WOODLAND TRUST

Impacts of nearby development on ancient woodland – addendum

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1. Executive Summary

In 2008 The Woodland Trust published a report on the impacts of nearby development on the ecology of ancient woodland. Further work on this subject has been undertaken since then and this report was commissioned to review work published since 2007.

The amount of woodland in the UK has been in decline for centuries, and whilst this decline appears to have been reversed in recent years, woodland only makes up a small percentage of the landscape of the UK. There is still a lot that is not known about the ecology of ancient woodland and its interaction with the surrounding landscape and this can make it difficult to predict the effects of development, or the best mitigation measures to put in place once development has taken place.

Broadly speaking development types can be categorised under twelve headings. Each development type can then result in five different effects; chemical, disturbance, fragmentation, invasion by non-native plant species and cumulative effects. These effects are not mutually exclusive and some development types may result in all five occurring. These potential effects are not all covered equally in the research with most work relating to fragmentation and the least work relating to chemical and cumulative effects.

If disturbance of ancient woodland is to take place then it is vital that the ecology of the wood is well documented and understood before the disturbance takes place. The connection between that woodland and other woods or remnants of woods in the area also needs to be understood as connectivity between patches of woodland is important for promoting species diversity within a landscape. Structural complexity of both the interior of the wood and the woodland edges should also be ensured to maintain habitat quality. Any restoration of woodland patches should be spatially targeted to ensure maximum success.

Many papers suggest the planting of buffer zones to protect core woodland habitat from the impact of development, but very few give figures for the size of buffer zones and those that do range in size from 50m to 400m. Only one paper reviewed the effectiveness of buffers, and this related to fencing rather than planted buffers. This is definitely an area that requires further research.

Overall very little research has been undertaken in the UK. Whilst much of the work undertaken in Northern Europe can be extrapolated to cover the UK, further work on British woodland would be beneficial to enhance our understanding of the impacts of development on woodland. The impacts of climate change and disturbance to fungal mychorrhiza are also areas that need further investigation.

Survey methods reviewed in the original report are still relevant today. However, it is becoming apparent from much of the research reviewed that the reliance on species number as a measure of habitat quality may not be reliable and a distinction between generalist and specialist species present in an environment may be needed.

Woodland is a finite resource and ancient woodland cannot be replicated once lost. It is important to understand each individual woods importance on a landscape scale as even small losses may have unforeseen impacts on other woods. Pressures from development are varied and are often not obvious, and without a thorough understanding of the ecology of individual woods these pressures are harder to predict and mitigate. Enhancement of existing woodland is key to promoting habitat health and in a climate of limited funding, spatially targeted restoration schemes are vital to improve the connectivity between woods.

WTPL/Fiona Granger

2. Introduction

In the UK only 12% of the landscape is native woodland, and of that only 19% is classified as ancient woodland (woodland that has been in existence since at least 1600AD). The amount of woodland in the UK has been in decline for centuries and the woods that remain and are often small and isolated from other woodland. Due to population size, the landscape in the UK is subject to multiple uses and as a result is highly fragmented. Woodland performs many functions within this complex matrix and it is often under pressure from encroaching development. The impacts on woodland from development are not always clear as they tend to be insidious and cumulative rather than one-off catastrophic events. Therefore controlling and monitoring the effects of development can be difficult.

In 2008 The Woodland Trust commissioned a report (Corney *et al.* 2008) to review existing literature relating to impacts of development on ancient woodland. This report seeks to update the original using relevant research published since 2007 and over fifty papers relating to the impact of development on woodland were found. This report is an update of the original report and therefore should be read in conjunction with it for a complete picture of the potential impact of development on ancient woodland.

3. Methodology

This report is based on a literature search that was conducted using a similar methodology to the 2008 report. A hierarchy of search terms was created (see Table 1 below) and the ScienceDirect database was then searched using combinations of these terms. In keeping with the original report, the word "woodland" was used as the primary search term because it was assessed to fit most closely with the objective of this report. The original report also identified 218 keywords that were relevant to the scope of the report and these were searched in combination with the relevant theme and research topic. If no results were returned in Step 1 then the theme was dropped (Step 2), then the research topic (Step 3). If no results were returned using the word "woodland" with a keyword, then the word "forest" was used instead (Step 4).

Table 1 Hierarchy of Search Terms

Step	Description
1	Woodland AND Keyword AND Research Topic AND Theme
2	Woodland AND Keyword AND Research Topic
3	Woodland AND Keyword
4	Forest AND Keyword

The original report searched four main online databases. Due to time constraints this report has searched one (ScienceDirect). On the whole only papers published since 2007 have been searched as this was the cut off date for the last report. However, in the process of searching, several papers missed in the original report were discovered and these have been included here for completeness.

Using the above methodology 59 papers were determined to contain material relevant to this review, and the contents of these papers form the basis of this update to the 2008 report. A full list of papers reviewed can be found in the references section at the end of this report.

Once the search was completed the papers were then ranked based on how relevant they were to the scope of this review. The ranking was applied as follows;

- 5 - given to those papers that contained all the search terms AND the paper specifically dealt with British woodland,
- 4 - given to papers containing most of the search terms AND the paper specifically dealt with impacts on British woodland.
- 3 – given to papers containing some search terms but the paper is not specifically about British woodland.

The 2008 report also had ranks of 2 and 1 which were given to papers that contained none of the search terms but were deemed to be relevant for some other reason. These rankings do not apply to any of the papers used for this report because only papers found using the methodology laid out in Table 1 on the previous page were used.

It should be noted that although a comprehensive set of search terms has been used to produce this report it is possible that some relevant research may not have been captured.

4. Development types and impacts

Twelve development types were identified in the 2008 report as having the potential to impact on ancient woodland. From this, five potential effects were hypothesised to describe the ways in which these types of development may impact on ancient woodland. These are summarised in Table 2 below.

Table 2 Development Types and Their Effects

Development Type	Potential Effect
Housing	Chemical effects Disturbance Fragmentation Invasion by non-native plant species Cumulative effects
Transport	
Commercial and industrial development	
Intensive Livestock Units	
Energy	
Quarrying and mineral extraction	
Waste disposal facilities	
Leisure and sport	
Military activity	
Water management	
Permitted development	
Cumulative development	

The 12 development types identified above may result in one or more of the five effects i.e. they are not mutually exclusive. The 2008 report discussed each development type in detail and reviewed the likelihood for each of the five effects to arise and the potential impact. For simplicity and to avoid repetition of previous work, this report discusses the five effects of development on ancient woodland rather than dealing with each development type individually. This is because papers reviewed for this report do not cover all of the 12 development types listed above (e.g. none of the papers reviewed cover the impacts of military activity, quarrying or intensive livestock units).

