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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: BD2111
2. Project title: Trends, long term survival and ecological values of hedgerow trees: development of populations models to inform strategy.
3. Contractor organisation(s): Forest Research
4. Total Defra project costs (agreed fixed price): £ 51226
5. Project: start date .... 05 January 2009
   end date .... 31 July 2009

6. It is Defra's intention to publish this form.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

The main objective for the study has been to develop a population model for isolated hedgerow trees in order to review, and if necessary amend, the 2006 HAP targets for hedgerow trees, in particular the number of young trees required to ensure that the isolated hedgerow tree population remains stable or increases. The second main objective was to collate and review existing information on the biodiversity value of hedgerow trees with emphasis on invertebrates, comparing where possible the role of isolated hedgerow trees and lines of trees. With the exception of more limited development of an expert decision key in favour of quantitative models, the objectives have been met and the outcomes discussed at the Stakeholder Workshop held at Forest Research, Alice Holt Lodge on 24 July, 2009. Discussion points and suggestions from the Workshop have been incorporated in the results and recommendations in the report. The key outcomes and conclusions are:

The modelling component has provided both predicted figures for the rates of recruitment of hedgerow trees needed to retain the current population and has also indicated the level of sensitivity of these parameters to changing assumptions, including management and human intervention. Conclusions from various sources, commencing with the concerns expressed in the 1951 Forestry Commission study and subsequently in recent Countryside Surveys and by the Tree Council, all agree that hedgerow trees in Great Britain are in sharp decline. In bringing these sources together, the present study is the first to model the extent of the decline and to provide quantitative indications of the necessary recruitment rates to halt and, if possible, to reverse the decline.

Simulations from the model suggest that concerted action is needed both to accelerate recruitment of isolated hedgerow trees and, equally important, to reduce the rate of mortality in the older cohorts of those trees.

The numbers of hedgerow trees needed 'just to stand still' are demanding:

- Annual recruitment of around 30,000 trees across GB is needed to stabilise the current population of 1.60 m isolated hedgerow trees, which is already reduced from the 1.67 m trees recorded in the CS2000 (adjusted downwards from the widely published figure of 1.8m trees);
- In relation to age structure/size of trees to ensure sufficient recruitment of new trees, an estimated 45% of hedgerow trees need to be <20 cm dbh, which compares unfavourably with the recorded value of 19%. This further emphasises the lack of recruitment at the required level needed to maintain a viable population of isolated hedgerow trees;

- Only 15,000 trees are currently being recruited annually. On this basis, the model projects a drop in total isolated hedgerow trees to as low as 1.05m trees over the next 50 years;
- From discussions at the Workshop in July 2009, it appears that mortality of older trees is accelerating in some areas of the country, although the cause of this mortality is unclear. There is some evidence that concerns about Health & Safety from unhealthy trees arising from the *Poll vs Bartholomew* judgement may lead to premature felling of trees where there uncertainty about their stability;
- The dominance of ash and oak in hedgerow tree populations may compromise future recruitment and survival trends, especially as these two species appear to be showing evidence of increasing decline in relation to climate change.

Ecological values directly applicable to isolated hedgerow trees have been difficult to assess and quantify. There is remarkably little verifiable and direct study on the absolute and relative roles of hedgerow trees as ecological features of the landscape. Overall, the indications were that isolated hedgerow trees have distinct and, sometimes, unique ecological values that would contribute significantly to the ecosystem services offered by this resource. Key findings were:

- Trees within a hedgerow are likely to encourage a wider range of invertebrate species than would otherwise be the case both by provision of greater niche availability and provision of shelter;
- Studies of moths by Merckx et al and of Diptera by Peng et al have shown clearly that abundance and diversity of the two invertebrate groups are enhanced by proximity to hedgerow trees, with further linkage to the width of the hedge and field borders;
- Inferences on interactions of BAP priority species with hedgerow trees suggest that many species benefit from the presence of this ecological resource, by virtue of structure and stability as well as enhanced food resources;

Bats and birds benefit from hedgerow trees both as roosts/breeding/feeding sites and as connecting features to facilitate movement through the wider landscape. In particular, the ‘darkness quality’ provided by canopy shading is likely to extend the foraging period by bats in the early evening as well as providing perches for some species.

Simulations of the recruitment and loss rates of isolated hedgerow trees, therefore, provide a quantitative measure of the scale of losses and the necessary replacement rates to be able to maintain or increase this valuable resource. While the ecological roles and values of hedgerow trees are regarded as positive, albeit with relatively few specific studies to quantify this contribution, there are many other attributes of hedgerow trees that support their retention in the landscape.

Landscape values

Other than the ecological values that have been the subject of review in this project, a related but highly valued attribute of hedgerow trees is the perception of how they fit into the wider landscape. This has been the subject of Landscape Character Assessment through the Countryside Agency with Natural England, Scottish Natural Heritage and Countryside Council for Wales. Information is brought together by the Landscape Character Network.

The British countryside has been divided into a series of National Character Areas, reflecting the particular landscape characteristics of each area. Some of these are highly relevant to the current topic of hedgerow trees and have been highlighted by Stokes & Hand (2004). For example, at the time of their review Stokes & Hand indicated that 38 areas (roughly 25% of the countryside) had hedge trees, shelterbelts and field boundaries as essential features of the landscape. These, and other, examples show that trees in hedgerows remain essential features of the landscape which are not just visual but provide links between local and regional landscape types. Issues of retention or extension of these National Character Areas are further drivers for more focussed policy for managing the dwindling population of hedgerow trees.

Lichens as ecological indicators

Although recognised as potentially valuable indicators of both air quality and local tree quality in this review, no specific assessment of lichen species abundance and diversity has been carried out. One of the interesting areas for further work is the relative capacities of trees within the hedgerow compared with wayside trees (i.e. along roads but not within the hedgerow itself) to support priority lichen species.

Felling of hedgerow trees

There are concerns at the number of mature trees being felled for Health & Safety reasons next to public highways, particularly arising from the *Poll vs Bartholomew* judgement of a duty of care to provide expert inspection and judgement on the stability of a given tree. For example, the felling of around 20,000 trees in Devon, felling in Wales and in Northern Ireland. Although there is a move to provide a British Standard on dealing with hazardous trees and consideration within the National Tree Safety Group of guidance on hazardous trees, decisions on whether trees should be felled still remains uncertain.

