Impacts of nearby development on the ecology of ancient woodland

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Notice to Readers

This report is based on the information collected during the period of study and within the parameters of and resources available for the project. We cannot eliminate the possibility of important information being found through further investigation. Reference to sections of text or particular paragraphs of this document taken out of context may lead to misrepresentation.

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Contents

1 Executive summary

Ancient woodland dates back hundreds of years and supports more threatened species than any other habitat in the UK. However, only around 550,000ha remains. It is a functionally irreplaceable resource for biodiversity that is also an important part of our cultural heritage.

Ancient woods have been fragmented for hundreds of years and by 1900 only 5 per cent of the UK was covered by woods. Although woodland cover has since expanded to 12 per cent, primarily due to planting of quick-growing conifer crops, the twentieth century saw further attrition of ancient woodland and an unparalleled increase in the intensity of land use between woods. Of the sites recorded on today's ancient woodland inventories, 48 per cent are smaller than five hectares. Therefore, many are very vulnerable to edge effects from surrounding land use.

The importance of ancient woodland is recognised in recent national planning policies across the UK and planning authorities and inspectors increasingly act to prevent its direct destruction. However, the threats posed to ancient woods by nearby development are not so widely appreciated. The aim of this review is to synthesise existing literature on the direct, indirect and cumulative effects of development on nearby woodland, and to relate these effects to ancient woodland in the UK.

Five hypotheses were identified to describe the ways in which nearby development may impact on ancient woods:

- chemical effects;
- disturbance;
- fragmentation;
- invasion by non-native plant species; and
- cumulative effects.

In this context, a systematic search strategy was implemented to provide coverage of as many of the potentially relevant subject areas as possible. Papers were ranked in order of their relevance. Papers whose title, keyword, or abstract fields contained at least some search terms, or literature that describes similar development impacts affecting woodland in Britain, provide the evidence that forms the main focus for this review. Less relevant material has been used where appropriate to substantiate reasonable assumptions. Where literature is not cited, observations are based on the authors' knowledge and experience.

Evidence indicates that nearby development may have substantial chemical effects on ancient woodland associated with:

- transport;
- commerce and industry;
- intensive livestock units;
- energy;
- quarrying and mineral extraction;
- waste disposal facilities; and
- cumulative development.

Impacts from chemical effects include:

- changes to the composition of woodland ground flora;
- reduced tree health;
- wildlife poisoning; and
- loss of soil micro-organisms, affecting nutrient cycling.

Major disturbance can be generated during construction, as well as on an ongoing basis by:

- housing development;
- commerce and industry;
- transport;
- quarrying and mineral extraction;
- leisure and sport;
- military activity; and
- water management.

Impacts arising from disturbance include:

- increased predation;
- reduced breeding success and population viability; and
- altered hydrological functioning or soil structure, leading to tree death and changes in the composition of woodland vegetation.

New development is frequently associated with the destruction or alteration of semi-natural habitats in the vicinity of ancient woods and the creation of large areas of terrain inhospitable for woodland species. Developments that create chemical or disturbance effects that penetrate nearby ancient woods may also effectively reduce them to smaller habitat islands. All types of development may lead to further isolation of ancient woodland:

- increasing distances between favourable habitats that species must cross;
- interrupting natural flows between habitats; and
- sub-dividing populations.

The net impact of developments on fragmentation depends on the existing land cover and land use. For example, while developments that replace or surround valuable semi-natural habitats may curtail movement by woodland specialist species, some of those sited on intensive-arable farmland may have potential to increase connectivity.

Transport and urbanisation, in particular, may create major landscape-scale barriers to movement of woodland species.

The likelihood of ancient woodland being invaded by non-native plant species is increased by a range of factors associated with construction, including:

- soil excavation and movement;
- altered environmental conditions; and
- modified hydrological processes.

Nutrient enrichment from developments, such as transport corridors, intensive livestock units and residential gardens, also increases the risk of non-native plant species invading woodland on an ongoing basis.

Ancient woodland is the recipient of the sum of a wide variety of effects generated by multiple developments. Ecological impacts may not be immediately apparent following project completion and may only be detected after substantial periods of time. For example, species responses may lag significantly behind cumulative fragmentation and landscape-scale change. However, the combined impacts of chemicals, disturbance, fragmentation and invasion by non-native plants are inadequately covered in the published literature.

Potential mitigation measures are described in relation to the various impacts of nearby development on the ecology of ancient woodland. These include:

- avoiding new development close to ancient woodland or creation of new movement barriers between woods;
- the use of Environmental Management Plans pre- and post-construction;
- creation of vegetated buffer zones to reduce chemical and disturbance effects; and
- reducing woodland isolation through targeted habitat creation.

Key knowledge gaps and research priorities are identified and it is recommended that research should focus on examining the cumulative effects of development. The report also proposes simple, cost-effective monitoring protocols for assessing the effects of nearby development on ancient woodland.

Ancient woodland is highly fragmented and is threatened by adverse management, overgrazing, non-native species, intensive land use, pollutant deposition and climate change. It is essential that new development does not further impact upon the functional integrity of this irreplaceable biodiversity resource. It is hoped that this synthesis of information on the impacts of nearby development on ancient woodland will ensure that these are properly considered in future planning decisions.

2 Introduction

2.1 Ancient woodland in the UK

Woodland is considered ‘ancient’ if the land it occupies has been continuously wooded since 1600AD. This threshold date was established because maps and relevant archive information only become widely available from that time (Peterken 1993). As woodland planting was uncommon before this period (Spencer & Kirby 1992), ancient woods are likely to have developed naturally and may be remnants of much older and more extensive woodland (Rackham 2003).

As the terrestrial habitat most representative of original, natural, stable conditions, ancient woodland is home to more threatened species than any other habitat in the UK. This has been documented by the UK Biodiversity Steering Group (1995), showing that broadleaved woodland supports almost twice as many species of conservation concern as any other habitat, e.g. more than twice as many as chalk grassland and almost three times as many as lowland heathland.

Many species with poor powers of dispersal have been identified as characteristic of ancient woodland. A substantial number of vascular plants are associated with ancient woodland to a lesser or greater degree (Hermy *et al.* 1999; Kirby 2006; Kirby & Goldberg 2002; Kirby *et al.* 2006), as are some mosses and liverworts (Stern 1992). The habitat requirements of some epiphytic lichens and saproxylic invertebrates point to even greater ecological continuity (Alexander 2004; Coppins & Coppins 2002).

Ancient woods have high intrinsic value, as sites where the interactions between plants, fungi, animals, soils, climate and people have developed over hundreds of years. As a result, they are functionally irreplaceable and cannot be re-created (Defra 2007; Forestry Commission/Defra 2005; Kirby & Goldberg 2002; Land Use Consultants 2001; Thomas *et al.* 1997; Woodland Trust 2002a). The UK Biodiversity Action Plan (Department of the Environment 1994) is explicit: “Given time, perhaps centuries, new woods may be able to achieve the same level of biodiversity as ancient woodland” but “the full suite of communities and features associated with ancient woodland can never be replicated”.

2.2 Inventories of ancient woodland

As ancient woodland is recognised as a key conservation priority, Ancient Woodland Inventories (AWIs) record sites over 2ha in area in Scotland (Walker & Kirby 1989), England and Wales (Spencer & Kirby 1992) and over 0.5ha in Northern Ireland (Woodland Trust 2007). These inventories are an important management tool in identifying ancient woods that may be at risk. However, the extent and distribution of ancient woods of less than 2ha in Great Britain is unknown (Kirby & Goldberg 2002). Research undertaken in Southeast England suggests that this may represent an additional 30 per cent of the resource in some parts of the country (Westaway *et al.* 2007).

2.3 Extent of ancient woodland

Nearly half the ancient semi-natural woodland (ASNW) which remained in the 1930s has either been cleared for agriculture or converted to plantation (Peterken 1993). Overlay of the AWIs with the National Inventory of Woodland and Trees (NIWT) shows that 44 per cent of Britain's remaining ancient woodland is now plantation on ancient woodland sites (PAWS – Table 2.1) in which the former tree cover has been replaced, often with non-native trees (Pryor & Smith 2002). About two-thirds of this plantation is coniferous or mixed.

Table 2.1. Areas (ha) of ancient woodland, ASNW and PAWS in NIWT (Pryor & Smith 2002)

	England	Wales	Scotland	Total GB
ASNW (ha)	193,460	26,972	64,570	285,002
PAWS (ha)	140,125	24,703	54,725	219,553
Total AW (ha)	333,585	51,675	119,295	504,555
PAWS/AW (per cent)	42	48	46	44

On this basis, the percentage of Britain's woodland cover that is of ancient origin is less than 19 per cent of total woodland cover (10.5 per cent ancient semi-natural woodland and 8 per cent plantations on ancient woodland sites).

2.4 Restoration of plantations on ancient woodland sites

Restoration of PAWS, by removing non-native species, represents the only opportunity to increase the area of ancient woodland with semi-natural characteristics (Pryor *et al.* 2002). Given the area of ancient woodland that has been converted to plantation (almost 220,000ha), restoration has the potential to reverse fragmentation of semi-natural habitats substantially and thereby place woodland biodiversity on a more sustainable footing (Woodland Trust 2000).

Research indicates that in over 80 per cent of PAWS stands there may be substantial survival of species and communities that are characteristic of ancient woodland (Pryor *et al.* 2002). Two-thirds of PAWS in this study had remnant ground flora typical of ancient woodland and more than half contained ancient trees. In 40 per cent of sites assessed there was valuable coarse woody debris still surviving from the ASNW stands felled up to 50 years previously. Pryor *et al.* (2002) conclude that the first priority for restoration of PAWS is to create the conditions in which remnant ancient woodland communities can recover. In most cases, it is suggested this will be best achieved by an appropriately targeted continuous cover system, rather than clear felling, and that retaining some conifers in the long term may be beneficial.

2.5 Threats to ancient woodland

Ancient woods are a highly fragmented resource and are increasingly surrounded by intensive land-use. Only 617 out of a total of approximately 40,000 ancient woods in Britain exceed 100 hectares (one square kilometre) and only 46 ASNWs exceed 300 hectares. Of the ancient woods recorded on the AWIs in Britain, 48 per cent are smaller than five hectares (Woodland Trust 2002b) and only 0.04 per cent of Northern Ireland (543ha) is ancient woodland (Woodland Trust 2007).

Beyond the conversion of ASNW to PAWS and the isolation of fragmented ancient woodland sites, there is a wide range of non-development threats that are relevant to ancient woodland, both ASNW and PAWS. These are summarised in Table 2.2, with examples of references where each threat is identified.

Table 2.2. Non-development threats to ancient woodland

	Cause	Effect	Reference
	Internal threats		
PAWS Management	Continued growth of non-native conifers	Shading out of native trees, understorey and ground flora	(Forestry Commission/Defra 2005) (Pryor *et al.* 2002)
PAWS Management	Forest herbicide use and creation of new roads or tracks in plantation (either current or replanted)	Direct damage to remnant ancient woodland species, loss of semi-natural regeneration	(Pryor *et al.* 2002)
PAWS Management	Clear fell of plantation and replanting/regeneration with non-native conifer, forming a dense thicket	Loss of any mature native trees retained and associated species, as a result of rapid exposure. Extraction damage to plants and soil. Ancient woodland plants out-competed by coarse vegetation. Impacts on associated organisms (e.g. epiphytes, birds, mammals, invertebrates)	(Forestry Commission/Defra 2005) (Pryor *et al.* 2002)
ASNW Management	Lack of active management, where species of temporary and permanent open ground survive that are associated with traditional management practices	Successional changes in woods that were formerly managed and consequent loss of species, e.g. fritillary butterflies in lowland England	(Forestry Commission/Defra 2005) (Hopkins & Kirby 2007) (Natural England 2008)
ASNW Management	Unsympathetic management, including removal of veteran trees for reasons of safety and/or tidiness	Loss of species diversity, lack of continuity of dead wood habitat and loss of species dependent on old trees	(Forestry Commission/Defra 2005) (Kirby *et al.* 2005) (Natural England 2008)
Threats to all ancient woodland types	Overgrazing, particularly by deer in the lowlands and sheep in the uplands	Decreasing structural and species diversity, impoverished ground flora and reduction in natural regeneration	(Fuller *et al.* 2007) (Forestry Commission/Defra 2005) (Natural England 2008) (Perrin *et al.* 2006) (Pryor *et al.* 2002)
Threats to all ancient woodland types	Rhododendron	Shading out understorey, regeneration and ground flora diversity	(Cross 1981) (Dehnen-Schmutz *et al.* 2004) (Forestry Commission/Defra 2005)

Continued overleaf …

	Cause	Effect	Reference
	External threats		
Adjacent land-use	Increasingly intensive land-use in the intervening matrix between ancient woods	Increasing negative edge effects penetrating ancient woods Increasing ecological cost of species movement between ancient woods and other semi-natural habitats	(Bateman *et al.* 2004) (Forestry Commission/Defra 2005) (Gove *et al.* 2007; 2004b) (Haines-Young *et al.* 2000) (Petit *et al.* 2004) (Pryor *et al.* 2002) (Willi *et al.* 2005)
Deposition	Nitrogen deposition arising from multiple sources	Excessive disruption to ecosystem functioning and changes in composition of biological communities	(Dragosits *et al.* 2002) (Forestry Commission/Defra 2005) (Natural England 2008)
Climate	Climate change, including phenological changes, changes in the location of species climatic-envelopes, increasing frequency of extreme weather events and increasing incidence of pests and diseases	Loss of synchrony between species Changes in species abundance and distribution (including arrival and loss of species) Changes in community composition Changes in ecosystem processes	(Broadmeadow *et al.* 2005) (Forestry Commission/Defra 2005) (Honnay *et al.* 2002) (Mitchell *et al.* 2007) (Natural England 2008)

Moreover, these potentially damaging factors do not act independently of one another or of impacts from nearby development. Some of these factors have been shown to combine to alter the species composition of ancient woodland (Corney *et al.* 2008).

2.6 Threats to ancient woodland from development

Development is here defined as activity which is subject to planning control (including development falling within the General Permitted Development Order). Ancient woodland is under threat from a range of development types: housing; transport; commercial and industrial development; intensive livestock units; energy; quarrying and mineral extraction; waste disposal facilities; leisure and sport; military activity; water management and permitted development. The threats posed are analysed in detail in chapter 4.

As only 14 per cent of the UK's ancient woodland is included in Sites of Special Scientific Interest (Langston *et al.* 1998), the protection of such sites relies on an awareness of the value of ancient woods among those operating the planning system (Smith *et al.* 2003). In a study commissioned by the Woodland Trust (Land Use Consultants 2001; Woodland Trust 2002a), 23 per cent of organisations that responded to a questionnaire (including planning authorities, wildlife trusts, the Forestry Commission and countryside campaigning bodies) were aware of ancient woods under threat. The responses brought to light 109 cases across Britain of ancient woods lost to or threatened by development in the preceding few years. Development threats associated with transport and infrastructure appeared to be the most significant (31 per cent of cases), followed by amenity and leisure developments (14 per cent), housing (10 per cent), and quarrying and mineral extraction (six per cent).

During the period 2000-08, the Woodland Trust was made aware of 338 cases where development threatened ancient woodland, involving 822 individual ancient woods. The threat to 456 of these woods remains, 277 have been saved, 21 partially lost and 68 destroyed (Woodland Trust, unpublished). There is a particular concern with regard to ancient woods of less than two hectares, as they are not included on the AWIs and their importance may go unacknowledged by planning decisions and their demise unnoticed.

The case against clearance of ancient woodland for development is recognised in national planning policy guidance for the UK (e.g. HMSO 2005; NAW 1996; PAN 1999) and is increasingly understood and acted upon by planning authorities and inspectors. However, evidence of incremental or insidious effects arising from nearby development is dissipated across the literature and, due to its inter-disciplinary nature, it has not been properly synthesised. As a result, it is less well understood and difficult to access.

2.7 Research objective

The aim of this review is to synthesise existing literature in refereed journals and 'grey literature' (e.g. reports by agencies, NGOs and consultancies) on the direct, indirect and cumulative impacts of development on the ecology of nearby woodland, and relate these effects to ancient woodland in the UK. It is hoped that presentation of information on the impacts of nearby development on ancient woodland will ensure that they are properly considered in future planning decisions, so that ancient woods can be retained, protected and appropriately managed for the benefit of current and future generations.

3 Methodology

3.1 How might ancient woodland be affected by nearby development?

The following hypotheses are intended to describe the ways in which nearby development may impact on ancient woods:

- **Chemical effects**
  The release of chemicals associated with development results in new or altered chemical processes, which may lead to changes in the composition and diversity of soil and plant species communities, as a result of processes such as:
    - Acidification (deposition of chemicals that make soils and tree bark more acid);
    - Eutrophication (an increase in nutrients, usually compounds containing nitrogen);
    - Toxic pollution (chemicals which immediately poison, or accumulate in species).

- **Disturbance**
  Development is associated with factors that cause species to avoid locations (e.g. noise, light, human activity) or that alter woodland physical characteristics (e.g. soil, hydrology) and vegetation, either directly (e.g. trampling) or indirectly (e.g. through affecting species interactions).

- **Fragmentation**
  Development in the vicinity of ancient woods may:
    - Destroy other semi-natural habitats and thereby effectively increase the distance between ancient woods and other suitable habitats for many species;
    - Decrease the probability of species dispersing successfully between woods or areas of suitable habitat by affecting species behaviour and increasing mortality, either directly (e.g. through collision), or indirectly (e.g. through increased predation), or acting as a physical barrier;
    - Increase negative edge effects, thereby reducing the area of suitable habitat for some species, particularly woodland specialists.

- **Invasion by non-native plant species**
  Development provides local sources of non-native plant species, aiding their initial colonisation, subsequent establishment and eventual invasion.

- **Cumulative effects**
  Any or all of the effects associated with development may combine to produce impacts which are more substantial than each of the effects in isolation.

3.2 Literature search

In the context of the hypotheses outlined above, a targeted search strategy was developed to provide coverage of as many of the potentially relevant subject areas as possible. These were divided into three themes (i.e. 'development', 'ecological impact', and 'woodland ecology'), with each containing a range of possible research topics (Table 3.1).

Table 3.1. Theme titles and research topics

	Development	Ecological impact	Woodland ecology
Research topic	Agricultural chemicals	Non-native species	Ancient forest plant species
	Agricultural stock	Chemical change	Animal ecology
	Agriculture	Chemical process	Avian ecology
	Commercial & industrial	Connectivity	Biodiversity
	Energy	Disturbance	Colonisation & dispersal
	Leisure and sport[†]	Fragmentation	Conservation & management
	Military installation	Impact	Context
	Permitted development	pH	Ecosystem function
	Quarrying	Spatial factors	Functional type
	Transport		Genetics
	Waste disposal		Habitat & niche
	Water management		Invertebrate ecology
			Monitoring
			Nutrients
			Plant ecology
			Population & community dynamics
			Response
			Seedbank
			Soil conditions

[†] Pheasant rearing and shooting is not considered in this report

Each research topic (e.g. ‘connectivity’) was addressed by the use of component keywords (e.g. ’corridor’), designed to systematically identify relevant studies; 218 keywords were generated for this purpose (Appendix 1). Searches were then undertaken using keywords in combination with other search terms and a habitat descriptor.

The term ‘forest’ is commonly used in the UK to denote an extensive area of, usually coniferous, trees. It is frequently used in reference to commercial timber management, for which considerable scientific research has been undertaken. The term ‘woodland’ is normally used in the UK to indicate a smaller area of (usually broadleaved) trees and is more frequently used in UK conservation literature. Although ‘woodland’ is a term not peculiar to the UK, elsewhere the term ‘forest’ is commonly used to describe any wooded area. The term ‘woodland’ was the primary descriptor used in this study, with ‘forest’ used on a secondary basis. Although this strategy places a limitation on the international literature sourced for this study, the term ‘woodland’ was assessed to fit most closely with the objective of this review.

To reduce return of sources unrelated to the review, searches were performed using each keyword in combination with the term ‘woodland’, and the relevant research topic and theme title. Where this did not return any results, non-keyword terms were removed in the following order: theme; research topic. If the final combination of keyword and ‘woodland’ did not return any results, ‘woodland’ was replaced with the term ‘forest’. The search hierarchy used to complete the search for each of the 218 keywords is shown in Table 3.2.

