); Forestry Commission (2009); City of London (2014)
Landscape	+	++	+	Forestry Commission (1998)
Education	+	++	+	Forestry Commission Scotland (2009); Butler *et al.* (2006)
Heritage	+	+	0	Crow (2004); Forestry Commission (2011)
Carrier/habitat				
Biodiversity	++	++	0	Forestry Commission (1999)
Significant positive effect = ++, Positive effect = +, no effect = 0, negative effect = - and significant negative effect = --, -? unknown but probably negative effect				

By contrast, it can be argued that invisible fencing system improves the quality of recreational activities at Epping Forest. Epping Forest receives about 4.2 million visitors annually (City of London 2014) and people use the area for walking, exercise, socialising, and improving mental health (Forestry Commission 2009). People also benefit from the appreciation of the landscape in an area like Epping Forest (Forestry Commission 2002) and it could be argued that the lack of fencing provides a more natural and desirable landscape. It could also be argued that the invisible fencing system itself provides a useful opportunity to monitor livestock and learn about cattle behaviour (Butler et al. 2006). The effect of the fencing system type on heritage values (Crow 2004) is likely to be minimal. Well-managed grazing can improve the biodiversity value of woodlands (Forestry Commission 1999), but the differential impact of the wooden fence and the invisible fencing systems is considered to be minimal.

Although not included in the analysis of ecosystem services in Table 10, people do derive cultural value from the welfare implications of different systems. Lee et al. (2008) explored the impact of electrical stimuli on cattle and concluded that the stress responses to low energy shocks are minimal and close to those when animals are being restrained during, for example, weighing. One proposed solution to address this challenge is to have only one or two ‘leader’ animals within a herd wearing the collars (Anderson 2007). However assessing which animals within a herd are recognised leaders can be complex and involves a combination of nature and nurture factors (Anderson 2007).

5.6 Conclusions

The work by Epping Forest demonstrates that invisible fencing is technically feasible for controlling the movement of cattle in wood pastures. A major argument for installing invisible fencing, rather than wooden fencing, is to allow unhindered public access. Invisible fencing achieves this and the process of including GPS transponders on the same collars is very helpful in allowing the stockperson identify the location of the cattle in the wood pasture at any particular moment. The negative impact of the invisible fencing on cattle welfare is considered to be minimal, and the ability to locate the cattle with GPS sensors probably offers welfare advantages. A set of husbandry guidelines for the use of invisible fencing is currently being developed.

The analysis here suggests that the cost of single loop invisible fencing over a 30 year period is about 44% greater than with a wooden fence. This is primarily a result of the assumed high costs of maintenance as the assumed capital costs are similar. In our analysis, we assumed that the maintenance costs of a ”double-loop” was double that of a ”single-loop” system. This may not be the case in practice if it was possible to install the outward and return ”legs” of the loop in the same position. At present the maximum length of a loop is 2000 m and hence the need to install a double loop arrangement for areas greater than 25 ha leads to higher assumed costs. Epping Forest uses a mix of wooden fencing (next to roads) and invisible fencing which seems to offer the benefits of invisible fencing where they are required whilst minimising the cost where it is not needed.

6 Summary of "soil carbon changes after establishing woodland and agroforestry trees in a grazed pasture"

This section provides a summary of a peer-reviewed paper that investigates the impact on soil carbon storage of a new area of wood pasture on grassland. In citing this work, please refer to the full paper: Upson MA, Burgess PJ, Morison JIL (2016). Soil carbon changes after establishing woodland and agroforestry trees in a grazed pasture. Geoderma 283: 10-20.

6.1 Background

An additional area of work, that was written up as part of the AGFORWARD project, was a study of the effect of establishing parkland on a grazed field on soil organic carbon. The study focused on field measurements within a 14 ha wood pasture system established in 1999 that offers conservation and cultural benefits (Agbenyega et al. 2009). The full results are described by Upson et al. (2016) and a brief summary is presented here for information.

6.2 Objectives

The objectives of the study were threefold: to assess the change in soil organic carbon (SOC) following conversion of pasture to silvopasture and farm woodland; to determine the relationship between SOC, soil bulk density, fine root mass density and mean soil moisture content; and to estimate the number of SOC samples required to ensure sufficient experimental power.

