disturbance to plant communities, resulting in significant reduction in vegetation cover, an adverse effect on bluebells should be expected, especially if the bulbs are eaten. Despite such concerns there has been only one detailed study of the relationship between bluebells and rooting, and this concentrated on recovery after rooting rather than damage caused by rooting (Sims, 2005). Many species other than plants inhabit the litter and surface horizons of the mineral soil which are disturbed by rooting. These include micro-organisms and small invertebrates that are involved in litter decay and nutrient cycling, and also larger invertebrates such as ants, woodlice, millipedes and beetles. Although these species are likely to be disturbed by rooting, the impact of boar on these invertebrates, which are important components of the woodland ecosystem, remains largely unknown.

Recent research on boar in Britain has focussed on investigating population size and spread, and on developing possible methods of control (e.g. Massei et al. 2008; 2010). However, one current project jointly funded by Defra and the Forestry Commission, includes studies on the impact of wild boar on biodiversity in which the relationships between rooting, ground dwelling invertebrates and ground flora vegetation are being observed. These studies, which are briefly described below, were carried out within the area of Kent and East Sussex occupied by the largest and oldest free living population of wild boar, which was estimated to comprise about 200 animals in 2004 (Natural England, 2007). This location was selected as many of the woodlands in the area are semi-natural broadleaves with bluebells and other typical ground flora species, and the invertebrate community is likely to be particularly rich.