Improvement in datasets and future monitoring

While there are excellent data from a number of sources, notably Countryside Surveys and Forestry Commission National Inventory of Woodlands and Trees, these all suffer from the relatively long periods between each cycle and the difficulty of ensuring precise positional information to enable local and regional rates of change to be quantified. The use of remote sensing should be an important part of any future surveys, particularly since techniques such as Lidar and ground radar are now being refined to enable tree height and volume to be estimated.

Recommendations from the study

1. An integrated approach to hedgerow tree management is urgently required. This should address the reasons for the serious decline in the numbers of trees and also develop strategies to plant new trees or encourage growth/regeneration from within the hedge. The new model developed in this study should be used to guide an evolving strategy, particularly with respect to regional trends and relative predicted contributions of different tree species.
2. The shortage of quantitative studies directly addressing the ecological roles of isolated hedgerow trees is a concern and should be addressed through more focused ecological studies. Scoping of a research programme to address the contributions of trees within hedgerows relative to isolated woodland and parkland trees and trees within linear features should be carried out. While invertebrates would remain as keynote indicators, their interactions with birds and bats within a quantitative framework would add value to a future research programme. Similarly, the microclimate attributes of trees within and in proximity to hedgerows should be linked to research on lichens in this habitat type.
3. Future survey and monitoring techniques should maximise the use of new remote sensing techniques both to aid quantification of trees within the hedgerow environment and to increase the frequency of assessment. In this way, trends in numbers can be assessed at a range of geographic scales and linked to the management and modelling recommendations above.
4. Data on tree species numbers within hedgerows are heavily skewed to oak and ash. Further research is needed, particularly related to future climate change scenarios, to determine whether this species mix is likely to be resilient and whether efforts to increase species composition should be increased.
5. Policies that determine whether tree felling for Health & Safety reasons is appropriate and justified should be reviewed, by research on the level of such felling and linkage to the National Tree Safety Group, leading to preparation of guidelines which link to the emerging policy in recommendation 1. Advice on risks from trees already exists and the different sources should be assessed to ensure that all available sources are easily accessible and consideration given to revising, updating and re-publishing key sources.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

Objectives of the Study (as defined in the original contract proposal and contract agreement)

The main objective for the study was to develop a population model for isolated hedgerow trees to review, and if necessary amend, the 2006 HAP targets for hedgerow trees, in particular the number of young trees required to ensure that the isolated hedgerow tree population remains stable or increases. The second main objective was to collate and review existing information on the biodiversity value of hedgerow trees, comparing where possible the roles of isolated hedgerow trees and lines of trees. These objectives were delivered through a structured approach involving the following main steps:

1. Using a range of datasets, a population model was developed to predict the number of replacement trees required to maintain a viable population of isolated hedgerow trees in Great Britain.

2. Using literature and expert knowledge, the biodiversity value of hedgerow trees was assessed with particular reference to invertebrates, comparing where possible the ecological differences in habitat and species of isolated hedgerow trees and lines of trees. While the study concentrated on invertebrates, other ecological groups were considered in the context of the particular habitat and its connectivity to other landscape components (e.g. birds, mammals).

3. Although there was an intention to review the threats to the survival of hedgerow trees, including any information on the impact of agricultural operations and likely effects of climate change, the data sets from the literature were insufficiently robust to allow this to be done in detail. Some consideration was given to development of an expert decision key to enable land managers to predict the likely future of their hedgerow trees either at hedgerow scale, farm scale or more widely.

4. The study identified and recommended future data gathering and research requirements to fill gaps in knowledge of the biodiversity of hedgerow trees and its maintenance and the information needed to verify the predictions of the population model.

5. The outcomes of the research were presented at a stakeholder workshop focussing on:
- Delivery of the main conclusions from the study,
- Discussion on future research requirements to underpin policy on hedgerow trees
- Consideration of field verification of the predicted outcomes from the current study.

With the exception of more limited development of an expert decision key in favour of quantitative models, the objectives have been met and the outcomes were discussed at the Stakeholder Workshop held at Forest Research, Alice Holt Lodge on 24 July, 2009 (a list of participants is in Appendix Table 10). Discussion points and suggestions from the Workshop have been incorporated in the results and recommendations in this report. Methods employed and results are presented in two main sections dealing with the model and biodiversity reviews respectively.

I: A model to describe and predict loss and required recruitment rates of isolated hedgerow trees

Recent countryside surveys have suggested that the stock of isolated hedgerow trees is in severe decline both for total trees and for the number of trees in the youngest age class. All the available data suggest that there are probably insufficient young trees to replace the older trees over the coming years with the consequence that the HAP target will not be met. The most recent set of data, The Countryside Survey 2007 (CS2007), showed that there were an estimated 1.6 million individual isolated hedge trees in Great Britain, of which just 350,000 trees were classified into the two smallest size classes (expressed as diameter at breast height, dbh), namely <3cm and 3-20cm .

The aim of this project was to combine the latest 2007 hedgerow dataset with data from the previous 50 years to develop and test a population model for hedge trees which can provide vital statistics on the number of new trees that may require planting on an annual basis and dbh class distributions associated with hedge tree populations that are classified as declining, stable or increasing.

1. Methods and data handling

Historical datasets

For many years the status of isolated hedgerow trees has been difficult to assess with few surveys collecting often incomparable datasets. Counts of trees have tended to be classified using either age, dbh or height classes but with little consistency in either the number of classes or their ranges.

Major datasets collected within the last 60 years include the Forestry Commission Hedgerow and Park Timber and Woods under Five acres 1951, The Forestry Commission Census of Woodland and Trees 1979-1982, the Forestry Commission National Inventory of Woodland and Trees (NIWT) 1995-1999 and the set of Countryside Surveys undertaken in 1984, 1990,1998 and 2007. Data from each of these surveys, which relate partially or completely to individual isolated hedgerow trees, are summarised for Great Britain in Appendix Table 1.

Although it is impossible to extract consistent long term data information on isolated hedgerow trees from these datasets there are obvious differences in the distribution of the numbers of young and old trees. The most recent Countryside Surveys highlight a much greater percentage of older trees in the population in comparison to the 1951 and 1979-1982 Surveys (Appendix Table 1). This is a worrying trend as any viable population requires sufficient younger trees to be recruited to ultimately replace the natural mortality of older ones. In fact in 1951, when the population distribution of hedgerow and park trees was showing a much "healthier" distribution than currently, the following observation was made after consideration of dbh class ratios, growth and recruitment rates;

".. the figures suggest that the volume of hedgerow timber is likely to diminish eventually, through insufficient recruitment of young trees, unless further planting is carried out".