6.3 Methodology

The measurements were made within a 14 ha site at Clapham Park (52°9'36''N, 02°8'27''W), near Bedford in England that includes separate areas of pasture, silvopastoral trees, and woodland. In 2012, fourteen years after tree planting in 1999, soil samples were taken from the woodland (20 locations), the silvopastoral trees (20 locations) and the pasture (40 locations) (Figure 11). Soil water contents (θv) were also taken from nine points.

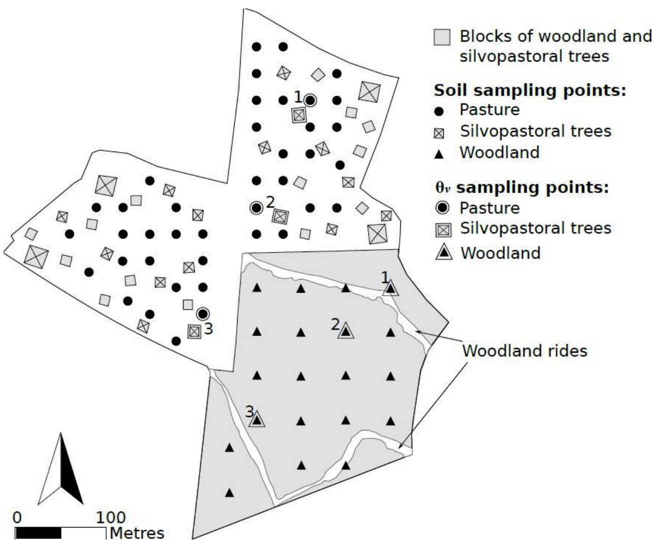

Figure 11. Schematic map of the Clapham Park field site. All hollow squares represent silvopasture tree blocks, and those sampled are denoted by cross. Soil sampling points in the pasture and woodland were arranged on 30 m × 30 m and 50 m × 50 m grids respectively (the former included a buffer to avoid taking a sample too closely to trees).

The soil organic carbon was measured of samples at depths of 5, 15, 30, 50, 83 and 120 cm, and associated soil bulk densities were taken at depths of 5, 15, 30, and 50 cm. It was assumed that the bulk density did not change below 50 cm. In addition, estimates were made of the above-ground carbon stock of the trees.

6.4 Results

Soil bulk density: overall the soil bulk density (ρ_b) below the pasture (1.19 ± 0.01 g cm^{-3}) was less ($p < 0.001$) than that below the woodland (1.23 ± 0.02 g cm^{-3}) and the silvopastoral trees (1.24 ± 0.02 g cm^{-3}) which were similar.

Water content: the volumetric water content (cm cm^{-3}) in the pasture (0.593 ± 0.003) was wetter ($p < 0.05$) than in the woodland (0.565 ± 0.003), and the driest soil was below the silvopastoral trees (0.540 ± 0.003).

Organic carbon content: fourteen years after planting, there were significant ($p < 0.001$) depth and treatment interactions on soil organic carbon contents. At a depth of 0-10 cm, the organic carbon content of the pasture (6.0 ± 0.2 g 100 g^{-1}) was greater ($p < 0.05$) than that below the silvopastoral trees (5.3 ± 0.2 g 100 g^{-1}), which in turn was greater ($p < 0.05$) than that below the woodland (4.6 ± 0.2 g 100 g^{-1}) (Figure 12). The woodland treatment also had the lowest ($p < 0.05$) organic carbon content at 10–20 cm. Below 20 cm, there were no ($p > 0.05$) treatment differences in organic carbon content at individual depth increments. Considered over the full depth, the mean level of organic carbon content in the three treatments were similar ($p = 0.091$).