Table 3.2. Search 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

3.3 Scientific literature

Information from refereed journals was obtained from four main online databases:

- Web of Science (Thomson Scientific), providing access to current and retrospective information from 8,700 international journals;
- ScienceDirect (Elsevier), a collection of over 1,900 journals;
- Scopus, technical and science literature drawn from over 14,000 titles;
- JSTOR, a digital archive collection of core science journals.

3.4 Grey literature

A range of online national and international databases of grey literature were searched (Table 3.3).

Table 3.3. Description of organisational publication catalogues interrogated

Organisation	Website
Canadian Forest Service	http://bookstore.cfs.nrcan.gc.ca/search_e.php
CEH Library Service Catalogue	http://www.ceh.ac.uk/library/index.html
Commonwealth Forestry Association	http://www.cfa-international.org/other_publications.html
Convention on Biological Diversity	http://www.cbd.int/information/documents.shtml
Countryside Council for Wales: Publications and research	http://www.ccw.gov.uk/publications--research/research--reports.aspx
Defra	http://www.defra.gov.uk/corporate/publications/default.htm
FAO - UN Food and Agriculture Organisation	http://www.fao.org/forestry/en/
Forestry Commission on-line catalogue of publications	http://www.forestry.gov.uk/publications
Google Advanced Scholar Search	http://scholar.google.com/advanced_scholar_search
International Tropical Timber Organisation	http://www.itto.or.jp/live/PageDisplayHandler?pageId=193
IUCN Forest Landscape Restoration	http://www.iucn.org/themes/fcp/experience_lessons/flr.htm
IUFRO	http://www.iufro.org/publications/series/research-series/
Japan MAFF	http://www.maff.go.jp/eindex.html
JNCC	http://www.jncc.gov.uk/page-1482
Lebanon Government (Ministry of Agriculture)	http://www.moe.gov.lb/Reforestation/
Lebanon Ministry of Agriculture	http://www.moe.gov.lb/Reforestation/
Metsähallitus	http://www.metsa.fi/default.asp?Section=1176

Organisation	Website
Natural England publications catalogue	http://naturalengland.communisis.com/NaturalEnglandShop/
NERC Open Research Archive (NORA)	http://nora.nerc.ac.uk/
PROFOR - Program on Forests	http://www.profor.info/publications.html
SNH Publications	http://www.snh.org.uk/pubs/default.asp
South Africa Department of Water Affairs and Forestry	http://www2.dwaf.gov.za/webapp/index.php?page_id=72
Switzerland State Secretariat for Economic Affairs (SECO)	http://www.seco.admin.ch/dokumentation/publikation/index.html?lang=de
Treesearch: US Forest Service	http://www.treesearch.fs.fed.us/
UNEP	http://www.unep.org/publications/
UNFF - Secretariat of the United Nations Forum on Forests	http://www.un.org/esa/forests/documents.html
Woodland Trust	http://www.woodland-trust.org.uk/publications/index.htm
World Agroforestry Centre	http://www.worldagroforestry.org/Library/index.asp
WWF International	http://www.panda.org/news_facts/publications/index.cfm?uPage=2
WWF UK	http://www.wwf.org.uk/researcher/polrepint.asp

3.5 Weighting

The search strategy identified a large body of literature (almost 800 sources). In order to select the most important material, a rank-scoring procedure was used to assign a weight to each publication (Table 3.4).

Table 3.4. Rank scoring system used to weight information sources

Rank	Description
5	Title, keyword, or abstract fields contain all search terms, or paper directly addresses specific development impacts (described by search terms) affecting woodland in Britain
4	Title, keyword, or abstract fields contain some search terms, or paper describes similar development impacts, affecting woodland in Britain
3	Title, keyword, or abstract fields contain only one search term. Paper describes development impacts which apply, but where context (i.e. habitat or species studied) makes the study less relevant to woodland in Britain
2	Title, keyword, or abstract fields contain no search terms, but paper may describe an effect linked to development
1	Paper useful for context only

Papers with rank scores 5 and 4 form the main focus for this review, although less relevant material (i.e. rank scores 3, 2 and 1) has also been used where appropriate. Knowledge gaps are highlighted in chapter 6 of this report.

3.6 Source origin

Some of the material presented in this review is from overseas studies. In many cases, these have been undertaken in analogous environments that are relevant to the UK in terms of both legislative framework and habitat, e.g. woodland in continental Europe. Studies from farther afield (e.g. Canada, USA, South America) have been used to illustrate potential ecological effects that are likely to occur in woodland. It is acknowledged that the extent and scale of such effects may be different in the UK.

4 Development types and impacts

4.1 Introduction

This chapter reviews development types and their potential impacts on the ecology of nearby ancient woodland in the UK. Each development type is addressed in turn with a brief introduction to its scope and scale.

Wherever possible, hypotheses outlined in chapter 3 (including cumulative effects of single development types) are explored using studies ranked 4-5 (see 3.5). In cases where such material is lacking, studies ranked 1-3 have been drawn upon, again where evidence was identified, to support reasonable assumptions. Where literature is not cited, observations are based on the authors' knowledge and experience. T

he strength of evidence and magnitude and likelihood of impacts are highlighted. Where exploration of a hypothesis in relation to one development type is equally relevant to another, it is cross-referenced. Effects of cumulative development (i.e. cumulative fragmentation and urbanisation) are addressed at the end of the chapter. A summary of the evidence is presented as a matrix and discussed in 4.14.

4.2 Housing

This section focuses on the effects of nearby housing development on ancient woodland but is relevant to other types of building development, such as, hospitals, schools, and caravan and mobile-home parks. The wider effects of urbanisation are dealt with in 4.13. Hypotheses in chapter 3 that it is reasonable to assume may relate are described below.

4.2.1 Chemical effects

The chemical impacts of housing development on nearby ancient woodland can be broadly divided into those that occur during construction and ongoing effects. They are often local in comparison to those from larger-scale industrial development. In consequence, they are infrequently reported in the scientific literature.

Building construction involves the storage, creation and use of a range of chemical substances hazardous to the environment, such as petrochemicals, cement dust or liquid swill. Construction waste may be discarded in the vicinity of woodland and hazardous substances unintentionally released or spilt onto soils or adjacent vegetation with immediate impacts and potentially long-lasting effects.

Following building completion and occupancy, a range of ongoing effects may impact upon nearby woodland, such as the use and disposal of pesticides associated with domestic gardening.

The Crop Protection Association publishes annual statistics on sales to each sector of the UK pesticide market based on their membership. In 2007, 3,395 tonnes of pesticide active ingredients were sold for garden and household use in the UK., including 2,862 tonnes of inorganic herbicides (Crop Protection Association UK Ltd 2008). Grey *et al.* (2006) reported on a survey investigating the use and storage of domestic pesticides, using a sample of households living in and around the Bristol area. The survey found that 93 per cent of subjects had used one or more pesticide product over the preceding year, with 76 per cent being used in the garden (e.g. weed killer, insecticide, slug pellets). The chemicals identified included over 260 different garden-related products, containing a large number of active ingredients, the majority of which were insecticides.

Ancient woodland plants may be vulnerable to herbicide and fertiliser drift up to 30m from the woodland edge (Bateman *et al.* 2004). Other groups of pesticides may display different toxicities and risk of drift. For example, both insecticides and fungicides are often applied in much finer sprays than herbicides and their impact may extend further into woodland (Gove *et al.* 2004a).

The frequency of fly-tipping into woodland may increase with increasing proximity of housing. Waste discarded in this manner may include items that are otherwise difficult or expensive to dispose, such as commercial white goods, or batteries. The dumping of domestic chemicals such as household cleaners, garden pesticides, petrochemicals, antifreeze, or other toxic substances, releases hazardous chemicals into the woodland, which may result in poisoning of wildlife.

Dumping of garden waste into woodland is likely to lead to local nutrient enrichment. This may encourage vigorous competitive plants, such as nettle *Urtica dioica*, hogweed *Heracleum sphondylium* or cleavers *Galium aparine*. These species may then thrive at the expense of woodland specialist plants that grow in less nutrient-rich conditions, such as wood anemone *Anemone nemorosa*, wood-sorrel *Oxalis acetosella*, and yellow pimpernel *Lysimachia nemorum*.

4.2.2 Disturbance

Disturbance from housing development may be both direct (e.g. human activity within/close to woods, light and noise pollution), and indirect (e.g. predation of wildlife species by pets kept nearby).

Unmanaged access within ancient woodland may lead to:

- proliferation of tracks and resultant erosion and/or local flooding;
- wildlife casualties as a result of trapping by, or ingestion of, discarded rubbish;
- local trampling of woodland plants (this subject is covered in more detail in 4.9 and 4.10);
- ongoing chronic disturbance impacting negatively on species habitat use, foraging opportunities and breeding success, which, while generally a concern, could also have a beneficial impact on some woods if it leads to a reduction in deer browsing;
- relocation or removal of timber, which is a valuable resource for ancient woodland deadwood organisms;
- removal of attractive, uncommon, or rare plant species (such as bluebell *Hyacinthoides non-scripta*, primrose *Primula vulgaris*, or orchid species *Orchidaceae*);
- vandalism of trees.

Ultimately, the combined effect of these disturbance factors may lead to reductions in species diversity and abundance, or even the elimination or absence of particular species from the wood (Hodgson *et al.* 2006).

A study of 40 forest fragments in Delaware, USA, found that human effects penetrate a considerable distance into woodland from exterior edges. Heavy recreation and disposal of garden or household waste caused 95 per cent of local damage in the first 82m from the woodland edge (Matlack 1993). There were also important interactions with other factors, for example, campsites, vandalised trees, and firewood gathering were negatively correlated with distance to the nearest road. In the absence of roads, penetration by recent dumping was reduced from 82 to 16m. Several forms of effect were clustered near houses (discarded Christmas trees, dumping of grass clippings and hacked trees), and footpaths (hacked trees, grass piles, pruned limbs, tree-houses, and woodpiles). This research suggests that small, or narrow, ancient woodland fragments are particularly at risk, as these disturbance effects may occur across most or all of the woodland area.

Noise associated with housing arises from a range of sources, including pedestrian and low-level traffic activity. Noise levels in residential areas are elevated but vary spatially and over time (Warren *et al.* 2006). They are likely to limit the distributions of animal species that are intolerant of noise and negatively affect their reproductive success near to woodland edges (Fernandez-Juricic 2001; Warren *et al.* 2006). This may be beneficial at some sites if, as a result, deer pressure is reduced but bird diversity has been found to be lower in noisier sites (Stone 2000).

Further noise pollution effects are identified in subsequent sections of the report, where they are specific to: roads (4.3); commercial and industrial activity (4.4); and low-level military jet-fighter and helicopter activity (4.10). Noise pollution emitted from housing development is likely to be less acute than that emitted by these sources, particularly in terms of volume. However, residential noise is an ongoing chronic effect.

Light pollution in residential areas is generated from buildings, streetlights, vehicle lights and security lights. Light pollution may include chronic or periodically increased illumination, unexpected changes in illumination, and direct glare (Longcore & Rich 2004). Artificial illumination reduces the visibility of the moon and the stars (Elvidge *et al.* 2001), affects species orientation differentially and may serve to attract or repulse particular species. This affects foraging, reproduction, communication, and other behaviour. It consequently disrupts natural interactions between species (Longcore & Rich 2004). Light pollution near to ancient woodland is, therefore, likely to substantially affect the behaviour of species active during dawn and dusk twilight or nocturnal species, such as moths, bats, and certain species of birds, resulting in the decline of some species (Arlettaz *et al.* 1999; Conrad *et al.* 2005; Longcore & Rich 2004).

Proximity of new housing development to nearby ancient woodland is highly likely to determine the type, frequency, and magnitude of potential disturbance effects. Woodland edge maintenance, including tree surgery or felling for reasons of safety or to avoid tree root subsidence, or the pruning of shrub species to improve visibility, may negatively affect woodland adjacent to new housing development. Where residential roads and paths link new housing development to existing ancient woodland, or pass nearby, they decrease the effective distance between the development and the woodland, which may increase risks of human disturbance from unmanaged access.

Gardens are an increasingly important refuge for many species affected by loss of habitat and food resources in the wider countryside. Gardens provide a range of different habitats for wildlife, despite the fact that garden vegetation is often dominated by non-native plant species. Feeding garden birds may help to sustain local populations. Nevertheless, housing proximity has been shown to affect wildlife breeding success indirectly *in adjacent areas*. For example, this may occur as a result of predation by other wildlife (e.g. magpie *Pica pica*), also attracted to the resources offered by gardens, and by domestic pets (Beckerman *et al.* 2007; Nelson *et al.* 2005; Phillips *et al.* 2005; Thorington & Bowman 2003).

4.2.3 Fragmentation

Housing development may increase isolation of natural habitats by creating or increasing barriers to movement (Belisle & Clair 2002). It may be associated with the destruction of semi-natural habitats and movement corridors between ancient woodland fragments, and ancient woods and nearby semi-natural habitats.

The net impact of housing on fragmentation is likely to depend on prior land use. For example, gardens and other planted areas may provide a valuable wildlife resource, as compared with intensive arable or improved pasture, However, species which make use of gardens are primarily generalist or edge species. Woodland specialists that are positively encouraged are usually from specific and more mobile species groups (e.g. birds). Most gardens are unlikely to sustain less-mobile woodland species (Blair & Launer 1997).

The degree to which fragmentation by housing development affects animals will also be determined by species-specific behavioural traits. For example, in one study, insectivorous birds were found to be more likely than omnivorous ones to avoid crossing between habitat patches adjacent to high-density housing (Hodgson *et al.* 2007).

4.2.4 Invasion by non-native plants

Most non-native plants are ecologically inconsequential in a semi-natural context, but some may pose a substantial threat to ancient woodland in the UK (e.g. rhododendron *Rhododendron ponticum*, cherry laurel *Prunus laurocerasus*, Japanese knotweed *Fallopia japonica*, and Indian balsam *Impatiens glandulifera*). They may form extremely dense stands capable of completely excluding native species, eliminating natural regeneration, and dominating large areas of woodland (Cross 1981; Dehnen-Schmutz *et al.* 2004).

Invasive plants may ‘escape’ from gardens or be dumped in nearby woodland. Housing may also make ancient woods more vulnerable to invasion by fragmenting semi-natural landscapes (With 2002), increasing availability of nutrients (Zink *et al.* 1995) and creating open, light areas and edges, all of which may favour introduced plant species. Some or all of these effects may be associated with new housing development located near to ancient woodland.

A New Zealand study on the movement of garden plants into 18 native forest areas of varying sizes found the number of non-native species in woodland was significantly related to adjacent settlement attributes: housing proximity; density; age; and presence in gardens of non-native plants (Sullivan *et al.* 2005). The number of houses within 250m of a forest area, alone, explained two thirds of the variation in the number of non-native plants in these forests.

4.2.5 Cumulative effects

Chemical effects, disturbance, fragmentation and invasion by non-native plants associated with housing development are likely to have a cumulative impact on nearby ancient woods. Disturbance associated with nearby housing is likely to have a greater impact on wildlife where conditions are already ecologically-stressed (in terms of habitat or food availability) as a result of fragmentation. This in turn is likely to favour the spread of non-native plant species. Consequently, increasing residential development has been shown to lead to declining species richness and diversity (Smith & Wachob 2006).

4.3 Transport

This section focuses on the effects of nearby transport corridors on ancient woodland. Although literature was sought on a range of transportation types (including roads, motorways, railways, docks, harbours, canals, airports and aerodromes), only searches for motorways, roads and, to a lesser extent, railways, returned specific results.

The area over which significant ecological effects extend outwards from a road is typically many times wider than the road surface and associated roadsides (Forman & Alexander 1998; Hawbaker *et al.* 2006). It often extends into adjacent woodland areas. A recent analysis of data from over 100 woodland sites in Britain found that roads through or adjacent to woods were more important than all other recorded boundary variables (e.g. presence of hedges) and grazing variables (e.g. presence of sheep or deer) in explaining the composition of woodland ground flora (Corney *et al.* 2006). They were also very important relative to site-level climatic and spatial variables.

Hypotheses in chapter 3 that it is reasonable to assume may relate to this section are described below.

4.3.1 Chemical effects

Likely chemical and disturbance effects of road construction and operation are illustrated in Figure 4.1.

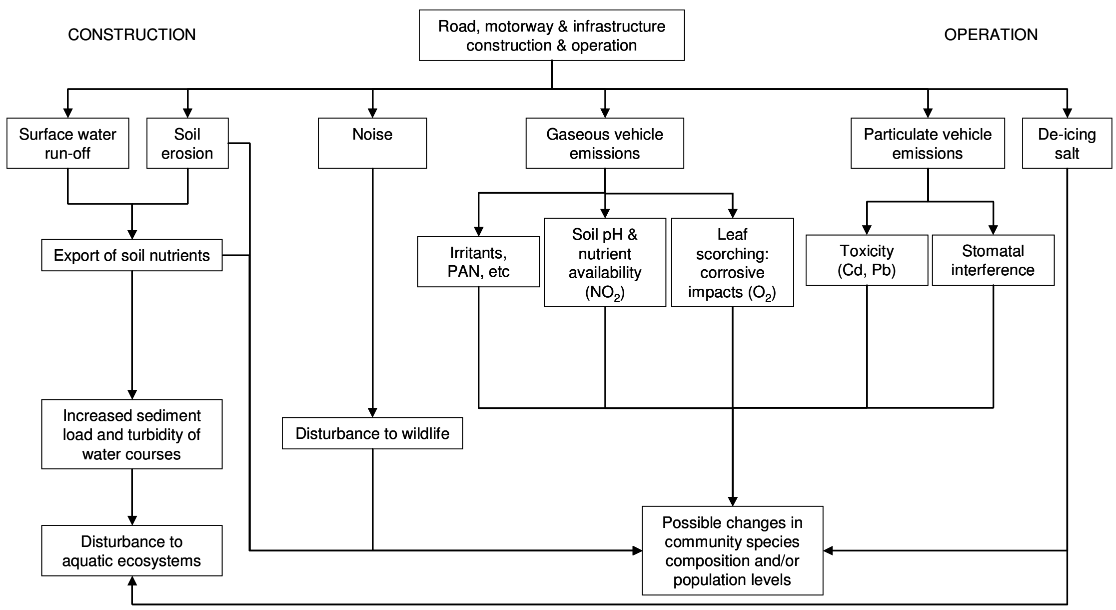

Figure 4.1. The major chemical and disturbance effects of road development. Redrawn from Sheate & Taylor (1990)

Application of herbicides and spillage of hazardous substances during construction may have local impacts on adjacent woodland. However, pollution connected with road and motorway development arises principally during operation, i.e. once these are in use (see Figure 4.1). Chemical pollutants connected with road use include road-salt, and gaseous and particulate emissions (Bernhardt *et al.* 2004; Sheate & Taylor 1990).

Chemicals used to de-ice roads in winter are primarily salts; sodium chloride, calcium chloride, or calcium magnesium acetate (Forman & Alexander 1998). The use of these chemicals increases sodium, calcium and magnesium to levels in the immediate environment that may be toxic to many species of plants, fish and aquatic organisms. Road salt is a substantial deterrent to amphibian road crossing and may also be harmful to roadside woodland amphibian populations, such as great-crested newts *Triturus cristatus* (Gent & Gibson 2003).

Road salt application, together with nitrogen from vehicle exhausts, has been shown to significantly alter the species composition and abundance of ground flora in woodland alongside roads in Germany (Bernhardt *et al.* 2004). Airborne sodium chloride is known to cause leaf injury to trees over 100m from roads, particularly in down-wind and down-slope directions (Forman & Alexander 1998).

Harmful gaseous emissions from vehicles include hydrocarbons, carbon monoxide, peroxyacetyl nitrate (PAN), nitric oxide and nitrogen dioxide, which can produce ozone (Forman & Alexander 1998).