4.1. Chemical effects

Chemical effects can arise from any of the twelve development types identified in the 2008 report. However, there is a lack of research on the chemical effects of development on woodland, and very few of the papers reviewed for this report explicitly covered this topic. Those that did mainly related to chemical deposition from vehicles.

Road networks are a potential source of air pollution that can impact on woodland. Emissions from vehicles contain a cocktail of pollutants that include nitrogen oxides (NOx), volatile organic carbons (VOCs), polycyclic aromatic hydrocarbons (PAHs), ammonia (NH_3), metals and particulates. These chemicals are wind dispersed to neighbouring vegetation, where they are then deposited on plant surfaces.

The majority of research into the effects of chemicals on plant growth appears to focus on roadside verges, with little concentrating on adjacent vegetation types of conservation significance. Given the dense network of roads in parts of the UK it can be reasonably assumed that there are many sites of specific conservation value that may be subject to pollution emitted from vehicles. These types of pollutants may directly affect plant growth or may indirectly make the plant less able to tolerate other environmental stresses. Keely *et al*. (2008) undertook a study to determine the impact of road transport on the growth and physiology of six bryophyte species. They observed an increase in nitrogen tolerant species close to the motorway and physiological changes in some species such as increased membrane leakage and changes to chlorophyll concentrations. They determined that the effects of pollution from roads could extend up to 200m from the road and that the effects they observed were directly related to the concentration of nitrogen dioxide. Keely *et al*. (2008) proposed that any new road project should include a buffer zone of between 100 and 200m from sensitive sites, to reduce the likelihood of these effects occurring.

Work by Fenn *et al*. (2010) in California found that nitrogen (N) enrichment of woodland caused by vehicle emissions caused changes in epiphytic lichen communities and promoted invasion by exotic grasses. An increase in N in the woodland ecosystem threatens the sustainability of that environment by increasing the stresses the system is subject to. They recommend that some reduction in N within the system can be achieved by physically removing leaf litter and some plants, but the effect of this is limited as the majority of the N will be contained within the soil itself. Ultimately the only solution to reduce N deposition is to improve air quality.

4.2. Disturbance

4.2.1 Noise

Most of the development types detailed in Table 2 opposite will result in the generation of noise. Some of this noise will be short lived (e.g. construction noise) whilst some may be persistent (e.g. traffic noise from a newly built road, noise from domestic dwellings, etc.). However, few studies have been undertaken to quantify the effect of noise, if any on woodland species. Work undertaken by González-Oreja *et al*. (2012) in urban parks in Mexico found that the higher the background noise level the lower the number of woodland bird species present. They also found that different species reacted differently to similar noise levels. This indicates that some birds are able to adapt positively to noise (e.g. by changing the pitch at which they sing), but some will respond maladaptively and disappear from an assemblage.

4.2.2. Vegetation clearance

When woodland is managed for recreational purposes an open understorey is often considered to add value, as it makes it easier for people to move around within the wood.

However, clearance of the understory has a negative effect on woodland birds and other animals. Heyman (2010) undertook controlled clearance of patches of understorey in a Swedish woodland and found that bird diversity was significantly reduced in areas where total clearance (100%) occurred. If clearance was patchier (up to 54% of vegetation removed) then bird abundance did not appear to be negatively affected. However, it should be noted that due to the short duration of this study it did not consider the long term effects of vegetation clearance on birds' ability to nest. The author notes that the persistence of some woodland bird species in the sample areas may have been due to avian site fidelity and that reductions in bird species composition may occur over time.

4.2.3. Light pollution

Anthropogenic light pollution is also a problem associated with development. Like noise, this may only be present during the building phase of the development (e.g. night lighting) or it may be a permanent feature of the development (e.g. street lighting). Kempanaers *et a*l. (2010) found that artificial night lighting had a strong effect on the timing of breeding and individual mating behaviour in five European songbird bird species. Female blue tits (*Cyanistes caeruleus*) were found to begin egg laying earlier if nesting close to artificial light sources. This could result in chicks hatching before enough food is available in the environment to support them. Artificial light also caused yearling males to start singing earlier. Early singing appears to be an important indicator to females of the quality of the male. However, yearling males are not necessarily quality partners for breeding females and artificial light may be enhancing the breeding success of males that under natural conditions would not be so successful. The length of the study was such that the environmental cost of these alterations to breeding timing and mating success was not determined, and this is an area that needs further research. Furthermore, Kempanaers *et al*. (2012) were able to discount noise as being the factor influencing the changes in behaviour because the control area had similar background noise levels to the study areas.

4.2.4. Trampling

Trampling along paths can change understorey vegetation considerably, with different woodland plant species being able to withstand different levels of disturbance. A three-year study by Hamberg *et al*. (2010) in Finland clearly showed the more frequently a path was used the greater the loss of vegetation. Even at low levels (less than 35 visits to a path per year) trampling resulted in a loss of up to 30% of the vegetation along a path. Higher use of paths (up to 550 visits per year) led to a loss of vegetation in excess of 75%. At lower path usages, vegetation cover was reduced but species composition remained the same, however at higher path usage species composition was altered. This indicates that low path usage is favourable if species composition of a woodland is to remain unaffected. Trampling may also cause disturbance to non-trampled vegetation through changes to micro-climate in the vicinity of the path and increased soil fertility due to disturbance of the soil along the path. Hamberg *et al.* (2010) recommend that the publics' movements through sensitive woodland environments should be contained to a well maintained path network to prevent the effects of trampling spreading to large areas.

Trampling not only reduces vegetation cover and alters species composition but it can also affect the sexual reproduction and genetic diversity within a species (Rusterholz *et al*. 2008). Many woodland species are clonal and therefore they cannot produce new leaves in response to damage to their structure caused by trampling. Disturbance of *Anemone nemorosa* plants by trampling significantly reduced the proportion of shoots that survived during the growing season compared to *A.nemorosa* in undisturbed areas. This led to a reduced genetic diversity within the disturbed population of *A.nemorosa*. When considering the restoration of disturbed woodland, conservation managers should consider that re-vegetation only using plants from within that ecosystem may result in a population with a genetically restricted gene pool. Therefore any subsequent populations may be even more sensitive than the original population to any form of disturbance. The presence of undisturbed woodland close to disturbed woodland could provide an important source of genetic diversity for woodland species.