6.5 Discussion

Change in soil organic carbon: in this experiment, the organic carbon content (units: g 100 g^{-1}) and the SOC stock (units: Mg ha^{-1}) of the pasture was greater than that of the tree planted treatments in the surface soil layer (0-10 cm). The mean SOC stocks in the surface layer of the silvopastoral trees and the woodland were 0.90 and 0.78 of that in the pasture respectively. The findings of Upson et al. (2016) agree with those of Shi et al. (2013) who reported that the response ratio (defined as the new SOC stock divided by the SOC stock of the control at each depth) in studies of tree planting on grasslands tended to be below 1.00 but not significantly different from 1.00.

Implications for the woodland carbon code: In 2011, a voluntary scheme called the Woodland Carbon Code was introduced in the UK to encourage woodland creation for sequestration benefits. Because of the uncertainty in the effect of afforestation on SOC stocks, the Woodland Carbon Code currently assumes no change in SOC stores following tree planting on grassland (West 2011). The results presented here support that the existing assumption that tree planting on lowland grassland does not increase soil carbon stocks.

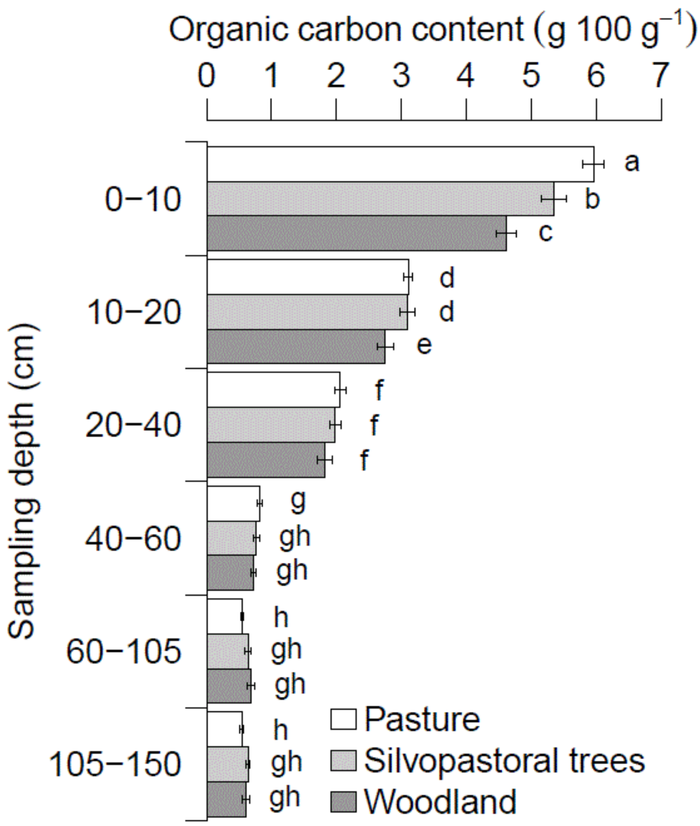

Figure 12. Organic carbon content at each of six depth increments in the pasture (n = 40), silvopasture tree (n = 20), and woodland (n = 20) treatments at Clapham Park in 2012. Error bars indicate standard errors of the means (from Upson et al. 2016)

Explaining the effect of tree planting on soil organic carbon: Upson et al. (2016) examines possible explanations for the observed decline in SOC below the silvopastoral trees and woodland, compared to the pasture. Reasons examined include pre-experimental variation across the site, pre-planting disturbance, changes in ground vegetation, and soil water effects. Upson et al. (2016) explain that the effect of pre-experimental variation and pre-planting disturbance is minimal. One plausible explanation is that the loss of perennial grass cover in the woodland understorey as the fast turnover rate of grass roots can help build up soil carbon. A second plausible explanation is that the tree planting led to a reduced soil water content and that this may have increased soil respiration.

Overall carbon storage: the higher carbon storage (including above-ground carbon) with the overall silvopastoral system (63.4 Mg ha^{-1}) compared with separate pro-rata woodland and pasture blocks (60.5 Mg ha^{-1}) suggest that the agroforestry system is more effective at storing carbon.

Methods of reporting SOC stocks and statistical power: Upson et al. (2016) also includes a substantial section that discusses the high number of replicates needed in research studies to get statistically significant results.