In the UK, nitrogen oxides are produced primarily by vehicle emissions (NEGTAP 2001). Moderate concentrations of nitrogen oxides produce both positive and negative plant growth responses, depending on species sensitivity to, or ability to capitalise on, increased nutrient load. Woodland is not a habitat in which nitrogen availability limits growth, as compared to nutrient poor habitats, such as moorland, but increasing nitrogen can alter the outcome of competitive interactions, changing the character of woodland vegetation, in terms of species composition (Sheate & Taylor 1990). There is recent evidence from woods across Britain that species increasing in cover are more likely to be associated with high nutrient status conditions. Some species have shown consistent increases (e.g. nettle *Urtica dioica*, rough meadow grass *Poa trivialis* and pendulous sedge *Carex pendula*) or decreases in abundance correlated with modelled nitrogen changes (Kirby *et al.* 2005)..

Nitrogen oxides can contribute to local acid rain, lowering soil pH levels, which have been linked to reduced tree root development and increased drought susceptibility in European forests (Matzner & Murach 1995). Research conducted in a wood at Rothamstead Experimental Station (UK) found that nitrogen deposition and consequent acidification reduces the total number of plant species and alters soil microbial processes (Goulding *et al.* 1998). Soil acidification can also reduce nutrient availability and increase solubility of deposited metals, such as lead. Nutrient deficiency combined with increased metal toxicity creates conditions of ecological stress for plant communities (Sheate & Taylor 1990). This changes the composition of the ground flora and may lead to competitive dominance by one or a few species able to tolerate harsh road-edge conditions (Sheate & Taylor 1990). However, there is evidence that, in general, woodland soils in the UK have become less acidic over recent years (Kirby *et al.* 2005).

Importantly, nitrogen deposition can stimulate increased decomposition and mineralisation rates, particularly if soil pH increases. Acting as positive feedbacks, these mechanisms further increase nitrogen availability in the soil, enhancing the nutrient effect of nitrogen deposition (NEGTAP 2001).

Turbulence caused by the passage of vehicles distributes particles emitted in vehicle exhausts into nearby vegetation. A study undertaken in woodland adjacent to the M6 motorway in England found that engine particles were concentrated on tree leaf surfaces adjacent to the road corridor, which became less frequent with increasing distance from the road. However, particles were sometimes carried for 200m or more through or over woodland, particularly in the direction of the prevailing wind (Freer-Smith *et al.* 1997). Ground-level air pollution of this kind can cause a substantial reduction in the health of trees, such as sessile oak *Quercus petraea* and beech *Fagus sylvatica*.

Trees in woodland next to two motorways surveyed in England (M62 & M40) showed increased defoliation, insect damage and poor crown condition (Bignal *et al.* 2007). This effect of roadside pollution extended approximately 100m into adjacent woods. This is consistent with the measured profile of nitrogen dioxide, which declined to background levels at about 100m (Bignal *et al.* 2007).

A study of woodland areas around the M25/M40 motorway junction in England has demonstrated that pollution from roads affects invertebrates (bagmoth *Luffia ferchaultella* larvae) that eat lichens (Sims & Lacey 2000; Sims & Reynolds 1999). Roadside pollution significantly reduced the feeding rate of these invertebrates on lichen gathered from areas adjacent to the motorways, compared to control sites. The causative agents of this effect included heavy metals such as lead, chromium, vanadium, and copper. The effect was directionally dependent on the prevailing winds but was spread over some 2km (Sims & Lacey 2000).

4.3.2 Disturbance

Large roads and motorways are associated with direct mortality of species (Forman & Alexander 1998). Increased noise pollution and activity disturbs wildlife and may ultimately lead to changes in community composition (see Figure 4.1). Removing adjacent trees or vegetation for road construction may also have hydrological impacts on remaining woodland. These may include reduced rainfall interception, increased surface water run-off and soil erosion, which may have long-term impacts on any remaining or adjacent woodland (Sheate & Taylor 1990).

Road kill is probably the leading cause of direct, human-linked animal mortality today (Forman & Alexander 1998). Wildlife casualty rates can be important locally (Mumme *et al.* 2000). Recent data demonstrates that road kills affect over 20 species of mammals in the UK, with approximately 10,000 sightings of mammal casualties each year between 2001 and 2004 (Mammals Trust UK 2005). Data collected in 2005 indicates that mammal road casualties of all species are significantly linked to the quantity of nearby woodland habitat (Mammals Trust UK 2006).

Nesting birds avoid habitat adjacent to well-used tracks, roads and motorways (Brotons & Herrando 2001; Foppen & Reijnen 1994; Ingelfinger & Anderson 2004; Reijnen & Foppen 1994; Reijnen & Foppen 1995; Reijnen *et al.* 1997). Other effects on birds can be quite subtle, for example, through acoustic masking of birdsong by traffic (Warren *et al.* 2006). Indeed bird species most affected appear to have song frequencies closest to that of traffic noise (Rheindt 2003).

Disrupted hydrological function caused by road building, particularly cutting construction, is likely to have long-term effects upon adjacent woodland, which could be considerable and possibly irreversible. Cuttings or drained slopes may lead to a reduced water supply in nearby woodland, resulting in loss of trees and/or changes in species composition. The scale of these physical impacts will depend upon the degree to which the local water table level and the main supply of water to the wood are affected (Sheate & Taylor 1990). For example, premature death of many trees occurred at the Woodland Trust's Hardwick Wood, near Plympton, Devon on land alongside a large road cutting created when the A38 trunk road was widened.

4.3.3 Fragmentation

The primary effects of road incursion into woodland are illustrated in Figure 4.2. The isolation effects identified are also relevant to roads routed across land between woods.

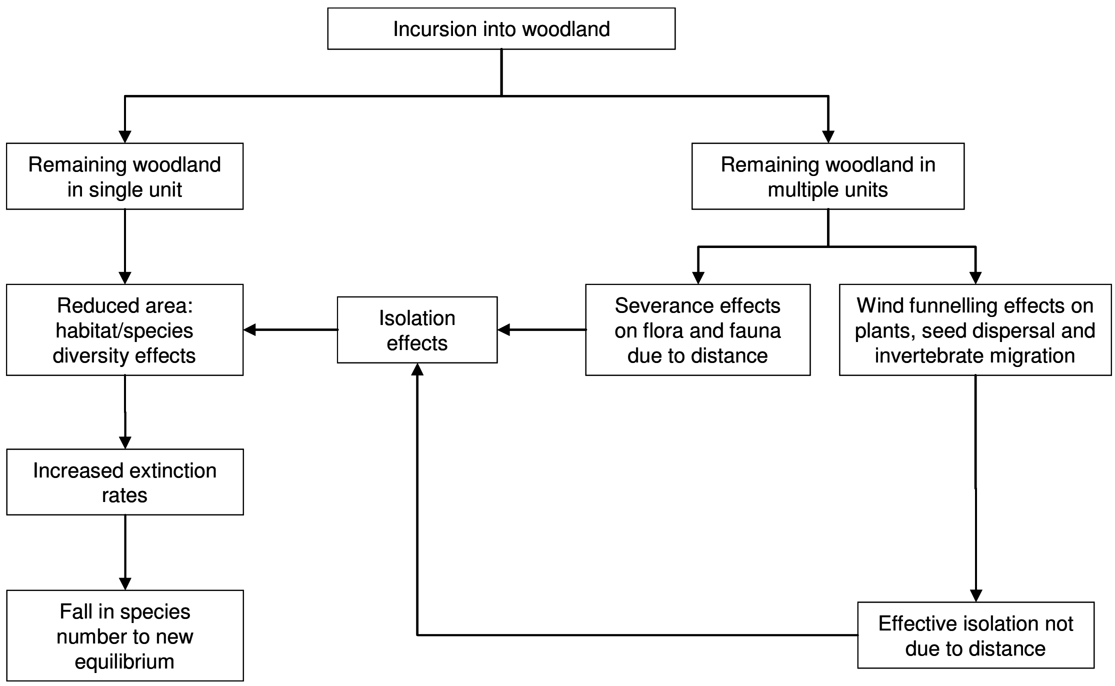

Figure 4.2. Species diversity effects as a result of woodland incursion. Redrawn from Sheate & Taylor (1990)

Woodland fragments, with small area to perimeter ratios, are particularly susceptible to physical impacts resulting from road development, as they lack core area, i.e. area that is unaffected by negative edge effects from adjacent land-use (Woodland Trust 2000). The isolation of large woods with a spatially varied structure that support a diversity of wildlife may also have a disproportionate impact at a landscape scale (Sheate & Taylor 1990).

Some species may take advantage of habitats alongside transport corridors (e.g. verges or hedgerows). These may act as valuable movement pathways for some species, where conditions are suitable (Mata *et al.* 2008), particularly in otherwise highly-arable landscapes. However, transport corridors can act as a barrier to dispersal and migration of species that seek to cross them (Pirnat 2000) and the open habitats along their margins (Koivula & Vermeulen 2005). Many species are known to be affected, for example: bumblebees; woodland ground beetles; and deer (Bhattacharya *et al.* 2003; Dyer *et al.* 2002; Koivula & Vermeulen 2005).

Motorways are major barriers due to their width, speed and frequency of traffic and wind-funnelling, which affects wind-dispersed invertebrate and plant populations (Sheate & Taylor 1990). This is also highly likely to be true of other substantial linear transport corridors (e.g. new railways and airport runways).

By reducing the amount of habitat that can be reached from a particular habitat patch (Eigenbrod *et al.* 2008), new transport corridors may isolate nearby woods, with consequent and inevitable species losses (Sheate & Taylor 1990). In this way, transport corridors may have landscape-scale effects, sub-dividing populations, with demographic and probably long-term genetic consequences (Forman & Alexander 1998).

4.3.4 Invasion by non-native plants

Non-native plant species are often abundant in roadside vegetation (Hansen & Clevenger 2005; Olander *et al.* 1998). Roadsides can act as a reservoir for such plants, facilitating the ongoing spread of non-native species into nearby wildlife habitats (Forman & Alexander 1998). Non-native species were found to be frequent up to 25m from road and railway corridor edges in forests in Banff National Park in Canada (Hansen & Clevenger 2005) with some species present more than 50m away.

4.3.5 Cumulative effects

Disturbance from noise, vibration, visual queues, pollution, and predators can cumulatively lead to species avoiding habitats. For example, pied flycatcher *Ficedula hypoleuca* breeding success in wooded areas in Finland decreases within 130m of nearby roads (Kuitunen *et al.* 2003). Woodland specialist birds in sagebrush steppe habitat adjacent to dirt and paved roads associated with natural gas extraction in Wyoming, USA are similarly affected (Ingelfinger & Anderson 2004). They are encountered less frequently within 100m of roads, even where traffic is light (less than 12 cars per day).

Disturbance to woodland birds associated with roads is particularly well-documented in the Netherlands (Foppen & Reijnen 1994; Reijnen & Foppen 1994; Reijnen & Foppen 1995; Reijnen *et al.* 1997). Effects measured for over forty woodland bird species vary between species and traffic usage but have been detected 40-1,500m from roads with 10,000 cars per day and 70-2,800m from roads with 60,000 cars per day. Reductions in the abundance of birds of 20-98 per cent have been recorded within 250m of roads, depending on species. Brotons & Herrando (2001) also documented reduced bird occurrence in wooded fragments up to 2,000m (2km) away from a main road. These studies consistently record that forest specialist bird species are more affected than generalists. It is conceivable that disturbance also deters deer from frequenting roadside woods to some degree, which may have a beneficial impact where browsing would otherwise be detrimental.

Transport corridors remove habitat, alter adjacent areas, and interrupt and redirect species movement. They subdivide wildlife populations, foster spread of invasive species, change hydrology and water courses and increase human use of adjacent areas (Hawbaker *et al.* 2006). Although the cumulative effect of these factors is not particularly well-documented, it is unquestionable that transport developments have a potentially profound effect on nearby ancient woods.

4.4 Commercial and industrial development

This section focuses on the effects of nearby commercial and industrial development on ancient woodland, including offices, factories, warehousing, and plant machinery. The wider effects of urbanisation are dealt with in 4.13. Hypotheses in chapter 3 that it is reasonable to assume may relate are described below.

4.4.1 Chemical effects

Atmospheric pollutants from some industrial processes may affect woodland over a wide area. Relative to other habitats, woods are especially vulnerable because they provide tall, large and ‘rough’ surface areas for deposition and assimilation of airborne substances (Fowler *et al.* 1999; Tamm & Cowling 1977). As a result, soil acidification and pollutant particulate concentrations, sampled along transects away from pollutant sources, have been found to be significantly higher in woodland than in non-wooded sites (Fernandez-Sanjurjo *et al.* 1998; Rieuwerts & Farago 1996).

Sulphur dioxide emissions are produced by various industrial processes, such as fertiliser manufacturing, aluminium smelting and steel making, and power stations (4.6.1). Sulphur dioxide causes visible injury to leaves, reduces photosynthetic pigments, inhibits metabolic processes, suppresses the growth and yield of plants (Agrawal & Agrawal 1991) and causes acidification, further reducing plant photosynthesis and impairing growth (Saarinen & Liski 1993). When sulphur dioxide is combined with water it forms sulphuric acid, one of the main constituents of acid rain. Sulphur dioxide acidifies sensitive soils and water bodies, and is toxic to plant life. Historically high levels of sulphur dioxide emissions have been linked to reduced tree growth and health, acidified woodland soils and associated changes in soil biota (NEGTAP 2001). The distribution of lichen, moss and liverwort species have also been affected, as sulphur dioxide acidifies substrates, such as tree bark and rocks. Although background levels of sulphur dioxide are currently decreasing, critical levels may still be exceeded close to some industrial areas (NEGTAP 2001), and new industrial processes, therefore, have the potential to increase local sulphur dioxide emissions.

Although road transport is one of the major emitters of nitrogen oxides in the UK, they are also produced by industrial processes during combustion at high temperatures. Therefore, the impacts on ancient woodland associated with nitrogen oxides produced by vehicle exhausts (4.3.1) are also relevant here.

Soil acidification often results from chemical pollutants such as sulphur dioxide and nitrogen oxides (Falkengren-Grerup & Bergkvist 1995; Makarov & Kiseleva 1995) but species vary in their sensitivity and responses to soil chemistry change (Hallbacken & Zhang 1998; Hill *et al.* 1999). In one study, three characteristic plants of ancient woodland (wood anemone *Anemone nemorosa*, yellow archangel *Lamiastrum galeobdolon* and wood speedwell *Veronica montana*) were found to grow better when soil pH was adjusted from 7.7 to 5.8 and 4.3 respectively. However, growth of nettle *Urtica dioica* and rough meadow-grass *Poa trivialis* also increased (Hipps *et al.* 2005). Such responses may result in substantial changes in the composition of woodland ground flora.

Woodland soil contamination by heavy metals (e.g. aluminium, vanadium, chromium, iron, nickel, copper, zinc, and lead) associated with industrial processes has an insidious effect on soil micro-organisms, many of which are critical to decomposition and nutrient cycling in woodland. There may be considerable time lags between pollution events and their impact on the composition of soil communities. Soils have large surface areas with substantial capacity for buffering pollutants. However, serious, long-term changes occur when insoluble heavy metals reach critical thresholds, (Evdokimova 2000; Fedorkov 2007; Palmborg *et al.* 1998; Vassilieva *et al.* 2000), including loss of whole functional groups of bacteria and cyanobacteria, which in turn impact on soil nutrient levels.

Heavy metals reduce the ability of plants to take up nutrients and retard growth. Combined heavy metal and sulphur dioxide pollution visibly damaged (i.e. reduced growth, discoloured foliage and defoliated) Norway spruce *Picea abies*, European silver fir *Abies alba* and European beech *Fagus sylvatica* trees in Slovakian woodland (Longauer *et al.* 2001). Heavy metals concentrate in upper soil layers, so trees with deeper root systems (e.g. fir and beech) may be at less risk but are still vulnerable. Where heavy metals are deposited in large quantities, there are likely to be reductions in seed germination, seedling survival, and plant health (Salemaa & Uotila 2001). These may combine with a loss of canopy foliage to promote competitive understorey plants (Vacek *et al.* 1999), which can increase at the expense of a more varied ground flora. In extreme circumstances, understorey vegetation has been found to be almost totally absent within 0.5km of pollutant sources (Salemaa & Uotila 2001).

A range of studies have considered the impacts of specific factory types. Forest soil chemical gradients related to the ammonium-nitrogen of the humus layer, and increases in levels of sulphur and calcium, have been reported at distances of over 3km from a pulp mill in central Finland (Holopainen *et al.* 1996). These changes caused injuries and changes to tree mycorrhizae (beneficial associations between plant roots and fungi, important for water and mineral absorption), leading to declines in tree health. Similar results have been found for a fertiliser factory in Lithuania (Stankeviciene & Peciulyte 2004) and from soils around a phosphate fertiliser factory in Poland (Bojarczuk *et al.* 2002), where plant growth was significantly depressed.

A study of the surroundings of a magnesium factory in central Slovakia (Cicak *et al.* 1999) found that a range of organisms were affected within a zone extending into the wider forest. Effects included: significant defoliation of oaks and hornbeams indicating chronic damage; a lack of mycorrhizae associated with trees located close to the factory; and a decline in breeding birds within increasing proximity to the factory.

A smelter and fertiliser factory in south-western Finland was found to significantly alter composition and diversity of ground-living forest arthropod communities (including insects, arachnids, and crustaceans). These showed marked differences between the most polluted site, 0.5km away, and other study sites 3, 5 and 9km distant (Koponen & Niemela 1995). Toxic metals deposited in the region surrounding a steel works in Finland have been found in woodland organisms (plants, beetles and ants) further afield, with elevated levels of iron detected up to 10km (Mukherjee & Nuorteva 1994).

4.4.2 Disturbance

Disturbance to woodland edges adjacent to commercial and industrial development and unmanaged access by people may impact on ancient woodland in the ways described for housing (4.2.2). Vehicles associated with the movement of personnel, customers, materials and finished goods will replicate many of the cumulative impacts of disturbance illustrated for transport (4.3.2; 4.3.5).

Industrial areas can produce chronic local light and noise pollution. Noise has been shown to have a negative effect on bird behaviour in adjacent woods (Stone 2000). A study in Canada found a significant reduction in bird pairing success at noisy industrial sites, compared with noiseless sites, when controlling for edge effects, human visitation, habitat quality and other factors (Habib *et al.* 2007). It is likely that industrial noise interferes with male bird song, such that females may not hear it at greater distances and/or it is less attractive to them due to distortion.

Commercial and industrial development may also be associated with the disturbance of hydrological processes within adjacent woodland. For example, the creation of engineered slopes next to woodland will replicate the hydrological impacts caused by the building of roads and cuttings, described above (4.3.2). Development may also involve canalising rivers adjacent to woodland, resulting in altered flow rates and flooding cycles (see 4.11.2). These effects will be exacerbated where development involves abstraction from rivers or streams adjacent to, or running through, nearby woodland. This is likely to lead to a change in species composition and, potentially, tree loss (Busch & Smith 1995).

4.4.3 Fragmentation

The fragmentation effects of commercial and industrial development are likely to be similar to those described for housing (4.2.3). However, they may create much larger physical barriers to movement than smaller residential areas. Intervening wildlife habitats destroyed during construction may also be larger, increasing distances between favourable habitats that species must cross to disperse, forage, or breed.

While shrubs and trees in residential gardens may facilitate the movement of some mobile generalist species between areas of favourable habitat, commercial and industrial developments are often more hostile environments for native species. A study of butterflies and birds across an urban gradient at six sites that were all former oak woodlands in California, USA, indicates that even well-landscaped developments do not maintain pre-development woodland-species richness, with gradual loss of oak-woodland species at more developed sites (Blair 1999; Blair & Launer 1997). Areas of commercial and industrial development may thus form substantial barriers to movement for many woodland species, exacerbating landscape-scale fragmentation.

4.4.4 Cumulative effects

The cumulative effects of commercial and industrial developments are likely to be most pronounced in terms of species avoidance or absence in their immediate vicinity. Chemical, noise and light pollution are likely to combine and create a biologically stressful environment surrounding industrialised areas. This may affect everything in nearby ancient woods from the soil organisms that underpin nutrient cycling to the trees, shrubs and ground flora that are their structure, to obligate woodland insects, mammals and birds. As chemical pollutants, and noise and light pollution to a lesser extent, are pervasive, impact zones from multiple commercial and industrial developments within a region may overlap compounding effects from any one facility.