The current model approach addresses the recruitment and mortality rates for sustainable hedgerow tree populations explicitly.

Data handling and modelling methods

Data

Using the CS2000 and CS2007 datasets it has been possible to extract individual tree data for four age-related population size classes, <3cm, 3-20cm, 21-50cm and >50cm diameter at breast height (dbh). It has also been possible to link the two surveys together as the vast majority of sample squares were surveyed at both time periods. Using individual hedgerow tree data from the CS2000 survey (Appendix Table 2), it has been possible to cross-reference each tree with its status in 2007 to record how many remained within their dbh size classes, the number growing into the next dbh class and the amount of natural mortality within each dbh class. As the data were recorded over a period of 9 years, all survival, transitional and mortality rates were converted to an annual rate using the standard negative compound interest formula. Trees dying between surveys were referenced to their initial dbh class regardless of their size at death as it is generally accepted that this does not lead to any serious bias unless the period between re-surveys is long. Estimated annual survival rates are given by region and major tree species in Tables 1a and 1b respectively.

Given the extremely uneven and often sparse distribution of hedgerow trees across region and tree species, it was not possible to reliably analyse regional and species specific components of the hedgerow population. Consequently all modelling effort was focussed on developing a population model for total GB hedgerow tree numbers.

Table 1: Annual hedgerow tree survival rates by dbh class a) GB region and b) major tree species (n>100)

a)		n	<3cm	3-20cm	21-50cm	>50cm
England	Easterly Lowlands	1392	0.967	0.980	0.980	0.981
	Westerly Lowlands	1527	0.885	0.983	0.985	0.991
	Uplands	95	1.000	1.000	0.972	0.994
Scotland	Lowlands	78		1.000	0.990	0.990
	Intermediate Uplands	4		0.926		1.000
Wales	Lowlands	159		0.983	0.982	0.993
	Uplands	237		0.926	0.964	0.936
GB		**3492**	**0.960**	**0.981**	**0.981**	**0.984**

b)		n	<3cm	3-20cm	21-50cm	>50cm
GB	Ash	1331	0.903	0.985	0.983	0.978
	Hawthorn	108		0.984	0.959	0.932
	Oak	1180	0.956	0.985	0.989	0.988
	Sycamore	174		0.979	0.990	0.983

Matrix model construction

A Lefkovitch projection matrix model (Caswell 1989) was used as the basis of the population model. This form of model can be used to:

i. predict future population trends for long-lived species that may have undergone changes in one or more vital rates.
ii. assess the influence of a particular rate on the growth of the population as a whole
iii. evaluate various management strategies.

This model, shown in Appendix Figure 1a, is defined by the equation:

$n(t+1) = An(t)$

where n(t) and n(t+1) are population vectors at time t and t+1, and A is a square matrix containing transition probabilities among dbh classes during one time step.

Elements (a_{ij}) of matrix A can be grouped into growth (G, elements in the sub-diagonal of the matrix, stasis (P, elements in the diagonal of the matrix), and fecundity (F, the upper row, except for the top-left element).

As detailed above, the transition matrix was populated using the estimated probabilities from the CS2000 and CS2007 Surveys. Estimates of the cells, P_1 and G_1 however, proved problematical. As expected, all trees in the <3cm class in 1998 grew into the 3-20cm dbh size class in 2007, with the result that an annual transitional rate probability could not be directly estimated. Estimates were obtained by assuming newly recruited trees in the <3cm dbh class remain within the smallest dbh class for the first 4 years of their life.

A final adjustment to the standard matrix projection model was made to simplify how regeneration was incorporated into the model. As it was unclear how many newly recruited trees came from natural regeneration, how many from new plantings and how many from the existing cohort of smaller trees within the hedge itself, it was decided to combine these elements together. This was achieved by setting elements F_3 and F_4 to zero and by adding an additional "new recruit" vector to the standard model, Appendix Figure 1b:

$$n(t+1) = An(t) + r$$

where r^T is the vector (r_1, r_2, 0, 0),
r_1 is the number of new recruits per year in the <3cm dbh class, and
r_2 is the number of new recruits per year in the 3-20cm dbh class.

Appendix Table 3 details the estimated transition matrix for isolated hedgerow trees in GB with fecundity in A set to zero.

Analysis of new recruits in the CS2008 dataset (i.e. isolated hedgerow trees that were present in a CS2008 sample square but not present in the same sample square in CS2000) suggested that trees were being recruited to the 3-20cm dbh class at a rate of 7.5 times greater than that of recruitment to the <3cm dbh class. This would tend to suggest that currently there is little natural regeneration or re-planting taking place and that most new tree recruits are emerging from the body of the hedge and, being both larger and more established, are classified immediately into the 3-20cm dbh class. This is a significant finding and suggests that further work is needed to classify age and size classes in surveys of hedgerow trees.

Stochasticity

Matrix models can be either deterministic (all vital rates are constants) or stochastic (vital rates vary over time). If environmental variation is low, or if little or no information is available on its magnitude, then a deterministic matrix is often used. However for the hedgerow tree population, it was possible to construct a stochastic matrix model using temporal and individual tree information from the Countryside Survey datasets. Uncertainty in transitional and survival probabilities were estimated using standard binomial distribution theory and temporal and individual variation modelled using normal and binomial distributions respectively.

A stochastic matrix model was written in the computer language Fortran77 to project population sizes over time and to assess the probability that the population would fall below a certain threshold. It was also possible to assess changes in the distribution of trees within the four dbh size classes.

Scenario modelling

To project the population size over a period of 50 years, a 1000 simulations were run for a series of recruitment rate scenarios varying from 0 to 50,000 trees per year. Within each simulation the following steps took place.

i. First, random values were drawn for survival and transitional probabilities using appropriate mean, standard deviation and distributional properties, ensuring survival probabilities did not exceed 1.
ii. Secondly, the transition matrix A was constructed using these random values and the vector n(t) formed by drawing a random normal selection from the CS2007 data summary table of the number of hedgerow trees within each of the 4 dbh classes.
iii. Thirdly, and for each year of the simulation, individual survival and transitional rates were allowed to vary using random values from appropriate binomial distributions whilst the recruitment rate was held constant at a fixed annual figure.