6.6 Conclusions

In agreement with many studies in the literature, Upson et al. (2016) found that tree planting on pasture was associated with a loss of SOC in the uppermost soil layer. The principal two explanations provided for this are the loss of perennial grasses in the understorey and an increase in soil respiration due to lower soil water contents. Relative to pasture, the 14 year old woodland increased carbon storage, but 37% of the increase in aboveground carbon storage was offset by soil carbon loss at 0–10 cm. A simple pro-rata analysis (described by Upson et al. 2016) suggests that the silvopastoral system was storing about 5% more carbon than the equivalent separate areas of woodland and pasture. The paper also suggests that the comparison of the systems could also be further enhanced by using the concept of carbon-time.

Although Upson et al. (2016) intensively sampled soil carbon over 0-150 cm profiles, they found no statistically significant differences in soil carbon stock below a depth of 10 cm. Power analyses indicated that despite the intensity of sampling, comparison of cumulative SOC values below 0–40 cm had a greater than 20% chance of falsely indicating no significant change. Upson et al. argue that this low power issue needs to be recognised more widely and there remains a need to establish new methods to statistically determine changes in carbon without excessive replication.

7 Lessons learnt

The research on wood pastures in the UK primarily focused on i) wood pasture restoration including the use of a management tool, ii) an assessment of the economics of ”invisible fencing” and iii) an assessment of the effect on soil carbon of new wood pasture establishment on grassland. The key lessons learnt are outlined below.

- An important objective in managing many wood pastures in the UK is to maintain or enhance biodiversity. A botanical survey across i) a restored and ii) an unrestored ancient wood pasture and iii) an unrestored secondary wood pasture showed that the greatest number of plant species was found in the restored ancient wood pasture i.e. the restoration which involved pollarding and opening up the woodland was successful in achieving its biodiversity objective.
- Another objective of ancient wood pasture management is to maintain or enhance a sustainable population of mature trees. A relatively simple model to predict the future age distribution of different tree species, called the ”Kirby model” which requires three parameters was tested in Epping Forest. Although the model has limitations, it was relatively easy to use. The model predicted that the population of mature beech trees would increase, the population of mature oak trees appeared to be stable, and the number of mature hornbeams was predicted to increase in the next 70 years and then decline.
- Epping Forest uses an ‘invisible’ fencing system which enables cattle management without above-ground physical barriers, relying instead on a buried wire-loop which produces a radio signal sensed by collars worn by the cattle. On approaching a boundary, the cattle hear a noise emitted by the collar, and if there is no change in direction the cattle receives a small electric shock (less than a conventional electric fence) which proves sufficient for the cattle to change direction.
- The use of GPS transponders on the collars is very helpful in allowing the stockperson identify the location of the cattle in the wood pasture at any particular moment. Some initial work indicated that it was possible to create a web-based platform to indicate the changing location of the cattle over time. However further work is still required to progress this.

- A financial analysis suggests that the cost of single loop invisible fencing covering about 25 ha is about 44% greater than with a wooden fence over a 30 year period. Hence the invisible fencing system is likely to be restricted to situations where unhindered access for the general public is valued highly. A mix of wooden fencing (next to roads) and invisible fencing elsewhere seems to offer the benefits of invisible fencing where required whilst minimising the cost where it is not needed.
- In a study on a wood pasture established in England on grassland 14 years ago, the organic carbon content in the top 10 cm was reduced by 10% in the silvopastoral tree plots, and 22% in a conventional woodland, compared to the pasture without trees. Possible reasons for this are i) a reduced grass cover beneath the trees reduces grass root turnover which can build up soil carbon, and ii) a reduced soil water content which increases soil respiration.
- In the same study, the greatest carbon storage (including above ground carbon) occurred in the woodland. However the carbon storage in the new wood pasture system (63.4 Mg ha^{-1}) was greater than the equivalent pro-rata value if the trees and pasture were kept separate (60.5 Mg ha^{-1}). This suggests that agroforestry is more effective at storing carbon, for a specified level of tree cover, than separate areas of trees and pasture.

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9 References

Agbenyega O, Burgess PJ, Cook M, Morris J (2009). Application of the ecosystem function framework to perceptions of community woodlands. Land Use Policy 26: 551-557.