4.5 Intensive livestock units

This section focuses on the effects of nearby intensive livestock farming on ancient woodland, including eutrophication resulting from animal waste arising from dairy, poultry or pig units. Hypotheses in chapter 3 that it is reasonable to assume may relate are described below.

4.5.1 Chemical effects

Intensive livestock and poultry units are a substantial source of ammonia, a common form of environmental nitrogen, including emissions from animal housing, muck-spreading, slurry spills, and intensive cattle grazing. Ammonia deposition causes local and widespread eutrophication; the increase and accumulation of chemical nutrients (Fowler *et al.* 1998; Pitcairn *et al.* 2002; Skiba *et al.* 2006). Close to livestock farms, ammonia concentrations may be very high with potential for deposition over a considerable area (Fowler *et al.* 1998; Skiba *et al.* 2006). The intensity of farming has been strongly linked to the degree of impact on woodland locally. The size of the affected woodland relative to its exposed edge is also an important factor.

Eutrophication can alter the composition of plant communities, changing competitive interactions that determine relative species abundance and diversity by differentially stimulating plant species growth (NEGTAP 2001). Acute exposure to nitrogen pollution causes visible damage to leaves and increases sensitivity to drought and frost (Krupa 2003). In extreme cases, it results in plant communities dominated by one or a few plant species that thrive on nitrogen enrichment (Krupa 2003).

A range of UK studies have recorded ammonia concentrations and deposition rates from poultry farms and assessed their effect on nearby woods (Fowler *et al.* 1998; Pitcairn *et al.* 2002; Skiba *et al.* 2006). At one site, measurements revealed annual mean concentrations of 23-63μg m^{-3} at a distance of 15m from the source, only declining to background levels after 270m (Fowler *et al.* 1998). Ammonia concentrations measured at three sites close to another poultry unit were 20 to 40 times greater than at a background site, also 270m away (Skiba *et al.* 2006). Both studies reported a directional effect caused by prevailing winds. At a third site, annual mean concentrations of ammonia close to farm buildings were large (60μg m^{-3}) and declined to 3μg m^{-3} only after 650m. Estimated total nitrogen deposition ranged from 80kg of nitrogen per hectare per year, at a distance of 30m, to 14kg of nitrogen per hectare per year, at 650m downwind. Nitrogen-loving plants were more common nearer to the farm buildings and emissions sources, while species diversity increased with distance (Pitcairn *et al.* 2002).

Effects of ammonia emissions and nitrogen deposition on lichen communities have been investigated in the area surrounding an intensive pig unit in central Italy. Ammonia deposition was highest (267μg m^{-3}) at the centre of the unit. A 98 per cent reduction in concentrations was achieved within 200m of the source (4.6µg m^{-3}) but only reached regional background levels (0.7µg m^{-3}) at 2.5km from the unit. Ammonia deposition was correlated with acidified tree bark and nitrogen-loving lichens. Nitrogen-sensitive species exposed in the centre of the pig unit showed visible signs of injury (Frati *et al.* 2007).

One UK study that compared 84 woodland-edge to centre transects found that the effects of elevated nitrogen on plants may extend at least 100m into ancient woods (Willi *et al.* 2005). Cover of ruderal and nitrogen-loving species increased at the expense of plants associated with ancient woodland. Although this was the presumed result of fertiliser drift from arable fields, the findings may be of wider relevance.

4.5.2 Disturbance

Some modern livestock units are, in effect, factory operations. As a result, many of the disturbance effects relevant to commercial and industrial developments that impact adjacent ancient woods (4.4.2) are also relevant to this land-use.

4.5.3 Fragmentation

Modern livestock units can present substantial barriers to species movement between ancient woodland fragments (see 4.2.3 & 4.4.3) not only due to their size, in some cases, but also the degree to which ammonia deposition makes land hostile in their immediate vicinity (Fowler *et al.* 1998; Skiba *et al.* 2006).

4.5.4 Cumulative effects

Intensive livestock and poultry units significantly increase local nitrogen concentrations. One study demonstrated that critical loads were exceeded over an area of 1km radius from large poultry farms (Dragosits *et al.* 2002). Woods were assessed as more likely than other semi-natural habitats to be affected by this emission source because of the ability of trees to capture pollutants from the air (Fowler *et al.* 1998; Fowler *et al.* 1999). Nitrogen from multiple intensive livestock units in the vicinity of woodland is likely to have a cumulative impact, compounded by nitrogen emissions produced by other sources, such as vehicle exhausts. It is estimated that 90 per cent of UK woodland receives ammonia deposition in excess of its critical load (Sutton *et al.* 2004).

4.6 Energy

This section focuses on the effects of nearby energy developments on ancient woodland, including power stations, sub-stations, wind turbines, power-lines and pipe-lines. Hypotheses in chapter 3 that it is reasonable to assume may relate to this section are described below.

4.6.1 Chemical effects

In common with commercial and industrial developments, electricity generating stations that use fossil fuels may emit many airborne pollutants, including sulphur dioxide (4.4.1), nitrogen oxides (4.3.1) and trace elements. All are known to have adverse effects on natural vegetation (Agrawal & Agrawal 1989; Boone & Westwood 2006). Woods are particularly likely to suffer as trees are good at capturing these pollutants (Fernandez-Sanjurjo *et al.* 1998; Fowler *et al.* 1999; Tamm & Cowling 1977).

Trees and other woodland plants in the vicinity of fossil-fuel power stations may suffer leaf discoloration and become defoliated to some degree. They have been shown to contain elevated concentrations of various toxic elements (e.g. arsenic, lead, cobalt) produced during combustion (Agrawal & Agrawal 1989; Boone & Westwood 2006). Lichens applied as bio-monitors near coal-fired power stations in Portugal have been shown to accumulate heavy metals, such as iron, cobalt, chromium, and antimony (Freitas 1995). A study conducted in Israel suggests that stack height reduces local concentrations of toxic compounds (Garty *et al.* 2003) but spreads emissions over a wider area, unless suitable filters are fitted to stacks.

A Spanish study suggests that pollution from nearby coal-fired power stations indirectly affects the foraging behaviour of woodland birds during the breeding season. Lighter leaf canopies were found in polluted areas, reducing densities of prey species. This has a negative impact on bird foraging behaviour during the breeding season with implications for breeding success (Brotons *et al.* 1998).

Renewable energy sources, such as wind and wave power, are unlikely to have negative impacts on adjacent woodland in terms of chemical changes.

4.6.2 Disturbance

As with commercial and industrial development, energy generation is associated with disturbance by people and chronic local light and noise pollution (4.4.2).

4.6.3 Fragmentation

The large land-take associated with fossil-fuel power stations and the hostile environment created for woodland specialist species may exacerbate fragmentation of ancient woods in the landscape. However, large installations that include substantial areas of rough ground may provide useful new habitat more permeable to species movement than the preceding land use, e.g. intensive arable or improved grassland.

Power-line and pipe-line corridors associated with energy supply (including renewable sources) may serve to fragment habitats by creating linear boundaries and open areas, which species may be unable to cross. However, where retained as semi-natural open ground and scrub, they may be valuable to wildlife, perpetuating historic continuity of temporary or permanent semi-natural open ground within or alongside the wood and serving as valuable movement pathways for some species, particularly in intensively-farmed landscapes.

Ecological gradients created, away from the installation, involve changes in resource availability and disturbance frequency. These may lead to changes in vegetation structure and species composition (Luken *et al.* 1992), which have been shown to affect breeding bird densities in woodland up to 220m away from power-lines (Kroodsma 1982).

4.6.4 Invasion by non-native plants

Power-line and pipe-line construction often involve soil disturbance. This produces soil chemistry changes, as disturbance leads to local nutrient release (Soon *et al.* 2000). Disturbed, nutrient-enriched soil, or bare ground, provides an invasion pathway for non-native plant species (Hendrickson *et al.* 2005). Intentionally or unintentionally, plants may be carried on earth-moving equipment in soil brought from elsewhere or from nearby where they already exist at a low level. Once non-native plant species become established, they may spread along new power-line or pipe-line corridors (Cody *et al.* 2000; Zink *et al.* 1995). Where these are adjacent to or intersect ancient woodland, they form a reservoir for invasion by non-native species.

4.6.5 Cumulative effects

In the vicinity of power stations, some woodland species impacted by chemical deposition may be unable to disperse to, or feed in, other more suitable habitats. Power stations and power-lines present barriers to movement, increasing biological stress and potential for local extinctions. It is also possible that the routes of different power-lines and pipe-lines may combine to entirely isolate some areas for some woodland species and amplify potential for invasion by non-native plants. As chemical changes associated with power generation may cover a wide area, it is likely that some woods, particularly in more urban areas, may suffer combined impacts from multiple generating stations.

4.7 Quarrying and mineral extraction

This section focuses on the effects of nearby quarrying, mineral and aggregate extraction on ancient woodland. Hypotheses in chapter 3 that it is reasonable to assume may relate are described below.

4.7.1 Chemical effects

Chemicals released during mining operations can enter ground and surface water bodies, including unnaturally high concentrations of hazardous substances such as arsenic and sulphuric acid. Clearly, these may have a negative impact on biodiversity. Critical levels of contamination are rare but historic cases, such as the Wheal Jane mine disaster in Cornwall, demonstrate that acid mine drainage can have catastrophic impacts on ecosystems downstream, e.g. riparian woodland.

Dust and chemical drift produced by quarrying and mineral extraction can affect woodland several miles downwind. At a wood 0.5km distant from an Austrian lime quarry and adjacent cement works, calcium levels were found to be five times greater than at a control site 30km distant (Berger & Glatzel 1998). At a lead smelting and former mining site, near Prague in the Czech Republic, metal concentrations (lead, zinc, cadmium, copper, arsenic and antimony compounds) in the mining area breached the UK threshold set by the Interdepartmental Committee on the Reclamation of Contaminated Land. Metal concentrations were significantly higher in soils from woods than from non-wooded sites along sample transects (Rieuwerts & Farago 1996). Increased levels of calcium, lead and other contaminants are likely to affect soil processes and vegetation (see 4.3.1, 4.4.1) with knock-on effects for species interactions.

4.7.2 Disturbance

Quarrying, mineral and aggregate extraction is noisy (e.g. blasting, processing, warning sirens) and involves other physical activity likely to cause disturbance in nearby woodland (e.g. large-scale movement of substrate, dust, vehicles). The behaviour of breeding birds and medium to large mammals is likely to be affected and they may avoid the area altogether.

Seasonal caribou *Rangifer tarandus* behaviour was examined near the Hope Brook gold mine, in south-western Newfoundland (Weir *et al.* 2007). Mine construction and operation resulted in caribou avoiding the area, up to 4km from the mine in most seasons. The number of animals and their group size decreased most in biologically stressful periods (i.e. late winter and during pre-calving and calving seasons), an effect detectable up to 6km from the mine centre (Weir *et al.* 2007). Large mammals may not be so sensitive in a UK context, as illustrated by the behaviours of urban foxes, badgers and deer. However, disturbance may perhaps be sufficient to limit deer browsing.

4.7.3 Fragmentation

Extractive industries often extend over a wide area with an associated road network. During their operation they can present extreme and hostile environments for woodland species (e.g. rock faces, quarry and open-cast mine floors, spoil heaps, settling lagoons, flooded gravel pits). As a result, they may often form an extensive barrier to movement by many woodland species, as described above (4.2.3; 4.4.3). The net impact on fragmentation following completion of quarrying or mineral extraction depends in part on prior land use. For example, some abandoned, quarries and spoil heaps can develop into a valuable wildlife resource, as compared with intensive arable or improved pasture. However, without post-operation mitigation measures to address toxic substances and restore landscapes, other areas can remain hostile to many woodland species in the long term.

4.7.4 Invasion by non-native plants

Changes to soil pH and availability of nutrients arising from quarrying and mineral extraction may make nearby woods vulnerable to invasion by non-native plants. This may be compounded by un-associated factors. For example, coltsfoot *Tussilago farfara*, a non-native plant in Gros Morne National Park Newfoundland, Canada, is normally unable to colonise undisturbed native woodland on naturally acidic soils. However, coltsfoot was able to invade woodland in areas where increases in light intensity and bare ground from anthropogenic disturbance accompanied elevated soil pH arising from dust, limestone or granitic gravel quarries nearby (Hendrickson *et al.* 2005).

4.7.5 Cumulative effects

The cumulative effects of quarrying, mineral, and aggregate extraction may be similar to those from other commercial and industrial development (4.4.5). They are likely to result in species absence or avoidance from areas of woodland close by. Dust or toxic compounds may also affect woods that are more distant. The range over which such effects may be apparent will vary, depending on a range of factors including the material extracted, the extraction process and local wind phenomena.

4.8 Waste disposal facilities

This section focuses on the effects of nearby waste disposal facilities on ancient woodland, including incinerators, land-fill sites, and recycling plants. The wider effects of urbanisation are dealt with in 4.13. Hypotheses in chapter 3 that it is reasonable to assume may relate are described below.

4.8.1 Chemical effects

Waste disposal facilities may be associated with toxic or nutrient-rich leachates and toxic air-borne pollutants unless properly controlled.

Some form of leachate arises from the decomposition of most waste material and the volume of landfill waste means that this disposal method produces considerable quantities. This may include dissolved organic matter, inorganic components (e.g. aluminium, ammonia, chloride, iron, sulphate, and zinc ions), heavy metals (e.g. copper, lead, mercury, and nickel), and polychlorinated biphenyls (PCBs) (Blais *et al.* 2003; Zanini & Bonifacio 1991). In newer landfill sites, leachate should be contained within an impermeable membrane and may be piped away to receive treatment. However, if the membrane or collection pipes leak, or where waste is not contained by effective management systems, the leachate may enter ground water, nearby springs and flushes.

The primary risks of leachate entering woodland nearby are associated with the very high nitrogen content and concentrations of toxic substances. The former may lead to nitrogen-loving species dominating the ground flora and a decline of woodland specialists that are unable to exploit the increase in available nutrients or compete successfully. The toxic substances carried by leachate may also have a range of specific negative effects on both plants and animals.

Incinerators convert waste into ash, gasses and particulates. The latter can include toxic heavy metals, such as arsenic, cadmium, chromium, lead, manganese, nickel, mercury, and vanadium (Blais *et al.* 2003). These toxic compounds may be deposited into woodland in the vicinity of the incinerator. Accidental releases of lead and polychlorinated biphenyls (PCBs) from waste incinerators have been reported in studies undertaken in Italy (Zanini & Bonifacio 1991) and Canada (Blais *et al.* 2003). The Canadian study reported a predominance of higher chlorinated PCBs in white spruce *Picea glauca* needles and snow within 3km of the plant. This review did not locate any publications on the long-term effect of such contaminants on adjacent woodland ecosystems.

4.8.2 Disturbance

Windblown litter from landfill sites and, to a lesser extent, recycling areas can accumulate in woodland edges, which may result in wildlife casualties as a result of ingesting or being trapped by rubbish. Vehicles that carry waste to landfill sites, and move and spread it once on site, are also likely to lead to low-level, ongoing disturbance to nearby woodland. Incinerators and recycling facilities produce disturbance effects similar to those produced by industrial and commercial processes (4.4.2).

4.8.3 Fragmentation

The likely effects of extensive landfill areas on fragmentation may be analogous to those created by quarrying and mineral extraction (4.7.3). The impact of incinerators and recycling facilities on fragmentation may be akin to commercial and industrial developments (4.4.3), creating inhospitable terrain inimical to many woodland species.

4.8.4 Invasion by non-native plants

It is reasonable to assume, as with quarrying and mineral extraction (4.7.4), that changes to soil pH and availability of nutrients arising from waste disposal facilities may make nearby woods vulnerable to invasion by non-native plants.

4.8.5 Cumulative effects

The primary impact of waste disposal facilities on nearby woodland is likely to be chemical change to soils or waters due to leachate or air-borne deposition. The type and extent of these changes may interact with the way in which such facilities also physically fragment and disturb the ecology of nearby woodland, thereby compounding these effects.

4.9 Leisure and sport

This section focuses on the effects of nearby leisure and sport development (e.g. stadia, leisure centres, motor racing tracks, sports fields, and golf courses) and associated activity (e.g. motor sports, shooting, paint-balling and war games) upon nearby ancient woodland. Hypotheses in chapter 3 that it is reasonable to assume may relate are described below.

4.9.1 Chemical effects

Golf courses, sports centres, and sports fields use a wide range of fertilisers and pesticides, principally herbicides. These may be applied using a variety of techniques, including knapsack sprayers for spot-treatment (frequently used for the maintenance of landscaped areas around buildings, or patches of weed species, such as thistles *Cirsium* spp., or nettle *Urtica dioica*), irrigation systems or tractor-mounted boom-sprays for coverage of large areas. Toxic chemicals may, therefore, enter adjacent woodland in several ways (e.g. direct overspread, airborne drift, surface water run-off or after entering watercourses).

There have been a number of studies of pesticide drift and fertiliser overspread in an agricultural context that are equally relevant to leisure and sports facilities. Chemicals from a boom-spray can drift at least 10m into woodland at wind speeds of 4-9.6km/hr (Gove *et al.* 2004b; Gove *et al.* 2007). The distance penetrated is affected by factors including wind strength, operator use, weather conditions (Williams *et al.* 1987) and structure of the woodland edge (Gove *et al.* 2004b; Gove *et al.* 2007). The potential vulnerability of ancient woodland plant species exposed to herbicide (glyphosate) and fertiliser drift can range from minor damage to complete mortality. The threshold of sensitivity to glyphosate can be as low as one per cent of the median field application rate. Differences among species in sub-lethal responses to herbicide drift and fertiliser overspread may lead to changes in plant community composition (Gove *et al.* 2007; Gove *et al.* 2004b). Other studies have detected edge effects believed to be caused by fertiliser drift from adjacent fields into ancient woodland extending 10 – 20m (potassium, magnesium), 20–30m (soil pH) (Bateman *et al.* 2004) and 20 – 100m (nitrogen) (Willi *et al.* 2005).

Motor sport activity near to ancient woodland is likely to replicate many of the chemical impacts associated with transport, as described above (4.3.1). For example, nitrogen oxides emitted by vehicle exhausts may enhance the growth of nitrogen-loving plants at the expense of those unable to exploit the additional nutrients or compete with those that can. Acidification, harmful gaseous and particulate emissions, and any petrochemical run-off may put ground flora in nearby woodland under stress.

4.9.2 Disturbance

As with other development types, sports and leisure facilities can lead to noise and light pollution. The penetrative effects of such disturbance are likely to depend upon the nature of the development or activity, distance from the woodland, and frequency of use. Associated activities may also substantially increase the likelihood of physical disturbance. This is particularly the case for leisure activities that may cross over into ancient woodland, either inadvertently or deliberately, from the adjacent land or woodland on which they occur. Effects are likely to include: trampling of vegetation; increased soil compaction; vandalism; and an increase in litter (see 4.2.2).

A wide range of leisure and sports developments lead to noise pollution (Clark 1991; Collins 2003). Motor sports, stadia, shooting (clay pigeon, target, and other forms) and sports fields are all associated with sudden percussive noises (e.g. gunfire, applause/crowd noise, loudspeakers or tannoy announcements, firework displays, amplified music). The impacts of ongoing chronic noise pollution are described in 4.2.2, 4.3.2 and 4.4.2. In particular, it is likely to affect the distribution and breeding success of mammals and birds in adjacent ancient woodland that are intolerant of noise (Fernandez-Juricic 2001; Warren *et al.* 2006).

Stadia, leisure centres, sports fields and golf courses, particularly driving ranges, are often equipped with extremely bright directional floodlights (Collins 2003). Where lighting illuminates areas of adjacent ancient woodland, it is likely to interfere with species behavioural patterns as described above (4.2.2). Populations of more sensitive species, active during dawn and dusk twilight or nocturnally, are likely to decline (Arlettaz *et al.* 1999; Conrad *et al.* 2005; Longcore & Rich 2004).