Sensitivity

A sensitivity analysis of the transition matrix A was carried out to see how inaccuracies in the parameter estimates might affect predictions and also how sensitive the model was to changes in parameters that could be influenced by management intervention. Changes to easily manipulated parameters can have a significant effect on population survival.
The sensitivity analysis was achieved by temporarily setting parameters F_3 and F_4 of the transition matrix A to the value 0.0024 and cells a_{23} and a_{24} (to account for recruitment into the 3-20cm dbh class) to 0.0180. These values were chosen to simulate a growth rate of λ =0.994, being the average growth rate of the GB hedgerow tree population over the last 20 years, for the transition matrix A, 0.994 (Table 2). Sensitivity of individual survival, transitional and fecundity rates were then tested, varying parameters one at a time, by increasing and decreasing their parameter values by 10% and comparing this with percentage change in growth rate (λ) of A.

2. Results – simulations.

Predicted population trends

The stochastic population model was run for 50 years into the future with a range of fixed recruitment rates varying from 0 to 50,000 trees per year. The results are shown in Table 3.

Results show that unless a minimum of 30,000 trees are recruited on an annual basis then the population of hedgerow trees will be expected to decline. The current rate of growth, λ =0.994, estimated between the 1984 and 2007 Countryside Surveys, suggests that little more than 15,000 trees are being recruited on an annual basis and, if this rate is maintained, the numbers of isolated hedgerow trees will decline to between 1.05 and 1.35 million over the next 50 years.

Distribution of trees within dbh classes

The current GB distribution of trees in the 2 smallest (<20cm) and 2 largest (>20cm) dbh distribution classes are 19% and 81% respectively, CS 2007 in Appendix Table 4. Results from the population trend analysis, Table 3, suggest that such a distribution is associated with a population in severe decline. A stable or increasing population would be expected to have at least 50% of its trees with a dbh <20cm , a proportion that was apparently being achieved in the 1951 and 1979-82 Surveys (Appendix Table 4) after accounting for measurement class differences.

Table 2. Estimated annual survival rates for isolated hedgerow trees in England, Scotland and Wales 1984-2007. Source: Countryside Surveys 1984, 1990, 1998 & 2007

England	No. trees (000's)	Surveys	Annual growth rate (λ)
1984	1649		
1990	1634	84-90	0.999
1998	1495	90-98	0.990
2007	1427	98-07	0.995
		84-07	**0.994**
Scotland			
1984	14		
1990	34	84-90	1.105
1998	31	90-98	0.989
2007	30	98-07	0.996
		84-07	**1.034**
Wales			
1984	178		
1990	138	84-90	0.972
1998	141	90-98	1.003
2007	144	98-07	1.003
		84-07	**0.991**
GB			
1984	1840		
1990	1806	84-90	0.998
1998	1667	90-98	0.991
2007	1602	98-07	0.996
		84-07	**0.994**

Table 3: GB population model predictions for number of isolated hedgerow trees.

Annual recruitment of trees	**25 years**			**50 years**			Growth rate	dbh distribution (50years)			
	95% lci	median	95% uci	95% lci	median	95% uci	λ	<3cm	3-20cm	21-50cm	>50cm
0	914,000	**1,042,000**	1,174,000	577,000	**675,000**	792,000	**0.983**	0%	7%	27%	66%
5000	1,015,000	**1,142,000**	1,282,000	726,000	**837,000**	959,000	**0.987**	0%	19%	27%	54%
10000	1,111,000	**1,239,000**	1,380,000	876,000	**995,000**	1,131,000	**0.991**	1%	27%	26%	46%
15000	1,201,000	**1,338,000**	1,482,000	1,027,000	**1,154,000**	1,312,000	**0.993**	1%	33%	25%	41%
20000	1,295,000	**1,433,000**	1,577,000	1,157,000	**1,314,000**	1,466,000	**0.996**	1%	38%	25%	36%
25000	1,401,000	**1,532,000**	1,681,000	1,322,000	**1,472,000**	1,664,000	**0.998**	1%	41%	25%	33%
30000	1,482,000	**1,632,000**	1,790,000	1,458,000	**1,635,000**	1,834,000	**1.000**	1%	44%	25%	30%
35000	1,586,000	**1,733,000**	1,907,000	1,604,000	**1,794,000**	2,017,000	**1.001**	1%	47%	25%	27%
40000	1,673,000	**1,839,000**	1,995,000	1,748,000	**1,959,000**	2,207,000	**1.003**	1%	49%	25%	25%
45000	1,782,000	**1,932,000**	2,094,000	1,905,000	**2,124,000**	2,374,000	**1.004**	1%	50%	25%	24%
50000	1,866,000	**2,034,000**	2,201,000	2,029,000	**2,267,000**	2,551,000	**1.004**	1%	52%	24%	23%

Sensitivity Analysis

The effect on the population growth rate of a 10% change in either mortality or recruitment rates are shown in Appendix Table 5. Largest percentage changes in population growth were related to changes in the recruitment rate of young trees and the mortality rate of the >50cm dbh class. Smallest changes were related to the mortality rate of the smallest dbh class, <3cm, resulting from the fact, as previously mentioned, that most newly recruited trees currently “by-pass” this group and are first recorded in the 3-20cm dbh class.

3. Discussion – model outcomes and predictions.

Historically, hedgerow tree data have often been combined with data from other non-woodland locations such as parkland trees, clumps of trees and linear features. In addition, trees have been recorded by dbh, height and age classes with little or no consistency between surveys. Consequently any attempted comparison between datasets collected within the last 50 years will necessarily be subject to a number of assumptions. The comparative number of young trees to old trees, irrespective of the type of non-woodland tree, can often be assumed to give a good indication of the long term well-being of the population. In this study, GB datasets have varied between 17% and 55% in the component of young trees <20cm dbh and most alarmingly there appears to be a decline in this percentage to the present day.

Annual mortality rates are obviously a key parameter to the long term viability of any tree population. Data from the CS1998 and CS2007 surveys estimated average annual mortality to be 4% for the <3cm dbh class, 2% for hedgerow trees between 3-50cm dbh and 1.5% for the >50cm dbh class (Table 1). There was some evidence that survival, as might be expected, was better in lowland than upland areas but insufficient data to attempt a fit of separate parameter estimates within the population model.

Sensitivity analysis was used to examine the impacts of various rates within the population projection matrix. As expected the effect of changing the recruitment rate has a large influence on population growth as highlighted in the results of Tables 3 and Appendix Table 5. Although the sensitivity analysis highlighted the fact that a 10% change in the <3cm dbh class mortality rate had least impact on the population growth rate, improvements to their establishment and survival could still mean this could become a key component in the population’s wellbeing if a comprehensive effort was made to increase annual recruitment through additional planting of new trees.