4.2.5. Grazing

Grazing is sometimes used as a means of sympathetically managing woods. However, Fuentes-Montemayor *et al*. (2012) have shown that the consistent presence of grazing stock in a site has a strong negative effect on British moth communities, although this effect was not consistent across all moth species. The presence of livestock in remnant woods has also been shown to increase nutrient levels of the soil, which in turn increases invasion of non-woodland species, thus degrading the quality of the habitat. Close *et al.* (2008) studied the effects of different levels of grazing eucalypt woodland remnants in Australia. They found that the higher the levels of grazing the greater the increase in soil nutrient levels. This in turn correlated with increased foliar levels of nitrogen and phosphorus which was associated with reduced tree health. However, under situations of light grazing pressure they found that woodland remnants contained higher levels of native understorey plants than those under high grazing pressure, indicating that not all grazing regimes have a negative effect. They recommend that eutrophication of woodland soils as a result of grazing should be minimised in order to maintain and enhance the quality of native woodland remnants. No comparable study of grazing in the UK was reviewed for this report and this may be an area that requires further research.

Although the presence of deer is not directly related to the development types covered in this report, their presence in a woodland needs to be considered as they have a negative impact on the ecology of an area. Deer grazing has been shown to impact on the presence of bankvoles in woodland (Buesching *et al*. 2011) and breeding birds (Holt *et al*. 2011).

4.3. Fragmentation

Of all the papers reviewed for this report by far the largest number dealt with issues of fragmentation and its impact on woodland. The types of fragmentation reviewed ranged from large scale fragmentation of woodland within the landscape matrix to small scale fragmentation of communities within woodland.

Rodríguez-Loinaz *et al*. (2012) found that in general fragmentation had a negative effect on plant species richness and diversity, but not all plant species responded in the same way. The smaller the patch size and the greater the distance between patches (patch isolation) the lower the species richness and diversity. This was particularly true for woodland specialist species, such as ferns, which have very specific habitat requirements usually only found in the interior of large, mature woods. Once woodland specialist species have disappeared from a patch the isolation of the patch becomes the main factor controlling the recruitment of woodland specialists back into the woodland. This theory is also supported by the work of Gonzalez-Vero *et al*. (2012) on the recruitment of myrtle (*M.communis*) to small woodland patches. They found that the smaller the woodland patch the lower the rate of seedling survival, and that this was associated with habitat impoverishment found within smaller woodland patches. The reduced seedling survival then creates a bottleneck within that habitat for plant recruitment into other patches.

More generalist species are not so affected by spatial isolation as they tend to be more evenly distributed across the landscape matrix and therefore they tend to dominate once woodland species become locally extinct.

The fact that different species respond differently to the effects of fragmentation indicates that the response of an ecosystem to fragmentation is not linear and that there may be ecological thresholds which make the effects of patch isolation greater for some species. Digiovinazzo *et al.* (2010) found that species richness when compared to patch size followed an s-shaped curve and that recruitment of woodland species was highest in patches between 1 to 40 hectares in size. Therefore, they recommend that conservation efforts concentrate on preserving those patches greater than 40 hectares and increasing the size of those greater than 1 hectare as small increases in size can result in large increases of biodiversity. However, they also found that connectivity between patches needs to be high to ensure maximum recruitment of woodland species to isolated fragments of woodland.

It is clear that the distance between patches has some connection to the likelihood of local extinctions occurring. However, few authors have attempted to quantify the level of patchiness required to ensure the persistence of a species. Alados *et al*. (2009) created a mathematical simulation of the destruction of juniper-pine woodland that attempted to resolve this issue. They found that there was a specific threshold of habitat loss for this community (>40%) that should not be exceeded, or extinction of that population was likely, as a result of patch isolation. Whilst the woodland that they studied is not typical of British woodland, the idea of there being a threshold for patch destruction is potentially applicable and needs further investigation.

Two thirds of British macromoths are associated with woodland and native tree species (Fuentes-Montemayor *et al*. 2012), so fragmentation of woodland is likely to have an impact on species composition and species number. Little research has been undertaken in relation to moths as most investigation of Lepidoptera has focused on butterflies because their lifestyle makes them easier to study. Moths are important pollinators and an important food source for other native animals (e.g. bats and birds). Like butterflies, moths have undergone a serious decline in numbers over the last few decades and one of the most important factors in this is thought to be habitat loss and fragmentation. Fuentes-Montemayor *et al*. 2012 found that patch size was directly related to the number of moth species found within a wood, with woodland <1ha showing poor species richness and abundance and woodland >5ha having the highest species richness and abundance. Merkcx *et al*. (2012) also demonstrated a link between woodland size and the abundance species richness of threatened macromoth species in British woodland.

The total amount of woodland within a landscape was also found to be directly related to species number, so even small patches of woodland may be beneficial if they are in close proximity to other woodland. The landscape scales at which this is relevant differed between macro moth and micro moth species. Micro moths are influenced at a much smaller scale (<500m) and macro moths at larger scale (1500m). However, the results for both types of moth indicate that landscape-scale management of woods would be beneficial to all moth species.

Merckx *et al*. (2007) found that butterflies from a fragmented landscape were able to find their way between suitable habitats faster and more efficiently than butterflies from a continuously wooded habitat. This has important implications for woodland that may be fragmented as a result of development, as it is not clear how long the lag time is between a population becoming fragmented and it then gaining the ability to efficiently identify suitable habitat in a fragmented landscape. It is possible that some local extinctions may occur because the population cannot adapt.

Almost all European bat species utilise woodland at some stages in their life cycle, however little research has been undertaken to show how fragmentation of this habitat impacts upon bats. Fuentes-Montemayor *et al*. (2011) found that woodland configuration was the most important landscape characteristic influencing the activity of two species of British bat (*Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*). Bat activity decreased in the study area as the distance between woodland patches increased. *Pipistrellus pygmaeus* in particular was shown to need a well connected network of suitable habitat on a landscape scale of 500m or less in order to capitalise on available resources. Whereas the effects of landscape were significant for *Pipistrellus pipistrellus* at much larger landscape scales (3km). Both species of bat responded positively to landscape heterogeneity suggesting that management and creation of woodland habitat would have a positive effect on these species.

Boughey *et al.* (2011) studied six British bat species and showed that 90% of the 1,129 bat roosts they surveyed were within 440m of broadleaved woodland, which suggests that bats are unwilling to travel much further than this to forage. Furthermore, they demonstrated that bat species benefit if up to 20% of the landscape within 1km of the roost consists of broadleaved woodland. However, none of the species studied showed a relationship between roost location and the size of the woodland patch, indicating that even small stands of woodland may be of value within a landscape matrix. The work of Boughey *et al.* (2011) echoes that of Fuentes-Montemayor *et al.* (2011) in that roost location was shown to be associated with the spatial arrangement of broadleaved woodland. This supports the idea that for bats at least, woodland conservation, management and restoration needs to be viewed from a landscape scale. The ideal in this case is woodland patches less than 440m apart and an increase of broadleaved woodland to 20% in the kilometre surrounding a roost.