Tidying of woodland edges, including pruning of trees and shrubs for visibility and safety, or to avoid subsidence caused by tree roots, affects woodland adjacent to leisure developments and areas used for associated recreational activities. This may lead to removal of deadwood habitat and the exposure of the woodland interior to increased sunlight and rainfall, reducing the quality of the internal woodland habitat for specialist organisms (Roovers *et al.* 2004).

Leisure activities on land neighbouring ancient woods and intensively-used paths created along the woodland edge are associated with a range of negative impacts on the adjacent habitat. Activity may increase soil compaction and reduce tree root competition, thereby altering the ground flora at woodland edges; effects that can penetrate up to 50m into neighbouring woodland (Hamberg *et al.* 2008).

Extensive unmanaged access within woodland, not confined to paths, can damage ground flora and may be a continuous source of disturbance to wildlife. In the English Midlands, Littlemore and Barker (2003) have shown that oak woodland can be remarkably sensitive to trampling. The equivalent of 500 passes of a person on foot over one summer prevented trampled bluebells *Hyacinthoides non-scriptus* from producing seeds even two years later. Ground-nesting birds, such as woodcock *Scolopax rusticola* may take flight when people pass up to 50m away, although distance varies depending on visibility through vegetation (Thiel *et al.* 2007). Disturbance is likely to be more pervasive where people do not keep control of dogs, which some species see as potential predators. An Australian study has shown that this can lead to a significant reduction in bird diversity and species abundance (Banks & Bryant 2007).

Leisure and sport activities, such as clay pigeon shooting and off-road driving, are often associated with road and track creation for vehicular access along or within woodland edges, in order to maintain productivity of nearby farmland. Track creation can cause severe damage to tree root systems, increased water run-off, soil erosion and compaction. These impacts may have significant long-term consequences for decomposition and nutrient cycling in affected areas (Olander *et al.* 1998). Intense compaction can reduce organic matter content significantly in surface layers (Ferrero 1991), the fertility index (measured using subsequent dry-matter production) and water infiltration capacity. It can also increase penetration resistance, affecting root growth of plants. Tests show repeated compaction inhibits root development and dry root and green matter production. A study in the Black Forest (Germany) found no vegetation growth after 20 years following initial soil compaction by vehicles and classified these soils as ‘long-term irreversibly degraded’ (Horn *et al.* 2007).

Camping in areas neighbouring ancient woodland is likely to replicate the impacts described above for paths created next to woods, resulting in trampling of vegetation (Gibson *et al.* 2000), soil changes (Marion & Cole 1996; Monti & Mackintosh 1979), loss of woody material (Hall & Farrell 2001) and disturbance along the woodland edge. Ground flora changes and reduced breeding success of birds and animals are likely to result. Deadwood removal, in particular, will have a critical affect on associated invertebrates. More than 1,500 invertebrate species in the UK are dependent on a succession of decaying wood (Alexander 2002). Where woodland access is unrestricted, these direct effects will be more pervasive, as campers seek fuel for camp fires. Owners of camp sites directly adjoining ancient woodland are also likely to 'tidy' woodland edges and fell trees in the interests of safety.

Picnic sites adjacent to woodland can have a strong local effect on woodland ecology. Sites with increased food availability attract larger-bodied and more aggressive bird species, which may in turn displace woodland specialists. An Australian study found that, unlike the bird communities of forest interiors, picnic areas were dominated by larger bird species. Predation by these species of artificial nests in woodland adjacent to picnic areas was several times higher than in interior habitats (Piper & Catterall 2006). Litter from picnic sites may also cause wildlife casualties (see 4.2.2).

Land take for golf courses in the UK has expanded rapidly in recent years but little is known about associated effects on woodland wildlife (Dale 2004). Remnant patches of semi-natural habitat, including woodland, may survive on golf courses and benefit some generalist species. However, courses have been found to maintain neither the original species composition nor the abundance of some groups of woodland species, such as butterflies (Blair & Launer 1997). Golf courses in less-developed landscapes may support woodland breeding birds but in more altered landscapes they tend to harbour species associated with urban areas (Jones *et al.* 2005).

Golf courses are often heavily used by people with much vehicle movement and associated noise. Potential impacts on woodland species are exemplified by a study of the breeding success of the endangered Ortolan bunting *Emberiza hortulana* on a wooded golf course in Norway. Throughout the study period, male Ortolan buntings that maintained territories in the golf course interior were unable to attract females. Less than half of the males located in the golf course periphery did so. By comparison, most males in a control woodland area were able to attract females.

Critically for this endangered species, all male birds emigrated an average of 13km from the golf course interior in order to breed. As a result, buntings disappeared from the golf course during the study period, despite the wooded setting and provision of natural habitat patches (Dale 2004).

4.9.3 Fragmentation

Many development proposals for sports and leisure facilities present potential barriers to species movement (e.g. buildings, hard surfaces and species-poor, intensively-managed grassland), similar to those created by commercial premises (4.4.3). However, the degree to which they may further isolate ancient woodland depends on the existing land cover and land-use. For example, while developments that replace or surround valuable semi-natural habitats may curtail movement by woodland specialist species, those sited on arable farmland may increase connectivity.

Off-road motor sports (e.g. 4 x 4 driving, or motorbike scrambling) and paint-balling and war games can cause loss of vegetation, soil erosion, compaction and increased rainwater run-off, resulting in long-term habitat degradation. This may inhibit species movement thereby increasing functional fragmentation of ancient woodland, particularly where such activities occur in adjacent non-ancient woodland or semi-natural open-ground habitats..

Disturbance created by leisure and sports developments that penetrates nearby ancient woods (4.9.2) may effectively fragment them into smaller habitat islands. Whole woods, or discrete areas, may consequently become unsuitable for some species of wildlife.

4.9.4 Cumulative effects

The chemical and disturbance effects of leisure and sports developments and associated activities may combine to ecologically stress animal and plant communities in nearby ancient woods. Chemical impacts on soil organisms and vegetation may affect nutrient cycling and herbivores. The response of disturbance-sensitive species may in turn affect other species with which they co-exist or that predate upon them. Furthermore, the distance such effects penetrate may create conditions in which certain species are unable to breed or remain within the woodland.

4.10 Military activity

Military activity is usually restricted to designated areas where other development is prevented. As a result, military training ranges, particularly areas that experience little or no disturbance, can become de facto nature reserves with high biodiversity interest relative to surrounding areas (Smith *et al.* 2002). However, military training in areas adjacent to woodland has the potential to cause severe ecological disturbance. This section focuses on the effects on nearby ancient woodland of mechanised and personnel exercises for military training. Hypotheses in chapter 3 that it is reasonable to assume may relate are described in the sections below.

4.10.1 Disturbance

Military training is associated with considerable physical activity, which may visually startle animals. Birds and reptiles are also highly sensitive to vibration (Bowles 1994) and are likely to avoid woods adjacent to heavily-used training areas.

Military activity produces noise from a range of sources: vehicles; artillery firing; projectile explosions; small-arms and other blast noise; mobile generators; bird-scarers; and aircraft. Such noise may be continuous or intermittent, sudden, intense, pulsed or occasional, and is likely to vary with time (Larkin 1996). It is likely to lead to sensitive species retreating from favourable habitat, increasing energy expenditure, reducing feeding time, and depleting energy reserves. Chronic noise may also interfere with species ability to communicate (Bowles 1994). Military noise is, therefore, likely to reduce individual animal survival and breeding success. It may also interfere with animal social interactions and parenting. The net result may be population declines of wildlife species in adjacent ancient woodland (Bowles 1994; Rheindt 2003; Stone 2000; Warren *et al.* 2006). Some species can become habituated to chronic low-level noise pollution but the sudden, percussive nature of some military noise mean that behavioural responses may not diminish with time. If this is true of deer, reduction in browsing may benefit some woods.

Low-level military jet-fighter and helicopter activity within 100m of woodland has negative impacts on mammals (Harrington & Veitch 1992) and birds (Delaney *et al.* 1999; Goudie & Jones 2004), reducing breeding success and increasing energy-expensive flushing events. One study reported deviations from normal behaviour patterns, including decreased courtship and increased aggression, which lasted between 1.5-2 hours after military jet over-flights (Goudie & Jones 2004).

Military training often results in soil compaction, root damage and increased rainwater run-off (Collins *et al.* 2006; McDonald & Glen 2007; Milchunas *et al.* 2000). As a result, training that occurs near ancient woodland increases the likelihood that edge trees will suffer physiological stress and damage, which may become apparent as crown dieback or defoliation (Applegate & Steinman 2005).

4.10.2 Fragmentation

Personnel and mechanised military training compacts soil and crushes or uproots vegetation (Applegate & Steinman 2005; Collins *et al.* 2006; McDonald & Glen 2007; Milchunas *et al.* 2000), altering competitive relationships between plant species and changing the composition of vegetation. Long-term disturbance from military manoeuvres has been shown to change understorey/overstorey species relationships in woodland and grassland. Higher levels of disturbance increased cover of grass and herbaceous flowering plants, relative to shrubs and trees (Collins *et al.* 2006; Milchunas *et al.* 2000). This may increase landscape-scale fragmentation by inhibiting movement of specialist woodland species.

A major outcome of military activity is often the creation of vegetation islands, surrounded by high-use trails and roadside-like vegetation (Collins *et al.* 2006). Such areas may be beneficial for some species which prefer more open conditions (Smith *et al.* 2002). However, they may also serve to extend distances between patches of woodland, increasing fragmentation and presenting barriers to movement for specialist woodland species.

4.10.3 Invasion by non-native plants

Changes in the proportions of bare ground, litter, vegetation cover and, especially, soil disturbance caused by personnel and vehicle movement are similar to those associated with energy infrastructure development (4.6.4). Military activity has been shown to increase the incidence of native weed and non-native plant species on training ranges (Milchunas *et al.* 2000). Military ranges may, therefore, serve as a reservoir or invasion pathway for non-native plant species into adjacent ancient woodland.

4.10.4 Cumulative effects

The degree to which the potential effects of military activity combine to threaten the ecology of ancient woodland in the vicinity is likely to depend strongly on how much disturbance it causes. By creating a stressful environment, such disturbance may effectively increase habitat fragmentation and reduce resilience to invasion by non-native plants, for which military ranges may act as a reservoir.

4.11 Water management

This section focuses on the effects of major water management projects, such as flood defence, river regulation, dam and reservoir construction, and large-scale drainage schemes, on nearby ancient woodland. Hypotheses in chapter 3 that it is reasonable to assume may relate are described below.

4.11.1 Disturbance

Water management projects may be associated with water abstraction, increased river channel incision, confinement or modification of surface water bodies and altered daily flow rates. They can have impacts upon the hydrological function of surrounding ecosystems, including: the alteration of flood frequency, duration, or intensity; modification of water tables; and local drought or water-logging. Such changes can have a profound impact on the species composition of vegetation and thus the ecology of adjacent riparian woodland (Busch & Smith 1995).

Artificially high or low water levels can create substantial problems for nearby ancient woodland. For example, water-logging from damming operations has been linked to die-back in neighbouring woodland (White 2007). Temperate woodland is also susceptible to drought and low water levels (Asbjornsen *et al.* 2004). Soil water shortages lead to water deficits, which may in turn result in reduced mineral uptake, growth, regeneration and increased drought-induced mortality (Breda *et al.* 2006; Broadmeadow *et al.* 2005; Gessler *et al.* 2004; Sardans & Penuelas 2007). Wet woodland species are adapted to natural flooding cycles (UK Biodiversity Steering Group 1995) and modification of seasonal inundation will, therefore, have a substantial impact on natural biological processes (Rood *et al.* 2007).

4.11.2 Fragmentation

Large-scale water management projects may further isolate ancient woods and inhibit movement of associated species. For example, dam and reservoir construction create large expanses of water that form an effective barrier to the terrestrial dispersal of woodland species. Surface water channels, used to drain large areas of low-lying land, may also block movement of terrestrial species. However, land drainage, often associated with agricultural production or new development, is likely to have a more significant effect by altering intervening habitat and thereby reducing landscape-scale connectivity between ancient woods and other semi-natural habitats. River regulation, particularly canalisation or culverting, may also fragment existing woodland by destroying movement corridors along areas of riparian vegetation.

4.11.3 Invasion by non-native plants

Water management projects are associated with large-scale disturbance and movement of soil and sediment, and alteration of ground water levels. These impacts increase the likelihood of colonisation, establishment, and eventual invasion by non-native species of nearby ancient woods, particularly those located downstream (see 4.6.4). In the UK, this may most notably increase the spread of Japanese knotweed *Fallopia japonica* and Indian balsam *Impatiens glandulifera* (Preston *et al.* 2002). In America, altered hydrology has been shown to contribute to invasion by non-native saltcedar *Tamarix ramosissima* into wet woods. It can out-compete native species such as Fremont cottonwood by taking advantage of the altered conditions. It has established extensive tracts of non-native scrub, which now dominate the Colorado river floodplain (Busch & Smith 1995).

4.11.4 Cumulative effects

Changes in hydrology in space and time resulting from large-scale water management may have a cumulative impact on landscapes, affecting tree health, the composition of woodland vegetation and the ability of species to disperse. This may make ancient woods less resilient to other drivers of change, including invasion by non-native species that may themselves be promoted by substantial disturbance of soil and sediment associated with water management projects.

4.12 Permitted development

Permitted development encompasses a very wide range of activities. The term comes from the Town and Country Planning General Permitted Development Order (GPDO), 1995, a Statutory Instrument that describes ‘permitted’ land-uses or activities that can be undertaken without the need to obtain planning permission. Table 4.1 provides a full listing of the development types covered by the GPDO, indicating the impacts potentially associated with each. The wider effects of urbanisation are dealt with in 4.13.

Although no references relating specifically to activity covered by the GPDO were found during the course of this study, many of the effects resulting from permitted development are likely to be common to those covered in previous sections.

4.12.1 Disturbance and fragmentation

Permitted development is likely to be associated primarily with disturbance and fragmentation effects. For example, maintenance or improvement of a road or adjoining land carried out by a local highway authority under Part 13 of the GPDO will be associated with impacts described in 4.3 (transport). Similarly, use of adjacent areas or adjoining woodland by members of certain recreational organisations (Part 27) may replicate disturbance and fragmentation described in 4.9 (leisure and sport) and 4.10 (military activity).

4.12.2 Chemical effects and invasion by non-native plants

It is possible that some activities covered by the GPDO may have chemical effects on nearby ancient woodland or promote invasion by non-native plants. Chemical effects may result from accidental release of hazardous substances, sewerage, and/or petrochemicals, during construction or maintenance activities. Increased risk of invasion by non-native plants is primarily associated with activities that cause disturbance to soils, riparian habitats, or watercourses.

4.12.3 Cumulative effects

Activities covered by the GPDO can occur incrementally within the vicinity of an ancient wood, un-assessed and un-monitored. The array of development types permitted, and their respective impacts on nearby ancient woodland, may have numerous compound effects that may, therefore, go unnoticed.

Table 4.1. Development permitted under the General Permitted Development Order (1995). Impacts likely to be associated with each development type are denoted: Chemical = Chem; Disturbance = Dist; Fragmentation = Frag; Non-native species = Non-; Cumulative = Cumu. Reference to report sections which provide context are provided.

GPDO Part #	Permitted Development	Impact	Report Section
1	Development within the curtilage of a dwelling-house, or enlargement of a dwelling house	Dist, Frag, Cumu	4.2
2	Minor residential operations; construction of a gate, fence, wall or driveway	Dist, Frag, Cumu	4.2
3	Changes of use of building; i.e. of a shop to use for storage and distribution	-	-
4	Temporary buildings and uses; moveable structures, works, plant or machinery	Chem, Dist, Frag, Cumu	4.2, 4.4
5	Caravan sites	Dist, Frag, Cumu	4.2, 4.4
6	Agricultural buildings and engineering operations	Chem, Dist, Cumu	4.5
7	Forestry buildings and operations; building construction, afforestation, road creation	Dist, Frag, Cumu	2.5, 4.3
8	Industrial and warehouse development; alteration of buildings, installation of machinery	Chem, Dist, Frag, Cumu	4.4
9	Repairs to un-adopted streets and private ways	Frag	4.3
10	Repairs to services; sewer, main, pipe, cable	Chem, Dist, Frag, Cumu	4.6, 4.13
11	Development under local or private acts or orders	-	-
12	Development by local authorities; alteration to small ancillary buildings, works or equipment	Dist, Frag, Cumu	4.2, 4.4, 4.13
13	Development by local highway authorities; maintenance or improvement of the highway or adjoining land	Dist, Frag, Non-, Cumu	4.3
14	Development by drainage bodies; maintenance or repair of watercourses	Dist, Frag, Non-, Cumu	4.6, 4.11
15	Development by the Environment Agency for the purposes of its functions	Dist, Frag, Non-, Cumu	4.6, 4.11
16	Development by sewerage undertakers connected with provision, improvement, maintenance or repair	Chem, Dist, Frag, Cumu	4.6, 4.11, 4.13
17	Development by statutory undertakers, including gas, electricity, and telecommunications suppliers	Dist, Frag, Non-, Cumu	4.6
18	Aviation development; development connected with provision of services and facilities at an airport	Chem, Dist, Frag, Cumu	4.3, 4.4
19	Development ancillary to mining operations; plant machinery, buildings, private railways, sewers, cables	Chem, Dist, Frag, Non-, Cumu	4.7
20	Coal mining development by the coal authority licensed operators; underground working or development	-	-
21	Waste tipping at a mine; deposit of waste derived from the working of minerals at that mine	Chem, Dist, Frag, Non-, Cumu	4.7
22	Mineral exploration; drilling of boreholes, seismic surveys, or other excavations	Chem, Dist, Frag, Cumu	4.7
23	Removal of material from mineral-working deposits	Chem, Dist, Cumu	4.7
24	Development by telecommunications operators; installation, alteration or replacement of apparatus	Dist, Frag, Non-, Cumu	4.6
25	Other telecommunications development; microwave antenna or other tall structures	Dist	4.6
26	Development by English Heritage/Cadw/Historic Scotland; maintenance, repair or restoration of building, monument, or land	-	-
27	Use by members of certain recreational organisations; recreation or instruction, including erection of tents	Dist, Frag, Cumu	4.9, 4.10

GPDO Part #	Permitted Development	Impact	Report Section
28	Development at amusement parks; erection, extension, or replacement of booths, stalls, plant or machinery	Dist, Frag, Cumu	4.9
29	Driver information systems; installation, alteration or replacement of system apparatus	Dist, Cumu	4.3
30	Toll road facilities; setting up and maintenance, improvement or alteration of toll facilities	Dist, Cumu	4.3
31	Demolition of buildings	Chem, Dist, Cumu	4.4
32	Schools, colleges, universities and hospitals; erection on site of any building required for use	Dist, Frag, Cumu	4.2, 4.13
33	Closed circuit television cameras; installation, alteration or replacement of a CCTV camera	-	-

4.13 Cumulative development

The cumulative effects associated with an individual case of any development type, or multiple cases of a single development type are dealt with in preceding sections of this report. However, combinations of different development types can substantially compound their impact on nearby ancient woodland through urbanisation and/or cumulative fragmentation of the surrounding landscape (Land Use Consultants 2005).

The UK is a small, densely populated island. Land Cover Map 2000 shows that more than half of the UK is used for intensive agriculture or is built-up (Fuller *et al.* 2002a&b), with areas such as Southeast England being particularly heavily developed (Land Use Consultants 2005). The effect on ancient woodland of cumulative development, linked by an expanding road network, is to continue to erode and interrupt natural processes, altering the structure of ecological communities and population dynamics of species (Underhill & Angold 2000; van den Berg *et al.* 2001).

There is growing evidence of the impacts of climate change on biodiversity, including changes in phenology, species distribution, community composition and ecosystem function (Hossell *et al.* 2000; Mitchell *et al.* 2007). It is highly likely that projected shifts in the locations where species may find suitable climate will require them to adjust their ranges in coming decades, if they are to survive (Honnay *et al.* 2002; Walmsley *et al.* 2007).