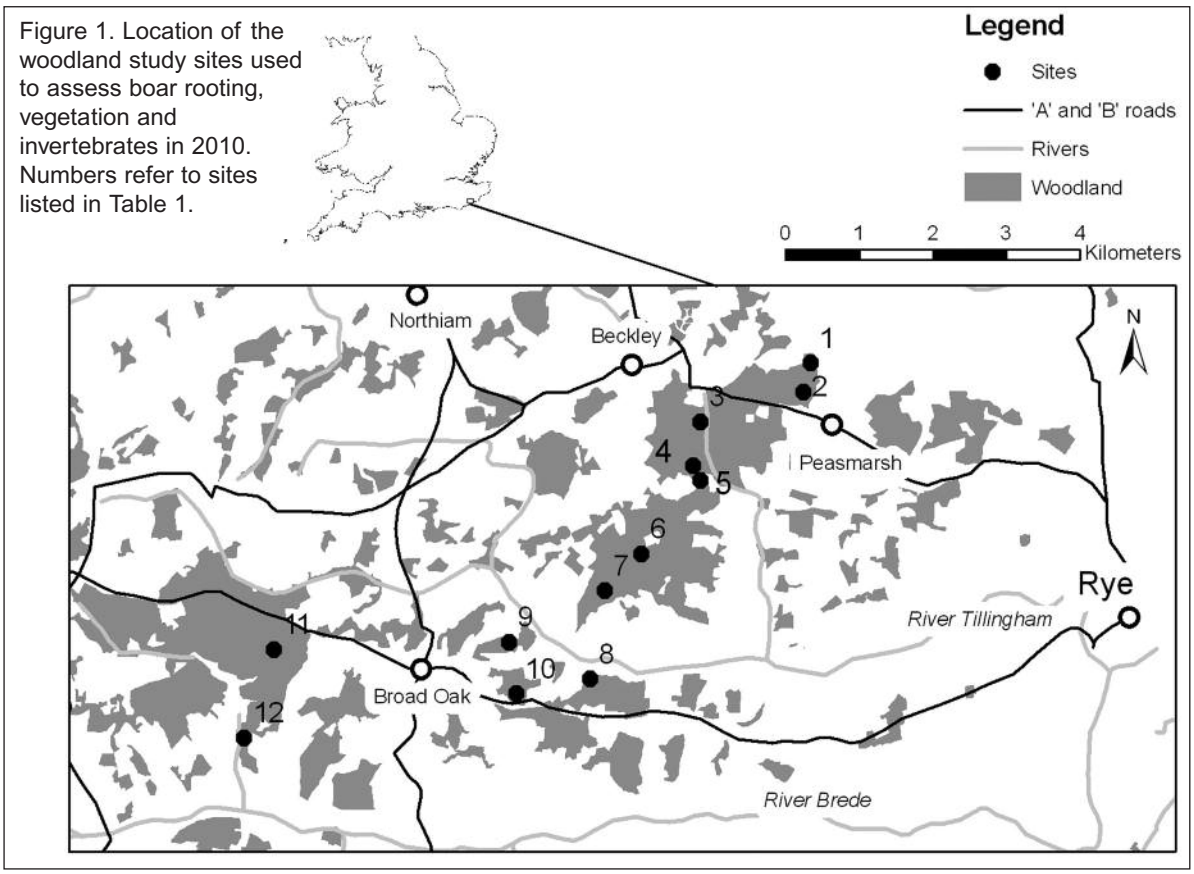

Figure 1. Location of the woodland study sites used to assess boar rooting, vegetation and invertebrates in 2010. Numbers refer to sites listed in Table 1.

Methods

Sites

The studies were carried out during 2010 at twelve sites in East Sussex that were visually inspected during March and selected to include woodlands in which there were differing amounts of rooting activity. The sites comprised stands of broadleaved trees, the majority of which were unmanaged coppice growing on clay soils typical of the area. Fourteen tree species were recorded during the study: oak and sweet chestnut were predominant in the overstorey, and hornbeam and sweet chestnut in the understorey (Table 1). During spring the ground flora of these woodlands is typically dominated by bluebell and anemone, but in summer the vegetation is very sparse due to the density of canopy cover.

Field studies

Invertebrates active on the ground surface and in the litter layer were sampled using ten pitfall traps per site arranged in two rows of five traps placed at 10m intervals. These were emptied every two weeks from April to August and the numbers of individuals in each of the main invertebrate groups caught in the traps were counted and recorded. Ground beetles were identified to species.

During May 2010, when bluebells were in full leaf, the amount of rooting activity and abundance of bluebells was assessed in the woodland surrounding the pitfall traps. This survey was carried out using thirty temporary 4 x 4m quadrats placed at 30m intervals along parallel transects 30m apart. The percentage of each quadrat covered by bluebells or affected by rooting damage was assessed using the following scale: 0, ≤ 3%, 4 ≤ 10%, 11 ≤ 30%, 31 ≤ 50%, 51 ≤ 100%. Rooting activity included both that restricted to the litter layer as well as disturbance to the mineral soil. Only recent rooting activity that was obvious without extensive searching beneath the leafy cover of the ground flora was included. Recent activity was determined by its fresh unweathered appearance and the absence of established plant cover including mosses and liverworts.

Rooting activity

There was great variation both between and within sites in the amount and distribution of rooting that was recorded. At some sites less than

Table 1. Characteristics of sites studied.

Site		Predominant Species		Structure	Rooting	Bluebells	
		Overstorey	Understorey			Freq.	%cover
1	Mill Wood - north	OK / SWC	HBM	SC / nCS	3	0.83	45
2	Mill Wood - south	OK / SWC	SWC	SC / nCS	29	1.00	31
3	Flatropers Wood - north	SWC	SWC	SC / HF	28	0.73	20
4	Flatropers Wood - south	OK	HAZ	HF	40	0.97	21
5	Beckley Wood	OK	HBM	HF	1	0.77	9
6	Rowlands Wood	OK	HBM	HF	<1	0.90	2
7	Burnthouse Wood	OK	HBM	nCS	3	0.20	2
8	Long Sowdens Wood	BI	HBM	HF	3	0.67	15
9	Twist Wood	OK	HBM / SWC	nCS	6	0.93	35
10	Maitland Plantation	SWC	SWC	SC	11	1.00	38
11	Coneyburrow Wood	OK	HBM	nCS	<1	0.57	17
12	Rafters Wood	OK	HBM / SWC	nCS / SC	5	1.00	30

Species: BI = birch; HBM = hornbeam; OK = oak; SWC = sweet chestnut.
Structure: HF = high forest; nCS = neglected coppice with standards; SC = stored coppice.
Rooting = Total percentage of site rooted - estimated from survey. Freq. = Proportion of quadrats with bluebells.
%cover = mean percentage cover of bluebells in quadrats where they were present in May 2010.