Overseas, other authors have demonstrated a similar association between patch size and species diversity. In Mexico, González-Oreja *et al*. (2012) showed that the larger the size of an area the more diverse the assemblage of birds found. Furthermore, the presence of saproxylic beetles in small woodland patches in Sweden has been shown to be dependant on the area of oak dominated woodland in the kilometre surrounding the study site (Franc *et al.* 2007). This indicates that qualities in the surrounding landscape have an impact on local species richness within an area, and not just the size of the stand being investigated.

Woodland can be fragmented on a smaller scale by the development of transport corridors through them, which results in linear clearings being created. The width of such structures may be relatively small but various studies have shown that some species cannot adapt easily to their presence. A review of linear clearings in tropical forests (Laurance *et al*. 2009) clearly shows that many woodland species will avoid even narrow clearings (<30m wide) and that those species that do not avoid the clearing are then susceptible to roadkill. This research is backed up by studies of both European and British species indicating that work from overseas can be extrapolated to a British context. Kerth and Melber (2009) have shown that busy motorways can restrict habitat accessibility for some forest dwelling bat species, but this effect is dependant on the bats foraging ecology. Bechstein's bats (*Myotis bechstenii*) which glean insects from vegetation do not in general cross the motorway when foraging or when switching roosts and those bats whose roosts were close to the motorway had smaller foraging areas than those further away from the motorway. Barbastelle bats (*Barbastella barbastellus*) which forage in open spaces, were less affected by the presence of the motorway and did cross it when foraging and switching roost location. The size of the road and/or traffic volume, rather than the presence of a road appears to be the fundamental limiting factor in the case of Bechstein's bats as narrower roads with a closed canopy overhead don't appear to restrict the movement of this bat species.

However, bats with roosts close to the motorway foraged within 50m of it, suggesting that disturbance from noise or lights are not the factors preventing them from crossing it.

Bats are not the only mammal shown to be affected by fragmentation of woodland. Red squirrels (*Sciurus vulgaris*) are also affected by fragmentation, but the effects are sex specific (Verbeylen *et al*. 2009). Female red squirrels are affected by patch quality, but male red squirrels are affected by patch size. This indicates that female squirrels are more resistant to fragmentation than male squirrels. The existence of sex specific responses to fragmentation makes the prediction of the effects of fragmentation on a population harder to determine.

McKenzie *et al* (2011) working in rural Northern Ireland showed that if broadleaved woodland habitat was within 50 metres of an existing building then the likelihood of it being built on was greater than for other habitat types the same distance from existing buildings, even though broadleaved woodland only formed a small percentage of the rural landscape studied. This indicates that in Northern Ireland at least some habitat types are preferentially used as building sites despite potential constraints to building.

Woods are often important areas for recreation, but this can cause small scale fragmentation as a result the creation of pathways through the wood. A study of urban forest fragments in Finland by Malmivaara-Lämsä *et al*. (2008) found that the population within 1-2 km radius of the fragment correlated positively with the area of paths in the forest and that on average 5% of the forest was made up of paths. They found that the soil microbial community was negatively affected 1m on either side of each path, resulting in changes to nutrient cycling within the forest and suggest that these affects should be taken into account when wanting to preserve a well-functioning forest soil microbial community.

4.3.1. Edge effects

The more fragmented a landscape becomes the greater the number of edges that are created. Edges are associated with higher temperatures and wind speeds, greater disturbance, increased water loss, the presence of non-woodland species all of which impact on the ecology of the woodland concerned.

Herbst *et al.* (2007) showed that evapotranspiration from trees was significantly higher at edges than in the interior of the woodland. This edge effect can dominate the water use of small woods because the higher the amount of transpiration the lower the rate of groundwater recharge. Therefore, the smaller the wood (and therefore the greater the edge to interior ratio) the lower the soil water recharge rate is expected to be. Changes to transpiration rates are not equal across all tree species with ash being more affected than oak, field maple and hawthorn. The effect of increased water loss only becomes negligible for woods greater than 100 hectares, so it is not unreasonable to assume that this effect impacts on the majority of British woods.

Increased exposure to solar radiation at woodland edges decreases soil moisture, due to increased rates of evapotranspiration as demonstrated by Herbst *et al.* (2007). The decrease in soil moisture leads to decreased decomposition of leaf litter, which in turn leads to reduced nutrient cycling within the wood (Riutta *et al*. 2012). The decrease in soil moisture at the edges did not appear to have an impact on the presence of macrofauna so it is hypothesized that it is the micro and meso fauna that are fundamentally affected by the decrease in moisture. The study by Riutta *et al.* (2012) was undertaken during a wetter than average summer and yet they were still able to demonstrate that decreased moisture availability at woodland edges impacted on leaf litter decomposition. Work in Finland by Malmivaara-Lämsä *et al.* (2008) supports the theory that decreased moisture at woodland edges leads to decreased microbial activity. They found that microbial communities were altered up to 50 metres from the edge with the biggest changes being found in the first 20 metres. These changes were strongly associated with decreased soil moisture, and led to decreased nutrient cycling.

The structure of the edge has also been shown to be an important factor in controlling how deep into a woodland the edge effects penetrate. Hamberg *et al*. (2009) used the abundance of understorey vegetation as a measure of the edge effect. They showed that at open edges the effect penetrated up to 30m, but this was greatly reduced for closed edges. The more complex an edge e.g. one with an abundance of shrubs and saplings, the weaker the effects of wind, light and heat on the edge. By studying the species composition of edges separately from those of the interior Gonzalez *et al.* (2010) found that the greater the proportion of edge to the interior the more likely the interior was to be colonised by light demanding species (which are more commonly found in edges). Therefore the amount of edge to interior, as well as the structure may be impacting on the species composition of the woodland as a whole. Furthermore, their work also indicated that current species richness may be linked to past patch shape due to a lag time between changes in shape and species response.

These studies indicate that increases in temperature expected as a result of climate change are likely to have large impacts on the moisture conditions at woodland edges and consequently have an impact on the woodland ecosystem as a whole. As the majority of woods in the UK are small much of the habitat within them is affected by its close proximity to the edge, and edge habitat actually forms a large percentage of the woodland present in a landscape.

Edges may also provide less than perfect habitat for woodland fauna due to other factors such as increased predation. Bird nest predation has been shown to be higher at woodland edges compared to woodland interiors (Ludwig *et al.* 2012). However, edges have also been shown to contain a higher density of nests that the woodland interior, which indicates that edges may effectively form an ecological trap for some bird species. Furthermore, Orłowski (2008) found that whilst woodland edges and hedgerows near roads are attractive habitat for many bird species, bird mortality close to roads is also high as a result of bird strike. This was particularly true for woodland species. However, in order to reduce the impact of roads on bird mortality he controversially proposes that treeless spaces are left either side of road developments and that any spontaneous regrowth of vegetation is cleared.