In the context of Government commitments to halt the loss of biodiversity, there is a need to consider the impacts of climate change on species, to understand their responses and to provide potential adaptation measures (UK Biodiversity Partnership 2007). This is in addition to commitments to reduce the impacts of fragmentation. For example, the EU Habitats Directive (EEC 1992) obliges the UK to endeavour to: improve the ecological coherence of the *Natura 2000* network; and to maintain or restore favourable conservation status to species of community importance, many of which have been adversely affected by cumulative development.

4.13.1 Cumulative fragmentation

Ancient woods have been fragmented for hundreds of years. It is estimated that only 15 per cent of England was wooded at the time of the Domesday Book in 1086

(Rackham 2003) and by 1900 only 5 per cent of the UK was covered by woodland. However, of the ancient woodland that survived in England, Scotland and Wales in the 1930s, only around half remains as ancient semi-natural woodland (ASNW). Eight per cent has been cleared for agriculture or development and 38 per cent has been converted to plantation (Spencer & Kirby 1992; Walker & Kirby 1989).

Today, only 617 out of a total of approximately 40,000 ancient woods in Britain exceed 100 hectares (one square kilometre) and only 46 ASNWs exceed 300 hectares. Of the woods recorded on the ancient woodland inventories, 48 per cent are smaller than five hectares (Woodland Trust 2002b). Therefore, many are very vulnerable to edge effects from surrounding land use (Woodland Trust 2000).

Basic principles of functional connectivity are that the land use between habitat patches has an impact on species movement (Murphy & Lovett-Doust 2004; Tischendorf & Fahrig 2000a & b) and that some land covers, or land uses, are more permeable to movement than others (Donald & Evans 2006). Although woodland cover has expanded to 12 per cent since 1900, primarily due to planting of quick-growing conifer crops, the twentieth century saw further attrition of ancient woodland and an unparalleled increase in the intensity of land use between woods. For example, 98 per cent of wildflower meadows and 190,000km of hedgerows have been lost since 1950 (UK Biodiversity Steering Group 1995).

Increasingly intensive agriculture has played a major role in isolating ancient woods, as has the net impact of cumulative housing, transport, industrial and commercial and other development types (Land Use Consultants 2005). The distances between surviving fragments of ancient woodland and other semi-natural habitats, and hostility of intervening environments, create cumulative barriers to movement (Peterken 2002), with long term genetic consequences for woodland specialist species (Honnay & Jacquemyn 2007).

Research indicates that maintaining a healthy population size and within-population genetic diversity are important for the maintenance of viable populations (Leimu *et al.* 2006). Small populations in remaining isolated fragments are more prone to extinction due to the loss of genetic variation (Lens *et al.* 2000). It is not only rare species that are at risk, recent research showing that common plant species are equally, or even more, susceptible to the genetic consequences of habitat fragmentation (Honnay & Jacquemyn 2007). A study examining the genetic aspects of pollinator decline has also demonstrated that species groups (bees compared to butterflies) are impacted differentially by cumulative fragmentation (Packer & Owen 2001).

Declines in species richness or changes to community structure in response to cumulative woodland fragmentation are well-documented, including for woodland plants (Honnay *et al.* 2002; Petit *et al.* 2004), birds (Brotons & Herrando 2001; Dowd 1992; Morimoto *et al.* 2006; Parker *et al.* 2005; Pidgeon *et al.* 2007; Tewksbury *et al.* 2006), and invertebrates (Gibb & Hochuli 2002). Species vary in their vulnerability to landscape-scale fragmentation, according to their dispersal ability, habitat specificity, predation and home range size (for animals) and population size. For instance, ground-nesting birds, and open-nesters in shrubs or trees, have been shown to be more sensitive to fragmentation than other birds (Lampila *et al.* 2005). One study demonstrated that nesting success is different for birds in edge and interior locations in fragmented landscapes but not in more intact landscapes, with edge locations in fragmented areas being more likely to fail (Driscoll & Donovan 2004).

Despite the substantial increase in woodland cover over the last century, cumulative landscape-scale fragmentation has affected populations of woodland mammals (Harcourt & Doherty 2005) and is one of the causes of population decline of the hazel dormouse *Muscardinus avellanarius* in the UK. This species is primarily a canopy dweller and is dispersal-limited in fragmented landscapes (Bright 1998). Dormouse movement along ecological corridors such as hedgerows does occur but is affected by gaps in cover and availability of food. Another arboreal mammal, the red squirrel *Sciurus vulgaris*, has been shown to be less affected by habitat fragmentation (Delin & Andren 1999), where patches are sufficiently close together in less-hostile surroundings.

Species responses may lag significantly behind cumulative fragmentation and landscape-scale change. An assessment of bird species extinctions from Kenyan woodland fragments found that only half the total number of extinctions had occurred within the first 50 years after isolation (Brooks *et al.* 1999). Time lags of 50-100 years in the response of plant species diversity to changing configuration of habitats in the landscape have also been detected for remnants of traditionally managed semi-natural grasslands in Sweden (Lindborg & Eriksson 2004).

4.13.2 Urbanisation

The substantial growth of urban areas is associated with extensive chemical effects, disturbance, fragmentation and invasion by non-native species (Beckerman *et al.* 2007; Forman & Alexander 1998; Hawbaker *et al.* 2006; NEGTAP 2001; Roy *et al.* 1999; Stone 2000; Warren *et al.* 2006). Macro-environmental impacts include: the 'urban heat island' effect (Oke 1973); soil hydrological changes; sky glow (Longcore & Rich 2004); and increased concentrations of gaseous pollutant emissions, including carbon dioxide, nitrogen oxides, and sulphur dioxide (NEGTAP 2001). Nevertheless, for some woodland species, it is possible that urban areas may provide more suitable habitats and be more permeable than surrounding intensively-farmed landscapes. For example, they can support higher densities of trees outside woods and other features, such as ponds (Gaston *et al.* 2005).

The impacts of urbanisation spread beyond the immediate physical boundaries of urban areas. In Melbourne, Australia, a study found that the abundance of weed species in native woodland up to 4km from an urban environment is linked to an increase in the local availability of nitrogen from anthropogenic sources, including air pollution and overland flow from nearby roads and drainage channels (Bidwell *et al.* 2006). The distance over which this effect is likely to be apparent in the UK will depend on a number of factors, including local nitrogen point sources, traffic flows, and soil mineralisation and nitrification rates. It seems likely that effect distances from urban areas will be related to population size.

A survey of 785 2km squares found that the UK's urban flora consists primarily of ubiquitous native species and introduced species characteristic of waste ground (Roy *et al.* 1999). The survey also found that the number of non-native plants is significantly greater in urban areas than in the surrounding countryside. This effect is amplified by the local extinction of native species characteristic of non-urban habitats, such as woodland (Roy *et al.* 1999).

Loss of suitable habitats and changes in vegetation composition resulting from urbanisation indirectly affect animals. Butterflies and birds were examined along a gradient of urban land-use on former oak woodland near Pale Alto, California (USA). It crossed from relatively undisturbed to highly developed areas, including a nature reserve, recreational area, golf course, residential area, office park and business district. The pattern of local extinction from the original oak-woodland suggested that any development was detrimental to the original species assemblage, with oak-woodland species progressively disappearing as the sites became more urban (Blair 1999; Blair & Launer 1997).

In disturbed urban habitats, species which remain have to work harder to rear young, than those in woodland habitats. Hinsley *et al.* (2008) investigated breeding success and parental daily energy expenditure in blue tits *Cyanistes caeruleus* and great tits *Parus major* in urban parkland (Cardiff, Wales) and deciduous woodland (eastern England). Pairs in the park reared fewer young, which also had lower body mass. The consequence of cumulative development in the UK is, therefore, to create significant differences in composition between populations that remain in woodland in urban areas, and populations in more rural locations (Fuller *et al.* 2005).

Research in the foothill oak woods of Placer County, USA, showed that many species were sensitive to residential development density at distances of 250-4,000m (Stralberg & Williams 2002). In Sydney, Australia, bird communities of urban parks, gardens and residential areas have been shown to be significantly different from bird communities in native woodland and scrub. This suggests that there is little overlap in the use of urban and native habitats by the majority of bird species (Parsons *et al.* 2003).

Taken as a whole the studies identified highlight that urbanisation is associated with chemical effects, disturbance, fragmentation and invasion by non-native species. Urbanisation has been demonstrated as a major cause of the loss of native plant species. Changes in vegetation composition indirectly affects animal species, with effects on bird species assemblages, breeding success and productivity especially well-documented in the science literature. Importantly, the impacts of urbanisation spread beyond the immediate boundaries of urban areas, affecting ancient woods in the surrounding landscape, as well as the species associated with them.

4.14 Summary of evidence

As documented in this chapter, nearby development can affect nearby ancient woodland in a range of different ways. Many of these effects can also combine, such that negative impacts on woodland ecology are increased. A summary of the way in which each of the development types listed in the present report may impact upon nearby ancient woodland is provided in Matrix 1.

Matrix 1. Summary of the evidence of the impacts of nearby development on the ecology of ancient woodland

	Chemical	**Disturbance**	**Fragmentation**	**Non-native species**
Housing	1	3	2	2
Transport	3	3	3	2
Commercial and industrial	3	2	2	-
Intensive livestock units	3	1	2	-
Energy	3	1	2	2
Quarrying and mineral extraction	3	2	2	1
Waste disposal	3	1	2	-
Leisure and sport	1	3	2	-
Military activity	-	3	2	1
Water management	-	3	2	1
Permitted development	1	2	2	1
Cumulative development	3	3	3	2

Coding: 3 = Good evidence for (or reasonable assumption of) a substantial impact; 2 = Good evidence for (or reasonable assumption of) a moderate impact, or some evidence for a substantial impact; 1 = Some evidence for (or reasonable assumption of) a moderate impact.

The matrix should be interpreted with caution, as the ranking of the strength of evidence is strongly influenced by the literature identified during the review. Where only weak evidence of an effect was unearthed, further review or future research may change this assessment.

There is good evidence from the literature, or it is reasonable to assume, that substantial chemical effects are associated with developments related to transport, commercial and industrial projects, intensive livestock units, quarrying and mineral extraction, and waste disposal. Literature provides good evidence, or it is reasonable to assume, that developments related to housing, transport, leisure, military activity and water management cause substantial disturbance. It is also a reasonable assumption, or there is good evidence, that developments associated with transport further, substantially, fragment functional connections between ancient woods. However, evidence does not suggest that development leads to a substantial increase in invasion by non-native plants, although, it does support the assumption that housing, transport and energy developments can have a moderate impact in this regard.

It is reasonable to assume that the cumulative impact of all ecological effects arising from urbanisation has a substantial impact on ancient woodland that is enveloped, as well as on woods in the surrounding landscape.

5 Mitigating factors and management solutions

Potential mitigation measures identified in the course of the review are considered in relation to each of the hypothesised types of impact identified in chapter 3.

As described in chapter 4, nearby development can impinge upon ancient woodland during construction and on an ongoing basis following completion of development. Impact sources may be local or distant. Degree of impact may be constant or vary over time. Management solutions must address this variation in order to successfully mitigate against the adverse effects arising from nearby development.

5.1 Chemical

Chemicals may reach ancient woodland from nearby development through a range of mechanisms including:

- Aerosol or spray drift (Bateman *et al.* 2004; Gove *et al.* 2004a);
- Application of road-salt (Bernhardt *et al.* 2004; Forman & Alexander 1998; Preston *et al.* 2002);
- Contaminated surface and ground water flows;
- Dumping of rubbish or garden waste into woodland (Matlack 1993);
- Dust (Berger & Glatzel 1998);
- Gaseous and particulate pollution deposition (Bignal *et al.* 2007; Fowler *et al.* 1999; Fowler *et al.* 1998; Freer-Smith *et al.* 1997; Freitas 1995; Palmborg *et al.* 1998; Pitcairn *et al.* 2002; Salemaa & Uotila 2001; Sheate & Taylor 1990; Sims & Lacey 2000; Sims & Reynolds 1999; Skiba *et al.* 2006; Tamm & Cowling 1977; Vassilieva *et al.* 2000).

Mitigation for chemical effects should, therefore, seek to reduce chemicals from nearby development reaching ancient woodland by addressing these mechanisms.

5.1.1 Environmental Management Plans

Construction of any development may involve the storage, creation and use of a range of chemical substances hazardous to nearby ancient woodland or wildlife habitats which adjoin ancient woodland. Environmental Management Plans (EMPs) are promoted as good practice within Environmental Impact Assessment (e.g. IEEM 2006; IEMA 2004; ODPM 2000), as a useful means of drawing together all mitigation activity. All impacts, including those arising from the use of chemical substances, should be considered and included. Planning Authorities can enforce EMPs through legal agreements. An appropriate EMP would be considered essential for any development where there are clear impacts on nearby ancient woodland.

An EMP should contain detailed provision for the specific protection of the woodland and associated habitats (such as water courses). Information should, therefore, be provided on the proposed methods for management and control of chemicals and chemical impacts, including chemical dust, and the disposal of hazardous substances. Each EMP should be site-specific, outlining the proposed management of construction activities in a local context. However, it is likely that in all cases the documentation should include:

- A management structure, setting out roles and responsibilities with regard to the environment, including a nominated environmental manager;
- An environmental risk register, detailing hazardous chemicals and showing how risks will be addressed;
- Descriptions of the type and location of chemical storage facilities;
- Environmental training procedures for staff;
- Procedures for addressing minor non-conformance or incidents;
- Procedures for dealing with major incidents.

The information provided in the EMP should be comprehensive and relevant to the scale of the development. An EMP required for the construction of a new power station, for example, will necessarily be of a different order to that required for the construction of a small housing development or athletics track.

Although implementation of an EMP should reduce the chemical risks inherent in construction activities, these cannot be entirely eliminated. As a result, a suitable buffer zone should also be placed between the ancient woodland and the development (see below).

5.1.2 Chemical buffers

Eliminating or reducing ongoing chemical emissions from developments near to ancient woodland is potentially problematic. There may be a variety of unregulated sources of chemicals, e.g. pesticide use associated with residential gardens and leisure and sports facilities. It may not be feasible to prevent ongoing activity even if critical loads are exceeded, e.g. nitrogenous pollution associated with poultry units, or vehicle exhaust emissions. However, it may be possible to mitigate the negative effects of chemical impacts by establishing buffer zones to reduce the likelihood of harmful chemicals reaching nearby ancient woodland. Buffer zones may be designed to surround point sources of pollution or to shield the woodland itself.

The simplest form of buffer is space; positioning the development further away from ancient woodland reduces the chance of harmful chemical impacts. In some situations, it may be appropriate simply to restrict activity (e.g. application of chemicals) within a zone (Gove *et al.* 2004b; Gove *et al.* 2007). Encouraging the development of dense woodland boundaries or restoring hedges around the edges of woods (Gove *et al.* 2004b) may also help to reduce the impact of chemical drift.

Woodland is the most effective habitat type at intercepting chemical nutrients carried in surface and ground water (Di & Cameron 2002). Newly planted woodland buffers have been shown to reduce the concentration of nitrogen carried in overland flows of swine lagoon effluent over a distance of 30m (Hubbard *et al.* 2007). Trees also capture both gaseous and particulate pollutants from the atmosphere (Bealey *et al.* 2007; Beckett *et al.* 2000; Freer-Smith *et al.* 1997; Skiba *et al.* 2006). Therefore, planting buffer areas with trees may be a particularly effective measure to reduce the ongoing chemical effects on ancient woodland of nearby development (Sutton *et al.* 2004).

Buffers planted around nearby ancient woodland will help reduce the cumulative effect of chemical impacts arising from new developments, and those already in place. They will also create a screen that may help to prevent some types of disturbance (see 5.2), provide additional cover for wildlife (Sutton *et al.* 2004), and may help to reduce edge to core ratios (Woodland Trust 2000).

Woodland can be planted around source areas (Sutton *et al.* 2004). This is more appropriate in cases where pollution is created at or near to ground level (e.g. intensive poultry units), as opposed to pollution emitted from tall chimneys or towers. It may also be suitable where there are several woods in close proximity to the new development, which would all benefit from the establishment of a single woodland buffer zone around the development itself. However, planting around source areas does not have the advantage of serving to buffer woods from additional chemical impacts arising from other nearby developments.

The width of woodland buffer zones capable of effectively mitigating against the effects of sources of chemicals will be dependent on: the type of development activity and anticipated emissions; the proximity of the wood to the emission source; the strength of the emission source; and local conditions, including prevailing wind direction in relation to atmospheric pollution sources. Research suggests that for overland flow and spray drift effects, buffers should extend to at least a 30-40m width, in order to be effective (Bateman *et al.* 2004; Hubbard *et al.* 2007). For developments likely to generate gaseous and particulate pollutant deposition, this should be extended to at least a 50-150m width (Deviaeminck *et al.* 2005; Spangenberg & Kolling 2004).

5.2 Disturbance

Development in the vicinity of ancient woods may cause disturbance as a result of:

- Activity visible from within the wood, causing flushing or avoidance (Banks & Bryant 2007; Hewison *et al.* 2001; Thiel *et al.* 2007);
- Acts of vandalism (Matlack 1993);
- Animal avoidance (Delaney *et al.* 1999; Foppen & Reijnen 1994; Goudie & Jones 2004; Harrington & Veitch 1992; Reijnen & Foppen 1994; Reijnen & Foppen 1995; Reijnen *et al.* 1997; Weir *et al.* 2007);
- Animal mortality (Forman & Alexander 1998; Mammals Trust UK 2005; Mammals Trust UK 2006; Pescador & Peris 2007);
- Changes to soil structure (Applegate & Steinman 2005; Collins *et al.* 2006; Ferrero 1991; Horn *et al.* 2007; Marion & Cole 1996; McDonald & Glen 2007; Milchunas *et al.* 2000; Monti & Mackintosh 1979; Sheate & Taylor 1990);
- Disrupted hydrological function (Sheate & Taylor 1990; White 2007);
- Light pollution (Arlettaz *et al.* 1999; Collins 2003; Conrad *et al.* 2005; Longcore & Rich 2004);
- Noise pollution (Bowles 1994; Clark 1991; Fernandez-Juricic 2001; Habib *et al.* 2007; Larkin 1996; Rheindt 2003; Stone 2000; Warren *et al.* 2006);
- Predation by pets or large-bodied birds (Beckerman *et al.* 2007; Nelson *et al.* 2005; Phillips *et al.* 2005; Piper & Catterall 2006; Thorington & Bowman 2003);
- Removal of dead wood (Hall & Farrell 2001) or plants;
- The dumping of rubbish or garden waste (Matlack 1993);
- Vegetation trampling (Gibson *et al.* 2000; Hamberg *et al.* 2008).

Mitigation should, therefore, seek to reduce disturbance from nearby development reaching ancient woodland by addressing these potential sources.

5.2.1 Avoidance

The type, frequency, and magnitude of disturbance events that may affect ancient woodland are likely to be determined by distance between the development and the wood. Locating development further away from ancient woodland will reduce associated disturbance. The minimum distance over which this is likely to be effective will depend on the type of development, the nature of disturbance, and the local context, including intervening land use, vegetation and topography.

It is important that access connected with any new development is managed effectively. Road and path creation that connects a development to nearby ancient woodland effectively renders any buffer zone ineffective and will facilitate some types of disturbance associated with unmanaged access, e.g. trampling, dumping of rubbish, vandalism (Matlack 1993).

Compaction by animals, people or vehicles seriously, and in some cases irreversibly, degrades woodland soils, harms tree roots, and destroys areas of ground flora (Applegate & Steinman 2005; Collins *et al.* 2006; Ferrero 1991; Horn *et al.* 2007; Marion & Cole 1996; McDonald & Glen 2007; Milchunas *et al.* 2000; Monti & Mackintosh 1979; Sheate & Taylor 1990). It is critical that construction vehicles and off-road recreation are not permitted alongside ancient woodland edges, in the area into which tree roots extend. Radial tree root extent depends on a number of factors, including species, tree height, substrate, and water table level. Maximum extents are known for a range of species that occur in ancient woodland in the UK (Stone & Kalisz 1991). These are approximately 10m for relatively small trees (apple *Malus* sp., birch *Betula* sp., cherry *Prunus* sp.), 20m for larger trees (ash *Fraxinus* sp. lime *Tilia* sp., Scots pine *Pinus sylvestris*), 30m for oak (*Quercus* sp.), and 40m for willow (*Salix* sp.).