20% of the quadrats observed showed signs of recent rooting whereas on one site every quadrat had some recent rooting; overall about half of the quadrats at any site were rooted. Similarly the area of each quadrat rooted varied considerably. On some the area rooted was less than 50 x 50cm but on others the area exceeded 2 x 2m. The estimated areas of each site rooted are shown in Table 1. These varied from <1% for Rowlands and Coneyburrow Woods to 40% for Flatropers Wood (south); for the majority of sites recent rooting had occurred over <10% of the area. For comparison, over a 5-year-period, damage to grassland adjacent to woodland in south-west England was regarded as light to moderate covering <30% of the areas observed (Wilson, 2004). In contrast, one study in North America reported that 80% of the surface area of Northern Hardwood forest may be rooted annually (Howe, Singer and Ackerman, 1981).

Boar tend to root the same areas repeatedly and in the American example cited above some patches were rooted 3-7 times in a growing season. The frequency of rooting at any point can only be determined by repeated observations over several years and we do not know whether this occurs in the woodlands studied. However, estimates of rooting were made at two of the sites in a pilot study during 2009, these were Flatropers Wood (south), which had large amounts of rooting, and Rowlands Wood where there was almost none; these results are consistent with those of the main study. In addition, observations made of five different rides in Beckley Wood during the pilot study, found that one was extensively rooted during the spring of two consecutive years whereas the others suffered little damage.

In the current study areas of recent rooting were generally small and if this is representative of the rooting that takes place in any year, and any repeated rooting is restricted to these areas, then the amount of disturbance caused by rooting could be low. However, the data are for one year only and it is not known whether they are typical for each woodland. The intensity and location of rooting is likely to vary according to a range of factors including variation in the size of the boar population and the quantity of acorns and chestnuts produced within a woodland.

Bluebells

The study was carried out at the height of the bluebell flowering season well before the leaves had begun to senesce. Consequently, the presence of bluebells is unlikely to have been