5. Invasion by non-native plant species

The original 2008 report specifically stated that nine of the twelve development types identified could promote invasion of ancient woodland by non-native plant species. However, if the mechanisms by which non-native species are able to gain a foothold in ancient woodland are understood it could be argued that all forms of development can result in changes which lead to this type of invasion.

Development adjacent to or within ancient woodland results in disturbance to the soil which can provide ideal conditions for non-native species to establish themselves. Disturbance to the soil releases nutrients and this can favour species not normally seen in British woods. In addition the creation of new edges, the removal of trees and understorey increases light levels and again this can favour the growth of non-native species. Housing developments close to woodland may also act as reservoirs for exotic species that then "escape" the confines of the garden. Open edges around a woodland may also facilitate the invasion of the interior by non-native species due to increased light levels and wind speeds (which may aid dispersal). To control this affect Hamberg *et al.* (2009) recommend avoidance of the creation of edges near botanically sensitive areas and that the length of edge is minimised.

Some non-native species already have a large presence in British woodland, for example rhododendron. However, wholesale clearance of non-native species is not necessarily the best way to resolve existing invasions of non-native species. Hewson *et al*. (2011) showed the occurrence of nuthatch, great spotted woodpecker, chiffchaff and dunnock was strongly associated with the presence of rhododendron in the understorey, which is at odds with previous studies and may require further investigation. In Australia, Stagoll *et al* (2010) showed a similar relationship in that the presence of blackberry (classified as a non-native noxious weed in Australia) in eucalypt woodland actually increased the presence of certain native bird species because it was providing foraging, nesting and sheltering opportunities that would not otherwise have existed. Therefore, a good understanding of the contribution of a non-native species to an ecosystem is required before vegetation clearance takes place.

Overall developers should be clear that soil disturbance and vegetation clearance can create conditions that not only have a negative effect on native species by increasing light levels and nutrient availability but that this may then favour non-native species. Planting schemes associated with developments close to ancient woodland should consist of native species to prevent escapes of non-native species into adjacent woodland.

5.1 Recruitment of non-woodland plant species

Woods are not only degraded by the presence of non-native species such as rhododendron but by the presence of non-woodland species. This is an issue not widely covered in the original report, but one that deserves consideration as non-woodland species can often out compete woodland species if the conditions are right. Hamberg *et al*. (2010) showed that trampling on paths cleared vegetation and revealed the hummus layer underneath. This in turn provided ideal conditions for non-woodland species to move from the woodland edge into the interior, because of increased soil pH and nutrient levels associated with the disturbance along the path. In woodland with high levels of trampling there was a significant change in species composition from woodland species to species more typical of open habitats.

5.2. Cumulative effects

By their very nature it is hard to quantify cumulative effects because the mechanisms behind them may not be clear and they may take place over long periods of time. The highly fragmented nature of the landscape of the British Isles means that species ability to respond to change is often restricted because other suitable habitats either do not exist or are so widely scattered that many species are too isolated to be able to move. This leads to local extinctions which then reduces the recruitment of species to more suitable habitats.

Climate change is a prime example of a cumulative effect that is hard to measure but may have a negative effect on ancient woodland. Changes in ambient temperature, precipitation levels and frequency of extreme weather events will all impact on a species ability to occupy a certain habitat. Every species has a climatic niche and climate change can result in this niche moving. Therefore, to prevent extinction a species will need to move along with its climatic niche. The fragmented nature of ancient woodland in the UK means that there is often a lack of functional connectivity between landscape types and this will prevent species moving to areas more suitable to their needs. Work in Scotland by Gimona *et al*.(2012) proposes the creation of wide-scale dispersal pathways along existing climatic gradients in order to facilitate the movement of species in the face of a changing climate. Furthermore, Gimona *et al*. (2012) suggest that climate change will lead to increased requirements for land for agriculture and that this could indirectly be responsible for the loss of existing woodland. In order to mitigate this they propose that any new stands of woodland should not be planted on land that may be earmarked as prime agricultural land in the future.

Changes in plant species composition of a woodland as a result of climate change is difficult to predict because different species will respond over different time scales. This in turn makes it difficult to determine how associated plant and animal assemblages will react and adapt to these changes. Climate change may result in unpredictable changes in the species pool of a region (Hewson *et al.* 2011) and therefore maintenance of habitat heterogeneity is vital to provide future habitats for species to occupy.

Woodland edges are likely to be at risk of increased susceptibility of desiccation as a result of predicted changes to climate (Riutta *et al.* 2012). This in turn will impact on the whole ecosystem process as nutrient cycling is reduced due to decreases in leaf litter decomposition.

5.2.1. Roads and urban development

Cumulative effects from roads and urban development include a combination of noise, light, increased mortality due to car collisions and barrier effects preventing normal movement of species. A study of Spanish bird communities (Palomino and Carrascal 2007) showed that the closer a bird community is to urban areas the more homogenised it becomes, and that this homogenisation can spread into adjacent habitats. In order to control this effect, and unlike many similar studies, they have quantified buffer distances for both roads and urban areas to reduce the impact of disturbance on woodland species (330m for roads, 400m for urban areas).

Cumulative effects from housing development are not just limited to high density housing schemes, but are also seen in more rural low density developments. As has already been shown different species react differently to the same types of development. The construction and presence of housing is often associated with bird species considered to be urban adapters, which can tolerate disturbances associated with human residential development. However, there are other species known collectively as urban avoiders, which can tolerate only low levels or indeed no disturbance of this type. Work by Merenlender *et al.* (2009) in California showed that at even very low housing densities (1 house per 4 hectares) bird communities were dominated by species considered to be urban adapters. Ground nesters were particularly negatively impacted upon, probably as a result of the presence of domestic predators such as cats and dogs.

Work by Gagne and Fahrig (2010) recorded a decline in abundance and species richness of woodland birds as the density of housing increased. However, their results supported those of Merenlender *et al.* (2009) because they suggested that a clustered housing development actually has less impact on a population of woodland breeding birds, than a more dispersed development. Their work did not quantify the size of undeveloped land required around each development to maintain populations of more sensitive species, and this is an area that needs further investigation.

The work by Merenlender *et al.* (2009) and Gagne and Fahrig (2010) on the effect of housing densities highlight the importance of protecting core woodland areas from even small levels of development.

Several authors found that a disturbance was often associated with areas that had already been disturbed (Linke & McDermid 2012), for example an area had a road built, and then houses were added at a later date. This type of cumulative disturbance pattern is common in multi-use landscapes and results in highly disturbed patches within the landscape matrix. The fragmentation effects of these patches on the ecosystem are not well understood as each disturbance is often viewed in isolation from existing disturbance.