The recruitment rate of new trees into the population is a key parameter in identifying how well a hedgerow tree population is performing. A lack of information between the numbers of naturally regenerated, planted and “from within the hedge” trees meant the standard Lefkovitch population projection model required an adjustment to the transition matrix with an additional recruitment vector containing a fixed number of annually recruited trees. Results from running this model 50 years into the future have been used to examine the viability of the hedgerow tree population (Table 3). Results show that an annual recruitment rate of 30,000 trees is required to stabilise the current population of 1.6 m trees and indicates that the number of younger trees ,<20cm dbh, needs to increase to between 40-50% of the total population (currently 1%).

There is little information on the reasons for tree mortality, particularly of those in the older, larger sized cohorts. While there will be natural mortality arising from the age of the tree and both biotic (e.g. Dutch elm disease, horse chestnut bleeding canker) and abiotic factors (e.g high winds), there is also evidence that, in some areas of the country, mortality of older trees is accelerating as a result of felling of trees for Health & Safety reasons. In the latter context, there are increased concerns arising from the *Poll vs Bartholomew* judgement [Poll v Viscount Asquith of Morley [2006] All ER D 158] of a duty of care to provide expert inspection and judgement on the stability of a given tree, with decisions on whether to fell based on a suitably high level of inspection expertise. There are valid concerns that application of the precautionary principle rather than expert inspection could lead to premature felling and accelerate the downward trend noted in surveys and in the model. This has been recognised by the establishment of a National Tree Safety Group to develop guidance on recognition and handling of potentially hazardous trees. It is recommended that further research and data gathering should be carried out to determine whether the felling of isolated hedgerow trees for Health & Safety reasons is warranted by their hazard status.

It is possible that the viability of the hedgerow population may also at sometime be compromised by the species composition of the hedgerow tree population. Data from CS2000 indicate that numbers of hedgerow trees were dominated by an estimated 1.35 million ash trees and 1.2 million oak (Appendix

Table 2), which when combined equates to more than 70% of the total population. Both these tree species, but particularly oak, are showing signs of decline and poor crown condition and growth (for example see http://www.forestresearch.gov.uk/fr/INFD-7AXGCJ) which indicates increased vulnerability to biotic and abiotic factors.

Future research

Model predictions are heavily dependent on the quantity and quality of the data underpinning them. In order to record recruitment and mortality rates over time regular surveys need to be undertaken and any changes incorporated into the transition matrix so that updated predictions can be made.

The recruitment rate of hedgerow trees, as estimated by the recent Countryside Surveys, would also benefit from further work. Appendix Figures 1a and b show an increasing population in the 2007 3-20cm dbh size class whilst the <3cm class continues to decline dramatically. It appears that large numbers of trees remained undetected within the hedge at the time of the CS2000 survey, but grew out of the hedge and were classified directly into the 3-20cm dbh class by the time of the CS2007 survey. For modelling purposes it would be informative to obtain estimates of the relative numbers of naturally regenerated and planted trees entering the population between consecutive surveys.

II: The Ecological Value of Hedgerow Trees: a review focussing particularly on invertebrates

4. Methods

Systematic literature review

References to scientific studies and published information on invertebrates associated with hedgerows and hedgerow trees were identified and collated from a systematic multi-database search of the main agricultural and biological sciences on-line databases AGRIS International, PASCAL, CSA Life Sciences Abstracts, BIOSYS and AGRICOLA (Appendix Table 6). These databases were searched using the key words *hedge(s)* or *hedgerow(s)* alone and in combination with *invertebrate* or *insect* or *arthropod(s*), and *tree(s)* or *isolated tree(s)*. Searches based on all of these key words produced 303 references, which was reduced to 125 references when studies carried out in orchards and sub-tropical and tropical regions were excluded. Citations and abstracts for each of these 125 references were printed out and cross-checked by two reviewers. References with information relating to the ecological value of hedgerow trees were obtained and printed out in full.

Other databases likely to hold references to information on hedgerows and hedgerow trees were also searched, including the CAB Forest Science database, CEH, EN & FC/FR library catalogues, the British Library and ISI Web of Knowledge (Appendix Table 7), as well as internet websites of organisations likely to have interest in hedges. These sources produced an additional 2624 references using the key words hedge(s) or hedgerow(s) with or without tree(s), out of which 166 citations and abstracts were printed (Appendix Table 7).

These searches produced references to a large number of studies on invertebrates associated with or living within hedgerows but, without exception, these studies looked only at the invertebrates living in the main body of the hedge or in the adjacent field margin. None of the studies looked at the invertebrate fauna living on hedgerow trees themselves.

Further searches of the most recent scientific publications, particularly 2008 and 2009 issues of *Agricultural & Forest Entomology*, *Current Contents*, *Agriculture, Ecosystems & Environment*, *Biodiversity & Conservation*, *Biological Conservation*, *Ecological Entomology*, *Journal of Environmental Management* produced three references to studies on invertebrates and hedgerow trees (Peng et al, 1992; Merckx et al. 2009a,b).

5. Results

Ecological studies on the fauna and flora of hedges

A large number of the studies on invertebrates, birds, mammals and plants associated with hedgerows and field margins were initiated in the 1960s and 1970s, when the loss of hedgerows from the landscape because of agricultural intensification and changes in land management, were becoming particularly noticeable and were starting to cause concern. Early studies set out to evaluate the importance of hedgerows for wildlife, to support their maintenance and conservation, and to provide an evidence base for influencing agricultural policy. Various studies listed the insects, spiders, molluscs and plants associated with hedges. Much of this early work was presented at a Symposium at Monks Wood Experimental Station in 1968 (Hooper & Holdgate, 1968) and was later summarised in the New Naturalist book *Hedges* (Pollard, Hooper & Moore, 1974). However, despite the title of the symposium and general references to the importance of hedgerow trees for invertebrates in the New Naturalist volume, there was no systematic study of the fauna living on trees in hedgerows.

Subsequent studies and a more scientific appraisal of the information gathered during earlier work, established that the abundance and diversity of invertebrates living in hedgerows is related to the species composition and diversity of woody plants making up the hedgerow, and to the structure and historical age of the hedgerow. Hedgerows rich in tree and shrub species and with a complex structure, which are features often associated with ancient hedgerows, support a much greater diversity of invertebrates (Clements & Tofts, 1992; Joyce, 1997; Maudesley, 2000; Corbett & Mole 2005; Pollard & Holland, 2006), birds (Osborne, 1982, 1984; Hinsley & Bellamy, 2000) and herbaceous plants (Deckers et al., 2004).