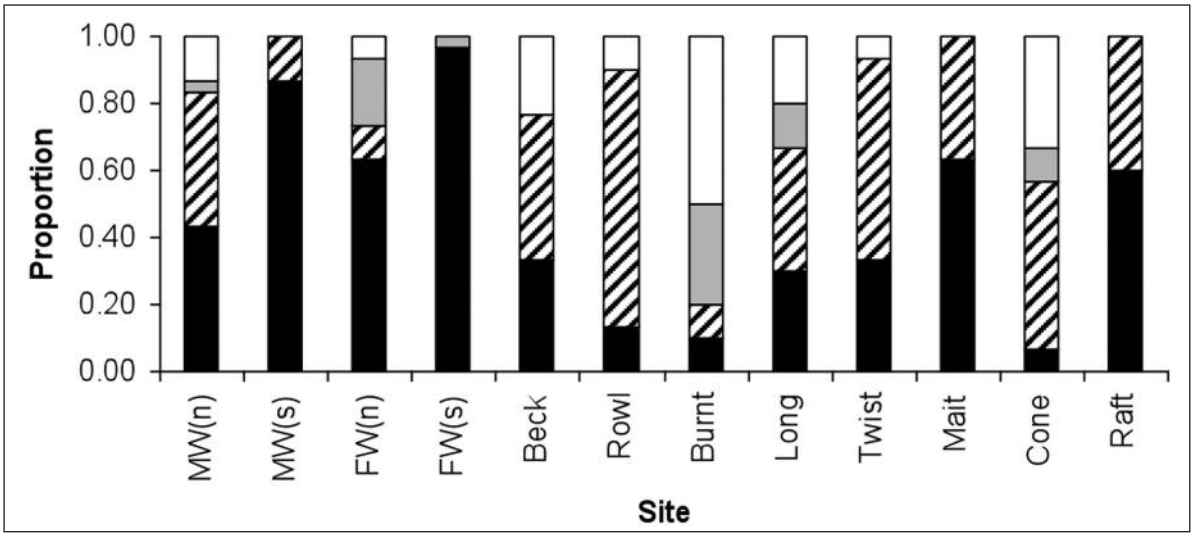

Figure 2. Proportion of sample quadrats with or without bluebells that were either rooted or unrooted: Black = Rooted with bluebells; Hatched = No rooting with bluebells; Grey = Rooted without bluebells; White = no rooting without bluebells. Sites are abbreviated names in same order as those listed in Table 1.

Table 2. Invertebrate groups caught by pitfall trapping at the woodland study sites in April-August 2010.

Invertebrate group	Number	%
Ants	24,614	36.5
Beetles:		
ground beetles	12629	18.7
rove beetles	4044	6.0
other adult beetles	3593	5.3
beetle larvae	2062	3.1
Centipedes	1102	1.6
Harvestmen	5937	8.8
Millipedes	2871	4.3
Spiders	5630	8.3
Woodlice	4967	7.4
Total	**67,449**	**100.0**

Number is the total number of animals caught in all traps at all sites.

Table 3. The 10 most abundant species of ground beetle caught in 2010.

Species	Number	%
Abax parallelepipedus	8500	67.3
Pterostichus madidus	2578	20.4
Carabus nemoralis	547	4.2
Nebria brevicollis	310	2.5
Pterostichus niger	204	1.6
Notiophilus biguttatus	180	1.4
Carabus violaceus	91	0.7
Platynus assimilis	38	0.3
Cychrus caraboides	36	0.3
Carabus problematicus	34	0.3
Others	111	0.9
Total	**12629**	**100%**

Others = 23 species each with <14 individuals caught in the traps.

missed and the cover recorded will probably be the maximum possible in the year. As for rooting there were large differences within and between sites in the amount and distribution of bluebells. At Mill Wood (south), Maitland Plantation and Rafters Wood bluebells were present on every quadrat observed, but at Burnthouse Wood they were infrequent (Table 1). Bluebell cover in each quadrat was also very variable with some having a few leaves whereas others had 50% or more cover. Average covers of bluebell on quadrats at each site varied between 2 and 45% (Table 1). The proportion of quadrats with or without rooting or bluebells is shown in Figure 2. At most sites there are quadrats with bluebells that are not rooted and others without bluebells that are rooted which suggests that the presence of bluebells does not necessarily mean that rooting will take place. If boar target bluebells deliberately as a source of food, then rooting close to bluebells should be more common at sites with few bluebells. Burnthouse Wood is the site at which both cover and frequency of bluebells were lowest (Table 1) and half (i.e. 50%) of the quadrats with bluebells were rooted. Other sites that had a comparable percentage of quadrats rooted were Mill Wood (north) (52%), Beckley Wood (43%) and Long Sowdens Wood (45%) (Figure 2), but these sites had substantially higher frequencies and greater cover of bluebells (Table 1). These data suggest that there is no obvious relationship between the presence of bluebells and the incidence of rooting.