WTPL/David Rodway

6. Mitigation and management solutions

To ensure that ancient woodland is protected and enhanced it is vital to have a good understanding of what is valuable in the landscape, not just the woodland in question BEFORE any development takes place.

The presence of individual scattered trees within a landscape may provide important habitat for woodland birds (Stagoll *et al.* 2010) and so should be preserved. Furthermore, active management of these scattered trees within a landscape could help to improve connectivity and function of any surrounding woodland areas. Merckx *et al*. (2007) identified hedgerows and copses with tall trees within the landscape matrix as being important markers for butterflies to find their way from one suitable habitat to another. The mechanism by which butterflies use these markers is not clear (visual, olfactory) but the higher these components were the more important they appeared to be. Therefore retention or creation of these types of structures within a landscape is thought to be important to increase connectivity between landscape types. Studies of individual forest remnant trees in Australia (Bennett *et al*. 2009) showed that they are often associated with genetically diverse soil fungal populations, and as such provide important resource islands that may help maintain landscape heterogeneity.

Tree regeneration should be actively encouraged in areas where disturbance has taken place, rather than just preserving what is left. Not only will this ensure more trees in the future but it will greatly improve the habitat available for other animals and plants. Work undertaken in Australia (Stagoll *et al*. 2010) has shown that the presence of regenerating woodland trees is positively correlated with a decrease in disturbance and an increase in the presence of woodland specialist bird species.

Patch size has been shown to be positively linked with species diversity and abundance, (Gonzalez *et al*. (2010), Digiovinazzo *et al*. (2010), Gonzalez-Varo *et al.* (2012)). This species-area relationship (SAR) is a useful tool but must be used with caution as not all species respond to fragmentation in the same way and there may be a lag between the disturbance occurring and the species composition of an area changing. Furthermore, from a practical point of view the highly fragmented nature of British woodland means that restoration of woodland on a landscape scale is unlikely to be feasible. The spatial arrangement of patches of any size across a landscape has been shown to be important to facilitate movement and recruitment of species across a landscape so restoration of even small patches may prove valuable.

Several studies have indicated that the maintenance of a structurally complex habitat is vital for providing the highest quality habitat for the greatest number of species. A comprehensive study of 28 bird species across 2668 stands of woodland in Britain by Hewson *et al.* (2011) showed the highest number of woodland bird species in woodland with an understorey compared to woodland with no understorey. Their in depth study of habitat characteristics clearly demonstrated the importance of habitat heterogeneity for maintaining bird diversity, but also makes it clear that different species require different combinations of plant species so no one woodland can benefit all species equally. Gazol and Ibanez (2009) found that woodland with a diverse canopy had a more heterogeneous understorey in terms of species cover and diversity. In the UK, habitats composed of a high number of tree species have also been shown to be beneficial to British moth species (Fuentes-Montemayor *et al*. 2012) and work by Merckx *et al.* (2012) also supports the idea that specifically managing woodland to promote a complex structure is beneficial to British macromoth species. Stagoll *et al* (2010) in Australia has shown a direct relationship between a "messy" environment with plenty of leaf litter, logs and a dense understorey and the presence of woodland bird species. The presence of litter has also been shown to positively correlate with tree health (Close *et al.* 2008) as it effectively acts as a mulch and prevents evaporation from the soil.

Heyman (2010) also showed that total clearance of the understorey had a negative effect on the presence of woodland birds, but that clearance of up to 54% of the understorey in a patch does not have a negative effect. This is potentially important for woodland being managed primarily for recreation purposes.

Structural complexity is also important at the edges of the woodland in order to reduce the impact of edge effects. Edge effects have been shown to penetrate at least 30m into a coniferous woodland with open edges (Hamberg *et al*. 2009), and this effect has shown to be even greater for broadleaved woodland. The smaller the woodland the greater the potential for edge effects so the provision of a complex edge structure will be important for reducing the penetration of these effects into the interior of the woodland. Edges created as part of a development tend to be very straight and the recovery time needed for these edges to regain a more natural sinuosity needs to be considered. Work by De Chant *et al*. (2010) investigating the impact of housing development on woodland has shown that on average it takes 7 years before any changes in edge structure can be determined and that a total of 14 years is needed before an edge will advance and increase in sinuosity. These changes are thought to be a combination of natural woodland responses to edge creation and actions taken by homeowners to further develop the woodland edge.

The use of passive management techniques such as fencing to prevent impacts of housing developments on neighbouring woodland should also be considered. McWilliam *et al*. (2010) reviewed the effectiveness of such techniques on woods in Canada. They found that boundaries needed to be carefully designed clearly delineate private from public land-uses. Even with this type of control in place encroachment activities continued to impact at the woodland edges and up to 50m into the interior of the wood. They propose the planting of buffer strips 50m wide to protect the more sensitive interior of the wood.

It should not be assumed that all conservation schemes are equally beneficial to all species. Fuentes-Montemayor *et al.* (2011) found that agri-environment schemes may not benefit some species of bat as the schemes are applied to relatively small areas and the bats studied are affected by landscape composition at larger scales. Therefore, they suggest that a landscape scale management approach is needed to effectively contribute to the conservation management of bats.

Quine and Watts (2007) reviewed a spatially targeted woodland planting scheme implemented in the Isle of Wight and compared it to planting schemes that were more concerned with expansion of individual woods. They found that the spatially targeted planting had been more successful in achieving potential biodiversity benefits, than those planting schemes that were site specific. This provides further support to the theory that in order for woodland restoration to be successful it has to be implemented at a landscape scale. The findings of Quine and Watts (2007) are supported by a study from Australia (Lindenmeyer *et al.* 2010) that also found for restoration planting to have maximum success for woodland birds (in terms in increasing species number and diversity) the vegetation surrounding the new planting needs to be taken into consideration. If the surrounding matrix contained existing patches of native species the size of the new planting was no longer significant. Lindemeyer *et al.* (2010) concluded that if the aim of a restoration project was to increase bird species and diversity then there is value in targeting the planting to areas where there is existing native vegetation. They also found that the age of a planting was not significant, but that the complexity of the planting which is often associated with age but not exclusively so, therefore lending weight to the argument that overall structural complexity is important.

Brunet *et al*. (2011) also found that levels of fragmentation in a landscape impacted on the colonisation of newly planted woods by woodland specialist species commonly found in the understorey of mature woodland. The more fragmented a landscape the slower the rates of colonisation and even under ideal situations a minimum of 60 years was needed for new plantations to attain the species diversity seen in core woodland. In order to facilitate recruitment of woodland specialist species to new plantings Brunet *et al*. (2011) recommend that the planting should be as close to existing woodland as possible and that the pH of the soil should be as close to the existing woodland as possible. Additionally, if the new woodland is isolated then planting of understorey species may be needed as generalist species tend to persist and increase over time in these woods, whereas woodland specialist species are able to outcompete generalists in new woods that are proximate to mature woodland.