British Standard 5837:2005 (BSI 2005) recommends principles for protecting trees during development. Ancient woodland should always fall within the category of 'trees to be retained'. The minimum distance around the woodland that should be protected by fencing should be extended to take account of tree species with the largest known radial root extent (Stone & Kalisz 1991), where this is larger than standard recommendations. Used in this way by developers and planners, BS

5837:2005 should ensure that nearby ancient woodland receives adequate protection from soil excavation, compaction and other negative impacts from nearby development.

Considerations of safety and protection of the built environment from falling tree limbs, or subsidence caused by tree roots, often lead to tree surgery or even felling. Surgery can be extremely damaging to older trees, and often significantly reduces the deadwood habitat that these may support (English Nature 2000). In order to avoid the requirement for subsequent work on ancient woodland trees, development should not be placed close to woodland edges. Data for tree root extent (Stone & Kalisz 1991) and tree height maxima should be used to locate development at a suitable distance.

Development near to ancient woodland should avoid altering the levels of surface and ground water bodies as a result of installing drainage systems, or creating new slopes or cuttings near to woodland edges. Local topography and substrate will strongly influence the distance over which protection and avoidance measures will be required. Hydrological surveys should inform the planning of engineering or construction work near to ancient woodland.

5.2.2 Disturbance buffers

Chronic disturbance is likely to be greatest at woodland edges (Matlack 1993) but may permeate throughout small woods and those with a relatively large edge to area ratio. Research suggests that disturbance by people at the woodland edge (e.g. trampling, dumping, vandalism) can penetrate up to 50-80m into neighbouring woodland (Hamberg *et al.* 2008; Matlack 1993; Thiel *et al.* 2007).

Planting woodland buffers, as described above (Sutton *et al.* 2004), will provide a physical barrier to many forms of disturbance, such as rubbish dumping, or vandalism. It will attenuate noise pollution (Huisman & Attenborough 1991), limit light penetration, and reduce the negative effects of compaction and vibration in adjacent areas. It may also help to screen the woodland, reducing the visibility of exterior activity for ancient woodland fauna (Thiel *et al.* 2007). Tree belts of 100m width have been shown to create a significant attenuation of road traffic noise (Huisman & Attenborough 1991), in comparison with pasture of equivalent width.

The scale of woodland buffers should be tailored to individual developments and anticipated levels of disturbance but should be at least 50-100m wide (Huisman & Attenborough 1991; Matlack 1993; Thiel *et al.* 2007). The addition of fencing to exclude access to both the area of new planting and the ancient woodland is likely to enhance the protective nature of this area, if public access is unmanaged. Where public access is granted, path maintenance is recommended, in order to channel access, particularly away from sensitive areas (Matlack 1993).

5.3 Fragmentation

Woodland in the UK is an extremely fragmented habitat (Bailey *et al.* 2002; Bailey 2007; Peterken 2002; Watts *et al.* 2005). Fragmentation interrupts natural movement flows (Pirnat 2000) and may alter population dynamics in the long term (Honnay & Jacquemyn 2007; Leimu *et al.* 2006; Lens *et al.* 2000; Underhill & Angold 2000; van den Berg *et al.* 2001). Fragmentation can also exacerbate damage caused by many other development-related impacts. Mitigation should, therefore, seek to counter further isolation of ancient woodland by nearby development.

5.3.1 Movement barriers

Dependent on existing land cover and land use, the construction of most new forms of development can create environments that are less favourable to woodland specialist species (Belisle & Clair 2002; Blair 1999), or conditions which make intervening habitat less suitable (i.e. disturbance or chemical factors). Construction of extensive built developments and hard standings, creation of large surface water bodies, exposure of bare ground or rock, and significant chemical effects or disturbance all present substantial local obstacles to species movement (Sheate 1986; Blair & Launer 1997).

Planning authorities and developers should assess existing connectivity of ancient woods at a landscape scale using Geographic Information System (GIS) evaluation tools in order to reduce the likelihood that ancient woodland will be further isolated by new development. For example, Biological and Environmental Evaluation Tools for Landscape Ecology (BEETLE) developed by Forest Research (Watts *et al.* 2005; Watts *et al.* 2007b; Watts *et al.* 2007a) could be used. Development that would create barriers to species movement between areas of ancient woodland should be specifically avoided. Planning authorities should identify areas that lie between ancient woods in development-sensitive zones. Such a strategic approach could reduce developers' costs of exploring opportunities in areas where they are less likely to receive approval.

5.3.2 Enhancing connectivity

Research demonstrates that maintaining woodland connectivity is important for species of ancient woodland in the UK (Bailey *et al.* 2002; Petit *et al.* 2004).

In some studies, linear corridors of hedgerows or tree lines have been found to be beneficial for more mobile plant, invertebrate, mammal and bird populations (Angold *et al.* 2006; Davies & Pullin 2007; Petit *et al.* 2004; Sitzia 2007). However corridor width and length are vital factors determining the use of such habitats by ancient woodland species. An Italian study suggests that corridor habitats are only beneficial for the movement of woodland plants where corridor width is at least 10m, and the distance between woodland areas is less than 100m (Sitzia 2007). Corridor habitats may, therefore, only be effective in increasing connectivity for many species where they are wide and woodland patches are already quite close together.

Achieving connectivity through the creation of new woodland habitat is a large scale undertaking. It can be targeted to increase woodland core area, thus serving to mitigate against negative edge effects (i.e. chemical and disturbance impacts), which may penetrate woods. Buffering large woods may be more useful for specialist species with poor dispersal abilities than connecting existing fragments (Woodland Trust 2000, 2002b; Aune *et al.* 2005; Dolman *et al.* 2007).

GIS evaluation tools, such as BEETLE, should be employed to identify areas for habitat creation that will help to mitigate against fragmentation by new development.

5.3.3 Restoration and translocation

As discussed in 2.3 and 2.4, restoration of plantations on ancient woodland sites (PAWS) has the potential to reverse fragmentation of semi-natural habitats substantially (Woodland Trust 2000). As such it may be an important mitigation measure, improving the quality of remaining patches of ancient woodland.

Wholesale translocation of ancient woodland affected by nearby development is impractical and not promoted as an appropriate mitigation measure. Ancient woods are irreplaceable and cannot be successfully moved or re-created (Defra 2007;

Forestry Commission/Defra 2005; Kirby & Goldberg 2002; Land Use Consultants 2001; Thomas *et al.* 1997; Woodland Trust 2002a).

5.4 Non-native plant species

The probability of invasion of woodland by non-native plant species is increased by:

- Altered environmental conditions (Forman & Alexander 1998; Hansen & Clevenger 2005; Hendrickson *et al.* 2005; Preston *et al.* 2002);
- Altered hydrological processes (Busch & Smith 1995);
- Increasing density of human population (Pysek *et al.* 2002);
- Increasing fragmentation (With 2002);
- Nutrient enrichment (Soon *et al.* 2000);
- Proximity of residential gardens (Sullivan *et al.* 2005);
- Soil disturbance (Cody *et al.* 2000; Milchunas *et al.* 2000; Zink *et al.* 1995);
- Visitation rate (Usher 1988).

Colonisation of ancient woodland by invasive plant species may occur during or subsequent to construction of nearby development. Such species may already exist in the vicinity or may be brought in with contaminated substrate during construction. They may also arrive on an ongoing basis, as a result of human activity associated with the development. Mitigation should, therefore, seek to address these different risk factors.

5.4.1 Construction management

It is recommended that existing populations of invasive non-native plant species within 250m of the development should be identified before any construction proceeds. Attention should focus on very invasive species such as Japanese knotweed *Fallopia japonica* (including *Fallopia japonica* var. *compacta* and giant knotweed *Fallopia sachalinensis*) but should also cover a list of other species likely to invade ancient woodland in the UK, including: Indian balsam *Impatiens glandulifera*; rhododendron *Rhododendron ponticum*; and cherry laurel *Prunus laurocerasus*. If populations of invasive species are located, specific management guidance should be prepared to minimise risk to nearby ancient woodland from movement of soil and plant material. The Code of Practice for Japanese knotweed (Environment Agency 2006) is an example of a structured approach.

All substrate brought to a development site within 250m of an ancient woodland should be from a source known to be free from non-native species. Machinery should be cleaned thoroughly, prior to working at such sites (Environment Agency 2006).

5.4.2 Avoidance

Following completion, developments may act as a diffuse and uncontrolled or unregulated source of non-native species, e.g. dumping of non-native species from gardens and invasion along road corridors. As a result, ongoing colonisation is hard to prevent and, once established, invasive species may be difficult and very costly to control (Usher 1988; Usher *et al.* 1988).

Plants originating in residential gardens are likely to occur in nearby woodland, where this is within 250m of housing (Sullivan *et al.* 2005). Avoiding developments known to generate ongoing sources of invasion (such as housing, transport corridors, and energy infrastructure) within 250m of ancient woods will substantially reduce the associated risk.

6 Knowledge gaps and research priorities

6.1 Introduction

Knowledge gaps identified during the course of this review cut across different development types and the hypotheses investigated (3.1). Research priorities are summarised in Table 6.1, below and those judged to be of particular importance are described further, in the sections that follow. Some specific kinds of development are highlighted as requiring further investigation, where it is apparent that insufficient research has been conducted. The use of current and ongoing ecological assessment to fill knowledge gaps is explored.

6.2 Research scope and coverage

Much of the current literature is based on academic research published in scientific journals. However, grants and journal editors' preferences favour studies that can be completed in relatively short time-frames, so studies tend to be narrowly focused on individual species or species groups. Alternatively, research may describe the effect of a particular development impact (e.g. noise pollution) on species but not consider ancient woodland. As a result, further research is still required in relation to how nearby development may affect wider woodland ecology, particularly in relation to some specific effects and development types that are poorly studied.

Ecological effects associated with development may not be immediately apparent following project completion and may only be detected after substantial periods of time (Brooks *et al.* 1999; Ellis & Coppins 2007; Lindborg & Eriksson 2004). Long-term monitoring programmes are, therefore, vital to increase our knowledge of ongoing development effects on nearby ancient woodland.

Development impacts on ancient woodland are inadequately covered by current UK-based research. Studies from overseas are valuable in illustrating the likely type and extent of development impacts on woodland and for suggesting possible methodological approaches but more research is required to assess potential and ongoing damage to ancient woodland in the UK.

6.3 Limitations

Although a structured review was undertaken, it was nonetheless constrained by the methodology employed. For example, it is likely that use of other keywords would have returned a different set of references. Therefore, the knowledge gaps described below may have already been identified and addressed. Consequently, literature relating to any specific proposals should be thoroughly investigated before investing in costly research. Nevertheless, the priorities identified below indicate where attention might be profitably focused, in the first instance.

6.4 Key knowledge gaps and research priorities

Specific knowledge gaps in relation to each impact type are identified in Table 6.1, ranked by priority. High priorities for research (i.e. those ranked 3) are described further in the sections that follow.

Table 6.1. Summary of knowledge gaps and research priorities

Impact type	Knowledge gap	Rank
Chemical effects	Effect distances (i.e. from source to woodland) for atmospheric pollutants produced by different categories of development, under UK regulatory conditions (Tr, Ci, En, Qu, Wf)	3
	Extent of use of pesticides and fertilisers for maintenance of gardens and amenity grass areas, and typical penetration distance into woodland (Ho, Ls)	2
	Type and extent of chemical damage caused by nearby construction and development of suitable management strategies (Ho, Tr, Ci, En, Wf, Ls, Pd)	2
	Long-term effects of nutrient enrichment on woodland plant species composition (Tr, Lu)	1
Disturbance	Effect of visible human activity, noise, and light pollution on wildlife in nearby woodland (Ho, Tr, Ci, En, Qu, Wf, Ls, Mi, Pd, Cd)	3
	Assessment of the damage caused to nearby woodland by modification of hydrological function during/following construction (Ho, Tr, Ci, Wm, Pd, Cd)	2
	Evaluation of wildlife mortality associated with fly-tipping and litter accumulation in woodland (Ho, Wf)	1
Fragmentation	Development of GIS tools for evaluating functional fragmentation of woods in a planning context (Ho, Tr, Ci, En, Qu, Wf, Ls, Mi, Pd, Cd)	3

Impact type	Knowledge gap	Rank
	Degree to which woodland in the UK is fragmented by urbanisation and the motorway and major road network (Tr, Cd)	2
	Use of residential gardens by woodland specialist species and extent to which use may be increased (Ho)	1
Invasion by non-native plants	Degree to which plants from residential gardens invade woodland in the UK (Ho)	3
	Development of management strategies to successfully reduce the likelihood of non-native plant invasion into woodland, during/following construction/soil disturbance (all)	2
Cumulative effects	The way in which chemical effects, disturbance, fragmentation, and invasion by non-native plants associated with both individual and multiple development types combine to generate effects greater than the sum of individual impacts on nearby woodland (all)	3
	Distance over which species avoidance of urban areas and motorway/major road corridors is apparent in the UK (Tr, Cd)	2

Ranking: 3 = high priority; 2 = medium priority; 1 = low priority.
Development type: Housing (Ho); Transport (Tr); Commercial and industrial development (Ci); Intensive livestock units (Lu); Energy (En); Quarrying and mineral extraction (Qu); Waste disposal facilities (Wf); Leisure and sport (Ls); Military activity (Mi); Water management (Wm); Permitted development (Pd); Cumulative development (Cd).

6.5 Chemical effects

The effects on woodland of atmospheric chemicals generated by development have been widely studied in many countries. However, it is essential to assess the distance over which these effects extend, within the UK's regulatory framework, in order to address their impacts on nearby ancient woodland.

The distances that chemical effects from intensive livestock units and road corridors pervade the landscape have been well-studied in the UK. This information should help to inform the future siting of such development to protect ancient woodland. Similar research needs to be carried out in relation to a range of classes and sizes of commercial and industrial developments, energy, quarrying and mineral extraction, and waste disposal facilities in the UK. This should include assessment of how topography and land cover between the pollution source and the wood alters the impact.

6.6 Disturbance

Developments and associated human activity near to woodland appears to be strongly associated with flushing events and avoidance of woodland edges by animals. The response of some species to noise (birds), light (bats) and some types of visible activity (birds and mammals) has been examined. However, assessment of the penetration distance of disturbance effects generated by a range of development types (including housing, quarrying and mineral extraction, and commercial and industrial development) on a wider range of woodland fauna should be prioritised.

6.7 Fragmentation

GIS mapping tools have the potential to be used to assess the degree to which woodland is isolated by development. Existing modelling techniques, such as Biological and Environmental Evaluation Tools for Landscape Ecology – BEETLE (Watts *et al.* 2005; Watts *et al.* 2007a; Watts *et al.* 2007b), could be adapted for this purpose. The need is not only to assess potential changes to the spatial arrangement of woods and wildlife habitats and the extent of physical connections but to determine their impact on functional connectivity, which is a measure of the ability of species to move across a landscape (Watts *et al.* 2008).

Models that determine functional connectivity require information on the relative costs to species of traversing different land covers and land uses, as well as the distance that negative edge effects penetrate woods and other wildlife habitats. It seems likely that empirical research will only ever substantiate permeability and edge values for a very limited number of species. As a result, models such as BEETLE rely on expert judgements and would benefit from input of permeability and edge values from a larger number of ecologists. Such research should aim to provide accessible tools for planners.

6.8 Invasion by non-native plants

Research should seek to determine the distance over which colonisation of ancient woods by invasive garden plants (e.g. rhododendron *Rhododendron ponticum*, cherry laurel *Prunus laurocerasus*, Japanese knotweed *Fallopia japonica*, Indian balsam *Impatiens glandulifera*, pheasant berry *Leycesteria Formosa*, shallon *Gaultheria shallon*, snowberry *Symphoricarpos albus* and Wilson's honeysuckle

Lonicera nitida) becomes statistically less likely, in order to inform necessary width of recommended buffer zones.

6.9 Cumulative effects

In order to evaluate the true impact of new development near to ancient woodland, a greater understanding is required of the way in which chemical effects, disturbance, fragmentation, and invasion by non-native plants, associated with both individual and multiple development types, combine at a landscape-scale.

It is widely acknowledged that cumulative effects are likely to have a substantial impact on ecosystem functioning (Land Use Consultants 2005) and their investigation is the most important research priority identified during this review. Such research poses a considerable challenge due to: the complexity of woodland ecology; interactions with other ecosystems; the large spatial scales over which some effects act; the frequently long time-lags before combined impacts may become apparent; and the difficulty of detecting interactions between multiple effects. Nevertheless, such research is vital to understanding the impacts of developments on ancient woodland.

6.10 Development types

A considerable amount of research undertaken into effects on woodland from nearby development focuses on housing, transport (principally roads), commercial and industrial development, intensive livestock units, energy, and cumulative development (urbanisation and cumulative fragmentation). By contrast, there are relatively few studies connected with: leisure pursuits, including golf, off-road motorbike and vehicle use, paint-balling, war games, and adventure parks; large-scale water management works that facilitate urban expansion, or increased production, e.g. flood defence or drainage schemes; waste disposal; wind turbines, telephone/microwave masts and associated sub-stations; and permitted development (see 4.12). Specific research should, therefore, be undertaken into the effects of these development types on nearby ancient woodland.

6.11 Ecological Impact Assessment

Environmental Impact Assessments (EIA) are required by the Commission of the European Communities Council Directive 85/337/EEC (amended by Council Directive 97/11/EC) in relation to the effects of certain public and private projects on the environment (IEEM 2006). It is likely that a developer will need to carry out an EIA where potential damage to nearby ancient woodland is expected to occur.

An Ecological Impact Assessment (EcIA) is a key component of the EIA process. An EcIA aims to provide a systematic and objective account of significant potential effects which may arise from the development. An EcIA should also involve ongoing monitoring of potential ecological receptors, such as ancient woodland, following construction (IEEM 2006). There is a need to establish a framework for collation of information collected during EcIA studies, so that, in future, it becomes possible to learn from case studies.

7 Recommendations for survey and monitoring protocols

The purpose of this chapter is to recommend simple, cost-effective survey and monitoring protocols for assessing initial and ongoing impacts on the ecology of ancient woods from developments, in order to build the evidence-base.

7.1 Existing survey techniques

A range of survey techniques already exist for sampling woodland habitats. These have usually been developed with a particular objective in mind (e.g. condition assessment of Sites of Special Scientific Interest). They are tested and comparable methods, which can be adapted without costly re-development.

The method proposed below is based on Common Standards Monitoring (CSM) guidance for woodland (Joint Nature Conservation Committee 2004a), and the 1971 and 2001 National Woodlands Surveys (NWS) (Bunce & Shaw 1973; Kirby *et al.* 2005). It differs from CSM guidance in that it focuses on detecting change rather than assessing woods against a defined ‘target’ state.

7.2 Survey scope

To establish the impacts of nearby development on the ecology of ancient woodland, with reference to the five hypotheses outlined in chapter 3, possible objectives for survey and monitoring include:

- Identifying impacts of individual effect types (chemical; disturbance; fragmentation; invasion by non-native plants) 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;
- Identifying impacts of cumulative effect types from cumulative development on individual woods.

Impacts of nearby development can only be detected and attributed if appropriate and timely surveys are undertaken. Design, implementation and interpretation of results needs to take into account that woods can suffer from effects that may take many years to become apparent and the need for adequate control of variables, if changes are to be attributed to any one particular cause (Corney *et al.* 2008).

Appropriate baseline data needs to be captured for individual woods close to developments for which planning permission has been granted but where operations have not yet commenced and for suitable control sites. Repeat surveys then need to be undertaken over time.

Some data collection should be generic to all development types, e.g. woodland area and ground flora composition. Surveys should also specifically target those effects most likely to be associated with each of the development types listed above. Techniques are presented that may assist in the detection of the different effect types. Recommendations are provided on methods most appropriate to each development type.

7.3 Sample selection

Whichever objective identified in 7.2 is being addressed, there is a need to control for the widest range of environmental variables, ideally including:

- Distance from the development to the nearby ancient woodland;
- Proximity to other developments;
- Land cover/use between the development and the nearby ancient woodland, particularly within 500m of the wood;
- Ancient woodland size;
- Geology, soil type and pH;
- Altitude;
- Topography between the development and the wood;
- Topography within the wood;
- Woodland aspect;
- Woodland type (i.e. dominant tree species);
- Woodland management.