Beetles

Large numbers of a variety of ground dwelling invertebrate groups were captured during the study (Table 2). Overall, ants were the most common group comprising 36% of the individuals caught. The majority were wood ants and almost all of these occurred at a single site. Beetles were the next most abundant group and more than half of these were ground beetles (*Carabidae*). This is a well-studied group which has been used widely as an indicator in studies of biodiversity; there are very good keys for British ground beetles and identification is relatively easy (Luff, 2007). Over the whole of the sampling period, 33 different species of ground beetle were captured although none were particularly rare or unusual. Six species were common (>100 individuals caught) while most of the rest were infrequent and represented by fewer than ten specimens (Table 3). The most frequent species was *Abax parallelepipedus* with more individuals caught than for all of the other

Figure 3. *Abax parallelepipedus*, the most abundant ground beetle species at the study sites.

species combined. At 18-25mm long, *A. parallelepipedus* is one of the larger ground beetles (Figure 3). It is widespread and a generalist predator typically found in woodlands, scrub and hedgerows. Although there were differences between sites in the mixture of species captured, a total of about fifteen species were recorded at each site regardless of the amount of rooting. There were also differences between sites in the total numbers of ground beetles captured, which appeared to increase with the amount of rooting in the woodland. There appeared to be no adverse effect of rooting on the ground beetle community and the same appeared to be true for the other groups of ground dwelling invertebrates.

Discussion

Despite concerns about the fate of bluebells in the presence of wild boar, bluebells remain common and many of the woodlands in the current study had dense patches of flowering plants. Bluebells are reported to be eaten by boar and evidence of rooting in areas of bluebells is often seen. However, if bulbs are desirable and specifically targeted as a source of food, why does such an abundance of bluebells remain after twenty years of boar activity, especially as bulbs are present in the ground throughout the year and available whenever the soil is sufficiently moist for rooting? If rooting for bulbs to eat is deliberate, then it often appears to be a fairly inefficient process as new shoots can often be seen growing in recently rooted ground and uprooted bulbs found laying on the soil surface (Figures 4, 5). Although studies indicate that the recovery of bluebells following rooting is rapid (Sims, 2005) impacts of rooting will depend on the frequency with which re-rooting occurs. If the time taken to re-establish a flowering plant is longer than the interval between re-rooting then decline is likely in the long-term. Current evidence suggests that if boar populations and rooting activity remain similar to those of the last twenty years then in the short-term bluebells are

Figure 4. Very recently rooted area in March with bulb and fragments of bluebell shoots laying on the surface of the disturbed soil.

Figure 5. Intensely rooted area with leaves of developing bluebell plants growing in the disturbed soil. The blanched sections indicate that these parts of the leaves were recently below ground.

not unduly threatened. They will survive but there may be a reduction in the amount of flowering.

Within the scant British literature on wild boar their impacts on trees are largely neglected, which is perhaps surprising as it is the trees that create the woodland habitat in which both the animal lives and bluebells grow. Standing trees can be affected in several ways: a small number are damaged when they are used as rubbing trees; rooting often takes place around the bases of trees and coppice stools and if this is frequent then large roots are likely to be damaged (Figure 6); regular rooting of the litter and surface horizons of the soil will affect the fine root system. Possible consequences of such damage include the creation of entry points for fungal pathogens and adverse effects on nutrient and water uptake. Natural regeneration could be affected in several ways; oak and beech mast provide a valuable source of food and regeneration of these species will probably be reduced, conversely rooting can create a good seed bed in which other species can regenerate. However if soils are disturbed frequently how will any trees of any species establish and survive?

Figure 6. Patch of deeply disturbed soil around the base of sweet chestnut coppice stool.

Free-living wild boar have been present for about twenty years within British woodlands, but their impact remains unclear and it is unknown whether or not their presence is beneficial. The small populations in restricted locations probably contribute to the lack of detailed information, but it may also reflect the apparently ephemeral nature of much of the damage or disturbance. For example, re-vegetation of rooted areas can occur quickly and available evidence suggests this is true for woodland species (Sims, 2005). Twenty years however, is a relatively short period of time in the life of a wood and any lasting effects of boar activity may not become apparent unless repeated studies are made over many years.

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