Whilst the presence of deer in woodland is not specifically related to development their presence may hamper the restoration of existing woodland and if present they should be considered in any management plan. Browsing and trampling by deer alters woodland structure by clearing large parts of the understorey, which may be vital habitat for other species. Buesching *et al*. (2011) demonstrated by the use of deer exclosures that browsing has a negative impact on bank vole populations which favour dense undergrowth, which in turn benefits the population of woodmice, which can adapt to more open woodland. However, denser undergrowth of the type that occurs when deer are excluded increased the total carrying capacity of the habitat for both small mammal species, probably due to the increased amount of food available. The presence of a healthy small mammal population within a wood is important as they form a food source for other woodland predators.

Birds are also impacted by the clearance of the understorey from deer browsing activity. A study of 16 British bird species (Holt *et al.* 2011) showed no positive associations between deer browsing and bird populations. Changes to the structure of the understory led to decreased amounts of food, suitable nesting sites and an increase in predation which all combined to impact on bird breeding success. Given the decline in a number of British woodland bird species, the exclusion of deer from parts of woodland earmarked for restoration may be required to enable woodland regeneration to take place.

Some woodland dwelling bat species have been shown to successfully make use of underpasses to cross motorways which would otherwise restrict their movement between roosts and when foraging (Kerth and Melber 2009). This appears to be particularly important for bats that forage close to vegetation or the ground and do not like crossing open spaces, for example Bechstein's bat. Therefore the provision of underpasses for bats should be considered during the construction of motorways or other transport corridors that fragment woodland habitat.

Some woodland bird species have been shown to react to low levels of development in the same way as much denser levels of development (Merenlender *et al.* 2009). Therefore an understanding of how individual species are likely to respond to a development is needed. The strong reaction of some woodland bird species to development has led some authors (Merenlender *et al.* (2009), Gagne and Fahrig (2010)) to propose that high density housing over smaller areas is actually preferable to low density housing developments in more rural areas.

Prevention of some of the cumulative impacts from housing can be as simple as putting a fence between the housing development and the woodland. Work by McWilliams *et al.* (2010) recorded different types of encroachment into woodland from nearby housing, including waste disposal, woodland recreation, garden extension and invasion by garden plants. The mean distance of encroachment was 16 m into the woodland and 95% of all activity was measured within 34m of the woodland edge. They found that if the woodland was separated from the housing by a grass strip, there was a tendency for homeowners to incorporate part or all of this strip into the garden.

If fencing was used, and the fencing belonged to the homeowner, then gates were often put into the fences to allow homeowners unrestricted access to the woods. If the fences remained in the ownership of the local authority the likelihood of gates being installed was reduced. Combinations of two or more restrictive elements (e.g. a fence and a grass strip) were not found to be anymore effective than one element on its own. The most effective way to reduce encroachment from housing developments is to minimise the length of woodland edge exposed to residential land use by designing the development perpendicular to the woodland rather than parallel to it. Planted buffer zones may also be effective in reducing the impact of this kind of development.

6.1. Buffer zones

In producing this report, a number of papers were reviewed that proposed buffer zones of various sizes to protect woodland from the impacts of different sorts of development. The following table summarises those references which proposed buffer zones as a means of mitigating the effects of development.

Table 3 Buffer Zones

Size of buffer	Reason for buffer	Reference
15m (minimum)	To protect woodland from the effects of development such as run-off, noise, damage to tree roots etc. There is no discussion about how the figure of 15m was reached. (UK)	Standing Advice for Ancient Woodland, Natural England, 30 May 2012 (taken from Bolnore Village appeal decision 2007)
50m	To protect woodland from encroachment activities from adjacent housing, such as waste disposal, garden extension. This paper specifies that the buffer should be wooded. (Canada)	McWilliam *et al.* (2010)
100 – 200m	To protect plant species from the effects of vehicle emissions from roads (UK).	Keely *et al.* (2008)
300m	To protect woodland bird species from the effects of roads (Spain).	Palomino and Carrascal (2007)
400m	To protect woodland bird species from the effects of urban development (Spain).	Palomino and Carrascal (2007)
?	Lightly wooded buffer around existing woodland to protect the core from impacts of development (UK)	Merkx *et al.* (2012)

Not all papers which proposed buffer zones as a means of mitigating the effects of development on woodland specified a size for the buffer. For example Merckx *et al.* (2012) recommended that a buffer zone of lightly coppiced woodland be planted around dark cores of existing woodland to protect that habitat from the more open matrix surrounding it. This management technique is proposed to specifically benefit threatened specialist British macro moth species, whilst providing improved habitat for other more generalist species, but the size of buffer required to achieve this is not stated. The lack of quantitative information about size and effectiveness of buffers is a concern, and is an area that requires further research.

7. Knowledge gaps and research priorities

In compiling this report it became clear that there are a number of gaps in the research of the effects of development on woodland. Most of these were also raised in the original report and that contains a comprehensive list of areas for further research. The lack of long-term studies is an ongoing issue and this is probably linked to the way in which research is funded.

7.1. Studies of British woodland

Out of the 59 papers reviewed for this report only 14 (24%) specifically related to Britain. Furthermore, the scope of this report was to look specifically at the impact of development on ancient woodland, but not one paper explicitly dealt with this environment. Either it is accepted that results from studies of existing broadleaved woodland (ancient or not) are applicable to all woodland or there is a massive knowledge gap relating specifically to ancient woodland.

7.2. Buffers

Many papers reviewed for this report detailed the need to put buffers in place to prevent impacts of development on adjacent woodland. However, only four papers quantified the size of buffer required, and only one looked at the effectiveness of buffers. There is definitely a requirement for more research into appropriate size and construction of buffers and then additional research to determine how effective these buffers are once they are in place. Without this type of information it may be difficult to convince developers of the validity of this type of mitigation measure.

The Trust has been involved in a number of planning decisions where a buffer zone has been required as part of the conditions of the development. A comprehensive list of these projects and then a review of the type of buffers constructed would provide useful practical information of the sort that is currently lacking.

7.3. Fungi

The importance of arbuscular mycorrhizal fungi in maintaining a healthy ecosystem is becoming better understood. However, this is a relatively recent area of research and it was not touched upon in the original report. Only a few papers covering this subject were found in preparing this report and the impact of development on this part of the woodland ecosystem certainly requires further investigation.