In practice, this means that a control site or sites (where development is not anticipated to occur) should be selected that share the same characteristics, in terms of these variables, as the site affected by development. To increase the robustness of results in relation to any of the objectives, the ideal would be to select a random stratified sample of sites affected by a particular development that represent a range of values in relation to all of these variables and a matching series of control sites.

There is also a need to anticipate the individual and cumulative effects of both individual and cumulative developments, and to attempt to select sites accordingly. Such a suite of sites could only be accumulated over time in response to planning permission being granted on developments close to ancient woods. The need for repeat surveys over a long time-span means that costs and practicalities, such as permission to survey, need to be borne strongly in mind from the outset.

Existing literature suggests that atmospheric pollutant effects associated with some development types (i.e. transport; commercial and industrial; intensive livestock farming; energy; quarrying, mineral and aggregate extraction) may be apparent at distances of up to 5km from the source. In such cases, it will be important to select a number of ancient woods at an increasing distance from the development in order to determine any effect gradient. Selection of matching control sites will require great care, to ensure that any results of monitoring are not confounded by effects from pre-existing developments within their vicinity.

7.4 Site information

Irrespective of development type, information concerning all environmental variables identified in 7.3 should be collected for sites affected by development and for control sites, during the initial site survey. Phase 1 methodology (Joint Nature Conservation Committee 2004b) may provide a useful means of recording adjacent and intervening land use/habitat data. This is a technique for rapid, visual recording of vegetation and land-use information over large areas of countryside. It uses a standardised alphanumeric and coloured descriptor sequence on an appropriately scaled map. Phase 1 information should be accompanied by an aerial photograph (if available), and notes, which describe the extent, boundaries, and exterior features of the woodland and adjacent habitat/land use in a detailed fashion. This information should be updated on subsequent visits, such that it provides an on-going comparison with the baseline assessment.

7.5 Sampling methodology

Two over-arching sampling methodologies are available: permanent plots allowing relocation in subsequent visits; or a structured representative assessment. There are advantages and disadvantages associated with both. Structured representative assessment is recommended. This technique avoids the sometimes lengthy process of placing, maintaining and relocating permanent plots but does not allow direct quantitative comparison of plots between years. However, it does allow semi-quantitative and qualitative comparisons to be made within and between woods in a structured but flexible manner.

Following the CSM methodology (Joint Nature Conservation Committee 2004a), the assessment should be based on a 'structured walk' that gives a reasonable and broadly representative coverage of the site, with a series of 10 observation stops. To reduce subjectivity in selecting stopping points, these should be marked on a map at an appropriate scale (e.g. 1:10,000) prior to entering the woodland and found using a Global Positioning System (GPS). Mapping is, therefore, associated with locating these points, rather than plotting points at which the surveyor has stopped. The route should include paths but should not be confined to them. It should traverse different stand types (i.e. dominant tree species and/or ages) and contours. As the purpose of monitoring is to detect change between visits, the route should overlap with that taken previously. However, some variation may be useful, particularly if the site dossier notes that a concern has been raised on, or subsequent to, a previous visit.

In order to assess the distance to which effects may penetrate into the woodland, at least two recording points should be located within each of the following zones, focusing on the side of the woodland facing the proposed development:

- Woodland edge: from boundary to10m into the woodland;
- Intermediate zone: between 10m and 50m into the woodland;
- Woodland interior: more than 50m from the woodland edge.

Some small or narrow woods may not have an interior and, in such cases, recording should be undertaken throughout the wood.

7.6 Recording

Recording sheets should be completed while on site, complemented by an overall site appraisal written at the end of the survey. This information, together with maps and photographs taken, should be stored securely as a site dossier.

Recording should occur at each of the 10 observation stops. Supplementary notes should also be made between each of these points. At each stop the surveyor should consider the surrounding area and attempt to briefly describe the woodland. This may equate to roughly a 50 x 50m plot, although its measurement is unnecessary.

Recording sheets should focus upon gathering information relating to the hypothesised effect types (see Table 7.1) using the methods detailed below. This information should be accompanied by explanatory notes and photographs.

Table 7.1. Monitoring methods suggested for each development type (appropriate method, ● ; consider method on a case-by-case basis, ○)

	Chemical	**Disturbance**	**Fragmentation**	**Non-native species**	**Cumulative effects**
Small housing developments	○	●	●	●	●
Transport	●	●	●	●	●
Commercial and industrial	●	●	●		●
Intensive livestock farming	●		●		●
Energy	●	○	●	●	●
Quarrying/mineral extraction	●	●	●		●
Waste disposal	●	○	●		●
Leisure and sport	○	●	●		●
Military activity		●	●	○	●
Water management		●	●	○	●
Permitted development	○	●		○	●
Urbanisation	●	●		●	●

7.6.1 Chemical effects

One of the simplest means of assessing chemical changes is to collect soil samples for subsequent analysis. This will allow measurement of soil pH, and levels of potassium, magnesium, and phosphate. Soil samples should be collected at observation points 2, 5 and 9. Samples should be taken from the top 10 cm of soil, using a trowel, and placed into separate sealed polythene bags taken for this purpose. Measurement of pH should be made, as soon as possible, on fresh samples. These should then be air-dried and sent to a relevant laboratory for determination of other chemical changes (Bunce & Shaw 1973).

Surveyors should be vigilant and record signs of herbicide, or other toxic chemical effects, (i.e. areas of dead or decaying vegetation) and eutrophication (i.e. stands of nitrogen-loving plants, such as common nettle *Urtica dioica* and cleavers *Galium aparine*). These may be particularly evident at woodland edges but may also occur within the woodland. Any cases of abnormal tree crown damage, defoliation, or leaf discolouration should also be recorded.

7.6.2 Disturbance

Anthropogenic disturbance and its specific cause should be recorded, including:

- Areas of trampled vegetation;
- Areas of bare ground;
- Paths and tracks;
- Rubbish;
- Garden waste;
- Fire/camp sites;
- Relocation or removal of standing live or deadwood (i.e. cut stumps, stems, or branches);
- Vandalism;
- Levels of surface water bodies;
- External noise associated with nearby development, which is apparent within the woodland;
- External shading or artificial light associated with nearby development, which is apparent within the woodland (the latter may require a night-time assessment);
- Human activity occurring outside the woodland (e.g. vehicular movement) which is visible from within the woodland.

7.6.3 Fragmentation

Barriers to species movement are likely to be created during construction, although in some cases they may develop as a result of subsequent use (e.g. eutrophication or accumulation of toxic chemicals in surrounding land). In either case, ongoing consequences, such as species loss, may occur over a considerable time-scale. Therefore, habitat connectivity should be assessed before construction of the development. It is recommended that a Geographical Information Systems (GIS) modelling approach is used, such as BEETLE - Biological and Environmental Evaluation Tools for Landscape Ecology (Watts *et al.* 2005; Watts *et al.* 2007a; Watts *et al.* 2007b).

7.6.4 Invasion by non-native plants

Presence and a visual estimate of percentage cover of species known to invade woodland should be recorded at each stop, using the DOMIN scale. These include: rhododendron *Rhododendron ponticum*; cherry laurel *Prunus laurocerasus*; Japanese knotweed *Fallopia japonica*; and Indian balsam *Impatiens glandulifera*.

It is suggested that the presence and percentage cover of the following species are also recorded:

- Himalayan honeysuckle (Pheasant berry) *Leycesteria formosa*;
- Shallon *Gaultheria shallon*;
- Snowberry *Symphoricarpos albus*;
- Wilson's honeysuckle *Lonicera nitida*.

7.6.5 Cumulative effects

Plant and bird communities should be recorded at each of the stops along the structured walk. This will require specialist surveyors.

Ground flora should be recorded by placing a 4m quadrat in typical vegetation at the stop point. All species present within this area should be recorded and a visual estimate of the cover of each species recorded using the DOMIN scale.

Bird surveys should be conducted using Common Bird Census or Breeding Bird Survey methodologies in order to obtain territory estimates (Gilbert *et al.* 1998). All bird species that are identified, either by call or sight, at each stop should be recorded. In order to standardise such recording, it will be necessary to record for a specific duration only (e.g. 10 minutes) at each stop.

Birds and plants that are not present or recorded during structured walk stops, but are encountered during the walk, should be noted.

7.7 Survey frequency

An initial survey should occur prior to development at sites affected and concurrently at control sites. This survey and repeat surveys should always be conducted during the same calendar months to limit recording bias, ideally during April-May. For example, many woodland plants only appear above ground for a limited period in spring, e.g. wood anemone *Anemone nemorosa,* and may be overlooked from June onwards. Similarly, bird species which call repeatedly during the breeding season may be less apparent later in the year. For birds, May would be better than April allowing most summer migrants to have arrived and established territories within woodland.

Dependant on the length of the construction phase, a repeat survey or surveys should be undertaken during this period, as effects of development may be differentially associated with construction, in comparison to the operating phase. Thereafter, monitoring visits should be repeated at least once every year for the first five years and subsequently at regular intervals, informed by monitoring results, on a permanent basis. This might be as infrequent as every five years. This regime needs to be maintained at all sites selected, both those affected by development and control sites. Care should be taken to ensure that the latter continue to remain valid, i.e. that they do not themselves become potentially affected by nearby development in ways that may confound interpretation of results.

8 Conclusions

8.1 The value of ancient woodland

Ancient woods have considerable ecological continuity and support more threatened species than any other habitat in the UK. However, only around 550,000ha of ancient woodland remains across the whole of the UK. It is a finite and functionally irreplaceable resource for biodiversity that is also an important part of our cultural heritage.

8.2 Development impacts

The importance of ancient woodland is recognised in recent national planning policy guidance across the UK and planning authorities and inspectors increasingly act to prevent its direct destruction. However, a wide range of development types affect nearby ancient woodland, including: housing; 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; and cumulative development. It is hypothesised that these cause five main impacts: chemical effects; disturbance; fragmentation; invasion by non-native plants; and cumulative effects.

Evidence examined demonstrates that all development types (with the exception of permitted development) are associated with substantial effects of at least one impact type (chemical effects, disturbance, etc.). In addition, some kinds of development are likely to be associated with the effects of multiple impact types. Evidence indicates that transport and cumulative development (urbanisation and cumulative fragmentation) are likely to have the greatest impact, arising from multiple effects.

8.3 Chemical effects

Chemicals, such as herbicides, pesticides, heavy metals, toxic or nutrient-rich leachates, and sulphur and nitrogen oxides, may reach ancient woodland from nearby development through a range of mechanisms. These include: aerosol or spray drift; the application of road-salt; contaminated surface and ground water flows; deposition of dust, particulate and gaseous pollution; localised acid-rain events; deliberate dumping of rubbish or garden waste into woodland; and accidental release or spillage of hazardous substances.

Chemical effects on nearby ancient woodland include: population-level responses to lethal and sub-lethal doses of toxic chemicals, or nutrient enrichment, that can significantly alter the composition of the ground flora and lichens, mosses and liverworts growing on trees or rocks; reduced tree health by inhibiting root development and retarding growth, increased drought and frost susceptibility, defoliation, or leaf discoloration, poor crown condition, and the promotion of insect damage; poisoning of animals, leading to mortality, reduced feeding rates, or species avoidance; and loss of soil micro–organisms, including tree mycorrhizae, thereby affecting decomposition and nutrient cycling.

Evidence indicates that transport, commercial and industrial development, intensive livestock units, energy, quarrying and mineral extraction, waste disposal facilities, and cumulative development all have the potential to create substantial chemical impacts on nearby ancient woodland.

Chemical effects arising from development should be avoided wherever possible, by maintaining minimum distances between new development and existing woodland. The construction-related chemical effects of nearby development should be managed through agreement and implementation of Environmental Management Plans. Ongoing impacts should be mitigated through the creation of woodland buffer zones of an appropriate width.

8.4 Disturbance

Development in the vicinity of ancient woods may cause direct disturbance effects as a result of: modified local hydrological regimes; vibration; noise and light pollution; vehicular collisions with wildlife; external activity visible from within the wood; an increase in wind-blown litter accumulation; and tree surgery or felling along the woodland edge for safety reasons or subsidence prevention.

Development near to ancient woodland increases the likelihood of unmanaged public access, leading to: trampling of vegetation and soil compaction; removal of dead wood or plants; acts of vandalism, and the dumping of rubbish or garden waste. Further indirect effects include predation of woodland fauna by pets or large-bodied birds that may be attracted to the area.

Disturbance may result in more frequent biologically-costly flushing events and increased mortality of animal species. Noise and light pollution interfere with interactions between species, affecting foraging and predation, reducing breeding success and thereby affecting ongoing population viability. Disturbance may, therefore, lead to species being eliminated from woods.

Engineering works or vegetation clearance near to ancient woodland may affect woodland hydrology, increasing the likelihood of water-logging or drought and leading to loss of trees and changes in species composition. Soil compaction adjacent to woodland increases water run-off and soil erosion. It can cause severe damage to tree roots, leading to tree defoliation, crown dieback, and death.

Evidence indicates that housing, transport, commercial and industrial development, quarrying and mineral extraction, leisure and sport, military activity, water management and cumulative development all have substantial potential to disturb nearby ancient woodland.

Developments likely to cause disturbance should be located away from ancient woodland, particularly those likely to modify local hydrological function. Where development is located near to ancient woodland, buffer zones should be retained to reduce the distance that disturbance penetrates. If possible, access to the woodland should be limited or managed.

8.5 Fragmentation

Ancient woodland is a highly fragmented habitat. New development may be associated with the destruction or alteration of semi-natural habitats in the vicinity of ancient woods and the creation of large areas of terrain inhospitable for woodland species. Therefore, development may increase the distances between favourable habitats that woodland species must cross to disperse, forage, or breed. In addition, developments that create chemical or disturbance effects that penetrate nearby ancient woodland may effectively reduce woods to smaller functional habitat islands. As a result, new development may significantly fragment ancient woodland habitats, creating substantial barriers to species movement, interrupting natural flows between habitat patches, sub-dividing populations, and altering the population dynamics of associated species and communities.

Transport and urbanisation, in particular, may create major landscape-scale barriers to movement of woodland species. However, evidence suggests that all development types may lead to further isolation of ancient woods. Nevertheless, the net impact of a development on fragmentation depends on the existing land cover and land use. For example, some new developments are associated with the creation of extensive rough ground or planted areas, which may have potential to increase connectivity if sited on intensive-arable farmland.

Landscape-scale connectivity of ancient woodland should be considered in all local and regional development plans. Development mitigation should seek to enhance the ability of woodland species to move between ancient woods.

8.6 Non-native plant species

The likelihood of ancient woodland being invaded by non-native plant species is increased by a range of factors associated with construction, including soil excavation and movement, altered environmental conditions and modified hydrological processes. Nutrient enrichment from developments, such as transport corridors, intensive livestock units and residential gardens, also increases the risk of non-native plant species invading woodland on an ongoing basis.

Research indicates that the proportion of non-native plant species in an area rises with increasing density of human population. As a result, evidence suggests that cumulative development is likely to promote non-native plant species invasion into ancient woodland, particularly in relation to housing, transport and energy infrastructure.

Developments that may provide ongoing sources of invasive non-native plants should not be placed close to ancient woodland. Where development does occur near ancient woodland, potential construction-related invasion pathways should be managed pro-actively using a structured approach to reduce risk.

8.7 Cumulative effects

Ancient woodland is the recipient of the sum of a wide variety of effects generated by multiple developments and development types. There are frequently long time lags before the combined impacts of chemical effects, disturbance, fragmentation and invasion by non-native plants become apparent and they are inadequately covered in the published literature. It is, therefore, of critical importance that future research focuses on establishing the cumulative effects of development near to ancient woodland.

9 References

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10 Appendix

Table 10.1. Thematic areas, research topics, and keywords used to search for relevant literature

Thematic area	Research Topic	Keywords	
Development	Agricultural chemicals	Fertiliser drift	Spray drift
	Agricultural stock	Chicken	Pig unit
		Dairy	Poultry
		Pig	
	Agriculture	Animal waste	Field boundary vegetation
	Commercial & industrial	Factory	Plant machinery
		Manufacturing plant	Warehousing
		Office	
	Energy	Gas line	Power-line
		Gas repeater station	Services
		Phone line	Sub-station
		Pipeline	Wind turbine
		Power station	
	Leisure and sport	Camping	Recreation
		Caravan	Shooting
		Clay pigeon	Stadium
		Golf course	War game
		Paint-ball	4 x 4
	Military installation	Bombing range	Military
		Firing range	Training area
	Permitted development	General Permitted Development	Minor development
		House extension	Residential
	Quarrying	Aggregate	Open cast
		Mineral extraction	Quarry
	Transport	Airport	Race track
		Highway	Railway
		Motorway	Road
		Port	
	Urbanisation	Caravan park	Mobile home park
		Hospital	School
		Housing	
	Waste disposal	Dumping	Litter
		Incinerator	Recycling plant
		Land-fill	
	Water management	Drainage	Internal drainage
		Flood defence	

Continued overleaf …

Thematic area	Research Topic	Keywords	
Ecological impact	Chemical change	Aluminium	Ozone
		Ammonia	Phosphate
		Ammonium	Poisoning
		Critical load	Pollutant
		Leachate	Pollution
		Magnesium	Sulphur
		Nitrate	Toxic compound
		Nitrogen	
	Chemical process	Acidification	N deposition
		Deposition	Nitrogen deposition
		Eutrophication	
	Connectivity	Connectedness	Forest continuity
		Connectivity	Landscape connectivity
		Corridor	Network cohesion
	Disturbance	Anthropogenic disturbance	Light pollution
		Disturbance	Noise pollution
		Human disturbance	Vibration
	Fragmentation	Area reduction	Habitat isolation
		Fragment	Increased edge habitat
		Fragmentation	Woodland fragment
	Impact	Choke	Recruitment limitation
		Dieback	Reproductive success
		Drought	Ruderalisation
		Dumping	Suffocate
		Fire	Trampling
		Hydrology	Water stress
		Increased salinity	Water table
		Local extinction	Waterlogging
		Nesting success	Wildlife casualty
		Predation	Windthrow
	Non-native species	Biological invasion	Plant invasion
		Exotic species	Weeds
		Invasive species	
	pH	Acid	pH-gradient
	Spatial factors	Area relationship	Mosaic
		Core area	Spatial cohesion
		Edge effect	Species-area relationship
		Forest edge	

Continued overleaf …

Thematic area	Research Topic	Keywords	
Woodland ecology	Ancient forest plant species	Ancient forest species Ancient woodland species	Ancient woodland indicator species
	Animal ecology	Animal ecology Animal movement Animal population	Fauna Foraging
	Avian ecology	Bird Bird populations	Bird species distributions Breeding bird
	Biodiversity	Biodiversity Biodiversity indicators	Biological diversity Breeding success
	Colonisation & dispersal	Colonisation capacity Corridor	Dispersal limitation Range contraction
	Conservation & management	Conservation management Mitigation Species conservation	Wildlife conservation Woodland management
	Context	Adjacent land-use Farming	Urban
	Ecosystem function	Ecological process Ecosystem Natural regeneration	Species diversity Species richness
	Functional type	Plant functional type Plant strategy	Plant trait
	Genetics	Genetic diversity	Inbreeding depression
	Habitat & niche	Habitat diversity Habitat edge Habitat island	Habitat loss Habitat quality Niche limitation
	Invertebrate ecology	Butterflies Coleoptera Insect Invertebrate	Lepidoptera Mollusc Saproxylic
	Monitoring	Ecological monitoring	Survey
	Nutrients	Nutrient availability Nutrient cycling	Nutrient leaching Nutrient stress
	Plant ecology	Botanical composition Flora Plant	Plant abundance Plant diversity Vegetation
	Population & community dynamics	Diversity Local-population size Minimum viable population	Population dynamics Rare species
	Response	Extinction Persistence Resilience	Stochastic extinction Stress
	Seedbank	Seed bank	
	Soil conditions	Soil chemistry Soil compaction Soil damage	Soil drainage Soil organic matter Soil surface disturbance