Anderson DM (2007). Virtual fencing past, present and future. Rangeland Journal 29: 65–78.

Anderson DM, Estell RE, Holechek JL, Ivey S, Smith GB (2014). Virtual herding for flexible livestock management - a review. Rangeland Journal 36(3): 205–221.

Beckett KP, Freer-Smith PH, Taylor G (1998). Urban woodlands: their role in reducing the effects of particulate pollution. Environmental Pollution 99(3): 347-360.

Butler Z, Corke P, Peterson R, Rus D (2006). From robots to animals: virtual fences for controlling cattle. The International Journal for Robotics Research 25: 485-508.

City of London (2014). Epping Forest Visitor Survey 2014- Results Report. City of London. Available at: https://www.cityoflondon.gov.uk/things-to-do/green-spaces/epping-forest/about-us/Documents/visitor-survey-report-2014.pdf

Crow (2004). Managing the historic environment in woodland: the vital role of research. In: Forest Research Annual Report and Accounts 2002-2003. Forestry Commission. Available at:

https://www.forestry.gov.uk/pdf/frannualreport0203full.pdf/$FILE/frannualreport0203full.pdf

Dagley J, Beecroft R, Vandermarcq B, Hartup M (2014). The invisible fence project. Conservation Land Management 12(2): 14-19.

De Groot RS, Wilson MA, Boumans RMJ (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41: 393-408.

Defra (2007). An introductory guide to valuing ecosystem services. London: Defra

Forestry Commission (1999). Domestic Stock Grazing to Enhance Woodland Biodiversity. Forestry Commission. Available at: https://www.forestry.gov.uk/PDF/fcin28.pdf/$FILE/fcin28.pdf

Forestry Commission (2002). Social and Environmental Benefits of Forestry Phase 2: Landscape Benefits. Forestry Commission. Available at: https://www.forestry.gov.uk/pdf/fclscaperep.pdf/$FILE/fclscaperep.pdf

Forestry Commission (2004). A sort of Magical place- People's experiences of woodlands in northwest and southeast England. Forestry Commission. Available at: https://www.forestry.gov.uk/pdf/fr0305_magical_place.pdf/$FILE/fr0305_magical_place.pdf

Forestry Commission (2009). Active England- The Woodland Project. Forestry Commission. Available at: https://www.forestry.gov.uk/pdf/active_england_final_report.pdf/$FILE/active_england_final_report.pdf

Forestry Commission (2011). Forests and soil: UK Forestry Standard Guidelines. Forestry Commission. Available at: https://www.forestry.gov.uk/pdf/FCGL006.pdf/$FILE/FCGL006.pdf

Forestry Commission Scotland (2009). A valuation of the economic and social contribution of forestry for people in Scotland. Forestry Commission Scotland. Available at: https://www.forestry.gov.uk/pdf/fcrp101.pdf/$FILE/fcrp101.pdf

Graves AR, Burgess PJ, Liagre F, Terreaux J-P, Dupraz C (2005). Development and use of a framework for characterising computer models of silvoarable economics Agroforestry Systems 65: 53-65.

HM Treasury (2013). The Green Book: Appraisal and Evaluation in Central Government. London: TSO 114 pp UK Government https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

Jose S (2009). Agroforestry for ecosystem services and environmental benefits: An overview. Agroforestry Systems 76(1): 1–10.

Kirby KJ (2014). What might a sustainable population of trees in wood-pasture sites look like? Hacquetia, pp.1–21.

Kirby KJ, Potvin C (2007) Variation in carbon storage among tree species: Implications for the management of a small-scale carbon sink project. Forest Ecology and Management 246(2–3): 208–221.

Lee C, Fisher AD, Reed MT, Henshall JM (2008) The effect of low energy electric shock on cortisol, [beta]-endorphin, heart rate and behaviour of cattle. Applied Animal Behaviour Science 113(1–3): 32–42.

Lopez Bernal A, Burgess PJ, Upson M, Garcia de Jalon S (2016). System Report: Wood Pasture and Parkland in the UK. January 2016. 41 pp. http://www.agforward.eu/index.php/en/wood-pasture-and-parkland-in-the-uk.html

Maddock A (Ed) (2008). Wood-Pasture and Parkland. In: UK Biodiversity Action Plan; Priority Habitat Descriptions.