7.4. Climate change

Several of the papers reviewed for this report touched on the subject of climate change, and its impact on woodland. There appears to be a general consensus that increases in temperature is likely to exacerbate edge effects. In addition, changes to temperature may also result in a species climatic niche moving, and this could result in local extinctions if the species is unable to move with its niche. Further work is required to try to predict the effects of climate change as this could help identify gaps in the connectivity of woodland across the landscape matrix as a whole.

7.5. Fragmentation across the landscape

A lot of papers reviewed for this report dealt with the effects of fragmentation on woodland. However, not many tried to quantify the levels of fragmentation that a species or assemblage could tolerate, although a number suggested that there were thresholds past which ecosystems could not easily recover. It is not unreasonable to assume that different species may have different thresholds and further work is needed at a species level to determine what these are. This would then help in identifying which woods are more likely to be at risk of degradation because of their isolation.


WTPL/Ilene Sterns

8. Recommendations for survey and monitoring protocols

The original report provides detailed methodology for surveying and monitoring woodland before and after development takes place. The objectives identified for surveying and monitoring are as follows;

- Identifying individual effect types from individual developments on individual woods;
- Identifying impacts of cumulative effect types from individual developments on individual woods;
- Identifying impacts of individual effect types from cumulative development on individual woods; and,
- Identifying impacts of cumulative effect types from cumulative development on individual woods.

When undertaking monitoring it is important that a baseline survey is undertaken to identify what exists in the landscape before any development occurs, and to determine what is special about that particular woodland. The links between the woodland and any neighbouring landscape features also need to be understood. This is important because the woodland in question may form an important linkage between other woodland remnants in the surrounding landscape. Once development has taken place monitoring is required to determine what if any ongoing effects the development has. Furthermore, the effect of other development in the surrounding area may need to be taken into account as disturbance is often autocorrelated.

The length of time over which this type of survey needs to be conducted over is not clear as there is little research in this area, but given the slow response time of many long-lived species to disturbance the longer the better. It may be difficult in reality to ensure that surveys are carried out over long periods because it is not clear who would be responsible for the data collection. This may be an area in which interested parties such as non-governmental organisations, educational institutions or other experts could work in partnership with developers.

8.1. Specialist species versus generalist species

Species richness at a study site is often used as an indicator of the value of a habitat, with those habitats with high species diversity considered to be of the most value. Furthermore, the presence of one or more woodland indicator species is often used as a measure to show that an environment is healthy. However, it is becoming apparent that this may not always be the case. As pristine habitats are degraded and fragmented, species that do not have very specific habitat requirements and can adapt to many different types of habitat will move in. However, more specialist species may persist, albeit at lower numbers. This can result in a moderately disturbed habitat containing higher species diversity than a very disturbed habitat or perversely an undisturbed habitat. Differentiating between specialist species and generalist species may be necessary to understand the effects that development is having on an ecosystem (Merenlender et al. 2009).

Niell *et al.* (2007) showed this effect when studying butterfly community composition in Californian oak woodland that was affected by rural residential development. They found overall species richness was highest at sites with only a moderate presence of oak woodland, because there was a large overlap of generalist and specialist species at these types of site. They propose that the presence of generalist species at a site may be a better indicator of ecological change taking place, than the decline of specialist species. Work by Rodríguez-Loinaz *et al.* (2012) also supports this conclusion as they showed that both patch size and patch isolation had a definite effect on species richness and diversity of woodland specialist species, but that this wasn't so clear for total species richness and diversity.

In Spain, Palomino and Carrascal (2007) demonstrated that bird species richness near urban developments was similar to non-urban areas, but it was dominated by urban-adapter species such as corvids (a 10 fold increase in this group was seen within 190m of an urban area). However, species abundance increased with increasing distance from urban areas and roads, particularly for more specialist species.

9. Conclusions

The twelve development types identified in the original report are associated with five effects. These effects are not mutually exclusive and may occur in combination with one another, which can make assessing the impact of each difficult. In the four years since the original report was published further research has been conducted into the impact of development on ancient woodland. However, huge gaps still exist in our understanding of the ecology of woodland and how it affects and is affected by the surrounding landscape. Some areas, such as fragmentation and edge effects, are well researched, whereas others, such as the effect of anthropogenic lighting or chemical effects from specific industries, are not. New areas of research have also been identified, such as the importance of fungal mychorrhiza within a woodland ecosystem, and this further complicates our understanding of the impacts of development on woodland. Woodland now makes up such a small part of our landscape that even small losses may have irredeemable impacts on the flora and fauna found in an area. Furthermore, it is not an easy habitat to replicate as many of the species that make up ancient woodland are long-lived and slow growing, and do not respond positively to any disturbance.

Woodland needs to be viewed from a landscape scale and not in isolation. The highly fragmented nature of the British landscape means that the removal of even a small part of woodland may have impacts on other pieces of woodland nearby. Equally the isolation of some woodland remnants means that efforts to restore them and provide connections to other similar landscape types should be a priority. If each woodland area is considered in isolation, rather than as part of a larger matrix of landscape types then important patterns of connectivity could be missed. A large number of the papers reviewed for this report stress the importance of valuing small patches of woodland or even individual trees as they may have an important function within the landscape matrix as a whole. Historically, emphasis has been placed on improving and conserving larger areas of woodland, but this may not necessarily be the most effective way of protecting woodland and the species that use this type of ecosystem.

Climate change may also become a more significant problem in the future as even small rises in temperature exacerbate edge effects, such as increased evapotranspiration. The effects of climate change plus isolation of woodland within a landscape may cause local extinctions of species that cannot move to more suitable habitats. However, the cumulative effect of climate change with other forms of disturbance can be hard to quantify and therefore will be difficult to monitor.

Many studies reviewed for this report provided evidence that the more heterogeneous a woodland's species composition is then the more beneficial it is to other species. Plant species appear to be able to disperse more easily in this type of environment and fauna also appear to thrive more easily. Structurally complex woods also have structurally complex edges and this decreases the distance in which edge effects penetrate into the interior of the wood. The more isolated a woodland patch is the less likely woodland specialist species will be recruited into it, and this applies to new plantings and existing woods. Generalist species can outcompete woodland species in this situation and woodland specialists may need to be artificially introduced to these areas.

Many papers suggest the use of buffers as a means of protecting core woodland areas, but very few provide quantitative figures for how big a buffer should be. Furthermore, none reviewed for this report discussed what form the buffer should take. This is an area that definitely requires more research.

Overall the papers reviewed for this report suggest that increasing connectivity between woodland patches is vital, as is decreasing the amount of edge. Furthermore, ensuring that woodland interiors and edges have highly complex structures improves the quality of the habitat they provide. The size of the woodland is not necessary an indicator of its ecological importance and therefore all woodland patches, or even remnant trees, should be viewed as being a potentially important resource within a landscape.

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