In intensively managed farmland, hedgerows are often the only remaining semi-natural habitat and they have been studied because of their roles as refuges for invertebrates (and birds and mammals), particularly entomophagous species, which also live or forage in adjacent crops (Joyce, 1997; Marshall & Moonen, 2002). Hedgerows also have the potential to act as corridors through the agricultural landscape, facilitating dispersal of individuals and helping to maintain the viability of otherwise fragmented animal and plant populations (Forman & Baudry, 1984; Burel & Baudry, 1990; Fry & Lonsdale,1991; Burel, 1996; Maudesley, 2000; Davies & Pullin, 2007). Studies on the role of hedgerows as corridors and in maintaining populations have focussed on ground beetles and spiders (Duelli, 1990; Joyce et al, 1997; Charrier et al, 1997; Thomas et al, 1997), butterflies (Dover, 1996; Dover & Sparks, 2000), molluscs (Pollard, Hooper & Moore, 1974), higher plants (Sarlov-Herlin, 2004), bats and birds (reviewed by Davies and Pullin, 2007), but none have investigated the specific role of hedgerow trees in facilitating dispersal or supporting animal populations.

Studies on hedgerow trees

<u>The perceived value of hedgerow trees</u>

Quantitative data on the invertebrates living on hedgerow trees, as distinct from data on species living within the body of the hedgerow, is notably lacking from the published literature. Most of the published information on the ecological value of hedgerow trees relates to bats and nesting birds. Lines of trees and structurally diverse hedgerows are recognised as important habitat features for bats, as they facilitate their movement through the landscape and connect foraging and roosting areas (Russ and Montgomery, 2002; Racey & Entwistle, 2003; Cowan & Crompton, 2004).). A number of bat species roost in cavities in old hedgerow trees (Appendix Table 8), and thirty-five of the 74 bird species that are found in hedges nest in trees; 17 of these nest in holes in trees (Moore, 1968).

The general opinion that hedgerow trees, particularly mature and veteran trees, are important for invertebrates and other animals, and that they significantly increase the ecological and conservation value of hedgerows, is based on observations of invertebrate communities on trees in woodland, along woodland edges and in old parkland and wood pastures. Trees generally support greater numbers and a higher diversity of invertebrates than shrub and herbaceous plant species (Strong et al, 1984; Straw & Ludlow, 1994), and they provide additional microhabitats for specialist invertebrate species, e.g. dead wood, fungi and epiphytic lichens and bryophytes (Kirby & Drake, 1993; Alexander, 2004). Consequently, the presence of trees within a hedgerow is likely to maintain a wider range of invertebrate species than would otherwise be present.

Thus, observations supporting the perceived value of hedgerow trees, although useful, are largely anecdotal and are not based on scientific study. As a result, descriptions of the ecological value of hedgerow trees in popular texts and hedgerow management handbooks, tend to be rather general and do not provide specific references or primary sources (e.g. Elton, 1966; Pollard et al, 1974; Dowdeswell, 1987; Muir & Muir, 1987; Clements & Tofts, 1992; Watt & Buckley, 1994; Rackham, 1990; Stokes & Hand, 2004; Barr et al, 2005; Bealey et al., 2009). The ecological and conservation value of hedgerow trees has rather taken on the character of an "accepted truth" without any direct supporting evidence. Consequently, it is not been possible to discover any scientific studies that have sampled invertebrates on hedgerow trees in a scientific and systematic manner, and which have compared the faunas of hedgerow trees with the faunas of trees growing in woodlands, parks and pasture woodlands. Consequently, there is no quantitative information on whether the fauna of hedgerow trees differs significantly from that of trees generally, and whether hedgerow trees are or are not an important resource for particular invertebrate groups. Hedgerow trees have certain attributes however, that are likely to influence their ecological value for invertebrates and which may make their associated invertebrate communities distinct from those inhabiting trees in woodlands, parks and other situations (Section 5; Appendix Table 9).

For example, hedgerow trees are distinct in terms of their open, sunny aspect, which will influence their importance for invertebrate diversity. Biological diversity is typically highest in edge habitats, in the transition zones between open vegetation and scrub and woodland, and some invertebrates are restricted to such areas (Ozanne et al, 1997; Wermelinger et al, 2007). Hedgerow trees, by their very presence, form extensive 'edge habitat' (they have been described as woodland edges without the wood!) and might therefore be expected to be particularly rich in invertebrate diversity. However, whether the invertebrate fauna of hedgerow trees is qualitatively different to trees growing in other situations, or from the same species growing low down within the body of the hedge has not been explored.

Despite not sampling hedgerow trees directly, there are 4 scientific studies on invertebrates in agricultural landscapes that indicate that the presence of trees within a hedgerow has a significant beneficial effect on insect populations, i.e. the studies of Merckx et al. (2009a,b,c) on moths and that of Peng et al. (1992) on flies.

Hedgerow trees and the abundance & diversity of larger moths

Merckx et al (2009a,b,c) have evaluated the effects of the presence or absence of hedgerow trees, and the presence of wide or narrow grassy field margins, on the abundance and diversity of larger moths in agricultural landscapes in Central England. Moths were sampled within selected fields using light traps positioned either next to or distant (≥100m) from hedgerow trees (predominantly oaks) and on wide or standard (narrow) field margins. Half of the fields selected for sampling were located in areas where farmers had taken up agri-environment schemes (AES) independently in the usual *ad hoc* manner, whereas the other half were located in areas where farmers had been targeted to take up AES and a greater proportion of the fields had wide margins and enhanced hedgerow management (although this did not include increased tree planting or changes in tree management).

A total of 243 moth species were captured during the study. Both abundance and species diversity were significantly higher where a hedgerow tree was present compared with where a tree was absent. Moth abundance increased by 60% and species diversity was increased by 38% in the presence of a hedgerow tree This effect however, was only apparent in areas where farmers had been targeted to take up AES options. The positive influence of hedgerow trees was larger than the effect of wide (6m) grassy margins, and was shown by the majority of moth species irrespective of whether they fed on shrubs & trees or on grasses & herbs (Merckx et al. 2009a). Mark-and-recapture studies showed that increases in abundance and diversity next to hedgerow trees were greater for species that were less mobile (Merckx et al. 2009b,c).

The most likely explanation for the increased abundance and diversity of moths close to hedgerows appears to be that the trees, by virtue of their large size and dominant position in the landscape, provide shelter and a more favourable microhabitat for flying insects, and therefore a point of concentration and aggregation for individuals. Moths and other insects that live in open agricultural landscapes are highly vulnerable to convective cooling, (Dover & Sparks 2000; Merckx et al 2009a,b,c) and large structural elements such as trees, which provide shelter, are likely to have significant beneficial effects.