Maddock A (Ed) (2011). Wood-Pasture and Parkland- UK Biodiversity Action Plan Priority Habitat Descriptions. Joint Nature Conservation Committee.

Mountford EP, Savill PS, Bebber DP (2006). Patterns of regeneration and ground vegetation associated with canopy gaps in a managed beechwood in southern England. Forestry 79: 389–408.

Natural England (2009). Environmental impacts of land management (Ed. C. Chesterton). Research Report NERR030, http://publications.naturalengland.org.uk/publication/30026. Natural England. page 63.

Natural England (2017a). FG1: Fencing. https://www.gov.uk/countryside-stewardship-grants/fencing-fg1

Natural England (2017b). FG6: Invisible fencing system. https://www.gov.uk/countryside-stewardship-grants/invisible-fencing-system-fg6

Nisbet T, Silgram M, Shah N, Morrow K, Broadmeadow S (2011). Woodland for Water: Woodland measures for meeting Water Framework Directive objectives. Edinburgh: Forestry Commission

Petritan IC, Marzano R, Petritan AM, Lingua E (2014). Overstory succession in a mixed *Quercus petraea–Fagus sylvatica* old growth forest revealed through the spatial pattern of competition and mortality. Forest Ecology and Management 326: 9–17.

Plieninger T, Hartel T, Martin-Lopez B, Beaufoy G, Bergmeier E, Kirby K, Montero MJ, Moreno G, Oteros-Rozas E, van Uytvanck J (2015). Wood-pastures of Europe: Geographic coverage, social– ecological values, conservation management, and policy implications. Biological Conservation 190: 70–79.

Redman G (2016). John Nix Farm Management Pocketbook September. Leicestershire: Agro Business Consultants Ltd.

Sharrow SH, Ismail S (2004). Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. Agroforestry Systems 60(2): 123–130.

Shi S, Zhang W, Zhang P, Yu Y, Ding F (2013). A synthesis of change in deep soil organic carbon stores with afforestation of agricultural soils. Forest Ecology and Management 296, 53–63.

Smith P et al. (2011) 'Chapter 14- Regulating Services', in UK National Ecosystem Assessment. The UK National Ecosystem Assessment Technical Report. Cambridge: UNEP-WCMC

Tyndall J, Colletti J (2007). Mitigating swine odor with strategically designed shelterbelt systems: A review. Agroforestry Systems 69(1): 45–65.

UK Government (2006). Commons Act. Available at: http://www.legislation.gov.uk/ukpga/2006/26/contents [Accessed April 2, 2015]

Umstatter C (2011) The evolution of virtual fences: A review. Computers and Electronics in Agriculture 75: 10-22.

Umstatter C, Morgan-Davies J, Waterhouse T (2015). Cattle responses to a type of virtual fence. Rangeland Ecology and Management 68(1): 100–107.

Upson M, Burgess PJ (2014). Initial Stakeholder Meeting Report: Wood Pasture and Parkland in the UK. 10 pp. http://www.agforward.eu/index.php/en/wood-pasture-and-parkland-in-the-uk.html

Upson M, Burgess PJ (2015). Research and Development Protocol for Wood Pasture and Parkland in the UK. April 2015. 9 pp. http://www.agforward.eu/index.php/en/wood-pasture-and-parkland-in-the-uk.html

Upson MA, Burgess PJ, Morison JIL (2016). Soil carbon changes after establishing woodland and agroforestry trees in a grazed pasture. Geoderma 283: 10-20.

West V (2011). Soil carbon in the Woodland Carbon Code. Tech. rep., Forestry Commission, Edinburgh. URL http://goo.gl/m83crZ

Woodland Trust (2012) Wood Pasture: definition, restoration, creation. Woodland Trust. Available at: http://www.woodlandtrust.org.uk/mediafile/100263358/pg-wt-2014-woodwise-2012-winter.pdf?cb=2dd754bdd48e4ffcac5e8c923ffc6dbb