That the positive effect of the presence of hedgerow trees was only apparent in those areas targeted for AES uptake, suggests that the ability of moth populations to respond to the presence of hedgerow trees depends on there being sufficient suitable habitat within the landscape for species to be able to move and congregate in the most favourable locations. Hedgerow trees therefore, appear to play an important role in facilitating the movement and dispersal of species. In this context, it is important to note that the beneficial effect of hedgerow trees was most evident for less mobile species, which generally would have more difficulty moving around the landscape.

A follow up study on 23 selected moth species confirmed the results of the wider study and showed that the presence of hedgerow trees had a greater impact on moths that fed on shrubs & trees than on species that fed on grasses & herbs (Merckx et al. 2009c). The greater response of the shrub & tree moths indicates that the positive effect of hedgerow trees is partly due to an increase in larval food resources. This might be expected, but the parallel effect on non-tree feeding species indicates that this is not the only explanation for the increase in abundance and diversity, and that the provision of shelter is equally, if not more, important for the majority of moth species inhabiting farmland. Mark-and-recapture studies showed that the shrub & tree moth species were generally less mobile than the grass & herb species and also, therefore, more likely to respond to the shelter provided by trees (Merckx et al. 2009a,c).

The beneficial effects of hedgerow trees in providing shelter was also shown to be important for an individual species of particular conservation concern, the pale shining brown moth *Polia bombycina*, even though this species has no direct relationship with trees (Merckx et al. 2009d).

This recent research illustrates the importance of hedgerow trees in providing shelter and food resources for larger moths within an agricultural landscape and that effects on abundance and diversity may only become apparent when embedded within a wider and more coherent framework of habitat enhancement. Larger moths are an important indicator group of invertebrates (Luff &Woiwood, 1995; New, 2004; Thomas, 2005) and therefore the results from the studies are likely to be applicable to other insect groups.

There is still a question as to whether the greater abundance and higher diversity of moths associated with the presence of hedgerow trees reflects a real increase in insect populations in the AES targeted areas or arises because insects in these areas are more able to disperse between habitat patches and congregate in the more favourable locations. To understand the population effect would require extensive sampling of larvae on trees and other host plants, in different habitats, which would be an extremely challenging task. However, even if the main effect of trees is to enhance movement and dispersal through the landscape, then this is still extremely important as it may lead to more viable insect populations and higher resilience of the landscape overall (T. Merckx pers. comm.). This ability to facilitate movement of insects and other animals through the landscape may become increasingly important in the future, as populations attempt to track changes in the distribution of suitable habitat brought about by climate change.

Hedgerow trees and Diptera

A similar, although smaller scale, structural effect of hedgerow trees on the aggregation of flying insects was recorded by Peng et al (1992), who studied the spatial distribution of adult flies (Diptera) at three heights and two distances (0m and 4.5m) from a large emergent hedgerow tree. Flies were caught using six suction traps that were suspended at 8.8m, 5m and 1.2m above ground on either side of a scaffold tower that was erected next to an 11.5m tall lime tree. The tree was growing up from the body of a hawthorn hedge running alongside a grass field and close to gardens and a young spruce plantation. Sampling was carried out during the last two weeks of July in 1986 and 1987.

A total of 84132 flies were caught during the study and all except one of the taxonomic families of flies that were sampled were caught more frequently close to the tree. Individuals of most of the families were concentrated at the middle level (5m). Only Anisopodidae, which are strong fliers, were caught more often in the uppermost traps, and Mycetophilidae (fungus gnats) were caught most often in the traps nearest the ground.

The hedgerow tree that was sampled was likely to have provided food resources (e.g. honeydew) for some of the adult flies, but for the majority of species its main function seemed to be the provision of shelter and as a mating station or swarming marker. The tree appeared to act as a centre of biological activity and the authors suggest that emergent hedgerow trees generally are likely to have an important influence on the distribution and local concentration of flying Diptera. Many of these dipterans, because of their abundance, are keystone species with a major impact on the diversity and abundance of other organisms, particularly birds and bats.

BAP Priority Species in the UK

The UK List of Priority Species and Habitats includes 413 invertebrate species of which 11 are closely associated with hedges (JNCC, 2007; Defra 2007; Bealey et al., 2009; UK Biodiversity Partnership at www.ukbap.org.uk; Appendix Table 8). Five of these species are associated with hedgerow trees; the maple wood-boring beetle (Gastrallus immarginatus, Anobiidae), noble chafer (*Gnorimus nobilis*, Scarabaeidae) and the golden hoverfly (*Callicera spinolae*, Syrphidae), all of which breed in old & decaying veteran trees, and the White-letter hairstreak butterfly (*Satyrium w-album*, Lycaenidae) and White-spotted pinion moth (*Xestia rhomboidea*, Noctuidae) whose larvae (caterpillars) feed on elms.

Insects

Maple wood-boring beetle, *Gastrallus immarginatus*
This rare beetle is associated with field maple *Acer campestre*, breeding in the bark of veteran standards or pollards in open situations. In Europe it has been reported from oak and other broad-leaved trees, but towards its northern fringes, as in Britain, it becomes increasingly confined to old, living field maples. *Gastrallus immarginatus* has been recorded in small numbers from Windsor Forest and Great Park, Berkshire since 1936, but in the 1990s it was discovered in woodland and parkland around Bredon Hill, on the Worcestershire-Gloucestershire border, and at Knole Park in Kent. Field maple is rare at Windsor and Knole Park, but around Bredon there are large numbers in old parks and hedgerows and *G. immarginatus* may occur there as a large dynamic meta-population. The status and distribution of this species in Europe is unknown, although in Germany it is regarded as endangered, as in Great Britain. Current factors causing loss or decline include loss of or damage to host trees through agricultural and other operations, poor age structure in field maple populations, leading to a future lack of breeding resource, and shading of host trees through reduction in grazing or planting of new trees (JNCC, 2007).

Noble chafer, *Gnorimus nobilis*
This beetle occurs in old orchards, open woodlands, pasture woodland and probably also in ancient trees in hedgerows where these occur next to its established sites. The larvae develop in rotting wood and wood mould in old standing trees, especially fruit trees (plum, apple, pear, damson and cherry), but also willow and oak. The normal development period seems to be two years. Adults have been found during the daytime on flowerheads of umbellifers. *Gnorimus nobilis* has been rare in Britain for over a century and appears to have undergone a considerable decline in range. There are recent records from the New Forest in Hampshire, from old orchards near Evesham, the Wyre Forest in Worcestershire and in Oxfordshire and Herefordshire. It is widely distributed throughout Europe. In the UK this species is classified as vulnerable (JNCC, 2007).

Golden hoverfly, *Callicera spinolae*
The larvae of this large hoverfly live in rot holes in mature hedgerow trees. It is a very rare species, known to occur in only a few sites in East Anglia, where its populations appear to move around. A Red Data Book species.

White-letter hairstreak butterfly, *Satyrium w-album*
Caterpillars of the white-letter hairstreak feed on the foliage of English elm *Ulmus procera* and wych elm *U. glabra*, typically on trees in hedgerows and along woodland edges. The butterfly is widely distributed across southern and central England and Wales, but it has shown a dramatic decline in population numbers because of the death of hedgerow elms caused by Dutch elm disease. *Satyrium album* occurs across Europe, except the extreme north and south-west, but in many regions it has declined because of the death and removal of elms and the loss of traditional hedgerows.

White-spotted pinion moth, *Xestia rhomboidea*
Larvae of the white-spotted pinion also feed on elm, but particularly on epicormic shoots of mature trees growing on damp ground. This species was widespread and well represented in central and southern England and parts of Wales until the 1970s, but since then it has seen a massive decline because of the disappearance of elm from the countryside. Huntingdonshire is the only area where it is now reported frequently and in numbers, but occasional records elsewhere indicate that the moth survives at low density in a few other places. *Xestia rhomboidea* has been recorded from all European countries except Ireland, Norway and Finland, and in many places it is local and rare.

Several other endangered moth species: barberry carpet, heart moth, pale shining brown, scarce vapourer and sloe carpet, have larvae that feed on deciduous trees in hedgerows (Appendix Table 8). A further 19 moth species that are widespread but declining rapidly, are also associated with hedgerows and hedgerow trees (R. Wolton, pers. comm.)

Bats

Hedgerows, lines of trees and other linear elements in the landscape are used by many species of bat to commute between roosting sites and foraging areas (Limpens & Kapteyn, 1991; Walsh & Harris,1996; Racey & Entwistle, 2003). Radio-tracking studies have shown that hedgerows and woodland edges, and other linear features, are important for most BAP priority bat species and other species, including lesser horse-shoe bats (*Rhinolophus hipposideros*) (Schofield et al, 2002; Knight, 2006), serotines (*Eptesicus serotinus*) (Robinson and Stebbings, 1997; Verboom & Huitema, 1997), brown long-eared bats (*Plecotus auritus*) (Entwistle et al., 1996) and pipistrelles (*Pipistrellus pipistrellus* & *P. pygmaeus*) (Verboom & Huitema, 1997; Downs & Racey, 2006), and greatly influence the way they utilise their environment. Whether isolated hedgerow trees help bats to move around the countryside more effectively than if they were absent has not been studied directly, but Knight (2006) recorded bats crossing roads at canopy level where roadside trees were present rather than at ground level or 2-3m when they were not; the latter strategy increased vulnerability to road traffic.

Bat species that typically forage within broad-leaved woodland, such as *P. auritus* and *R. hipposideros*, also forage along and within hedgerows and around individual trees (Entwistle et al., 1996; Motte & Libois, 2002; Knight, 2006). *Rhinolophus hipposideros* feeds primarily on Diptera, Lepidoptera (moths) and Neuroptera, which are taken on the wing but close to the canopy, and it may target swarming insects as a major part of its foraging strategy (Beck et al., 1989; Knight, 2006). Non-migrating insects tend to concentrate near the top and on the lee side of vegetation structures and barriers, especially hedgerows and shelterbelts (Lewis, 1969, 1970), and therefore these types of locations are likely to provide higher prey densities for bats compared with open areas (Downs & Racey, 2006; Knight, 2006). The studies of Merckx et al (2009a,b,c) and Peng et al. (1992) suggest that isolated hedgerow trees may be particularly important in this respect. They demonstrate that the abundance of moths and flies, key prey for bats, are significantly higher close to hedgerow trees, which may have an important influence on bat foraging strategies. Taller and more structurally variable hedgerows are likely to provide increased shelter, better protection from predators and more insect food (Verboom & Huitema, 1997; Racey & Entwistle, 2003). This assumption is supported by Wickramasinghe et al. (2003) who found a significant correlation between the number of feeding buzzes and hedgerow height in their study of bat activity in organic and conventional farms in England.

Bats also rest on trees whilst commuting or between bouts of foraging, and some hunt from perches or glean insects from foliage (Entwistle et al., 1996; Schofield et al., 2002; Smith & Racey, 2005; Knight, 2006). The presence of trees in a hedgerow should increase opportunities for such behaviour.

At the landscape scale, the presence of hedgerow trees, by concentrating food resources and providing further opportunities for hunting and roosting, and probably by increasing the general abundance of moths and other insects, is likely to improve the quality and general suitability of an area for bats. Walsh and Harris 1996 showed that tree lines were selected in all land classes and hedgerows in all except two types of arable land in their analysis of the National survey of bats and their habitats in Britain. They concluded that tree lines and hedgerows were important corridors linking habitat patches in the landscape, and Oakeley & Jones (1998) showed that, in south-west England, there were significantly more pipistrelle maternity roosts in areas where there were greater numbers of water features and continuous hedgerows with emergent trees.

Mature trees also provide night and day roosting sites for a number of bat species, and hedgerow trees may be important in increasing the total number of roost sites available. Smith & Racey (2005) have pointed out that field boundaries need to be managed to maintain mature trees with cavities to provide day roosts for Natterers bats (*Myotis nattereri*). Knight (2006) concluded that tree cover, and not necessarily woodlands *per se*, and edge habitats were of key importance for *R. hipposideros*, and recommended protection and encouragement of hedgerows as a priority action and in particular the encouragement of emergent standard trees in hedges.

Birds

Most of the BAP priority bird species that live in farmland use hedgerows in one way or another, e.g. for cover, nest sites, song posts, as hunting perches and to find food, but few are specifically associated with hedgerow trees (Whittingham & Evans, 2004). Bird species richness and the numbers of nesting and wintering birds in hedges are positively correlated with the physical size of the hedge, its height, composition and structural variability, the number and height of trees, and the presence of a ditch or bank (Arnold, 1983; Osbourne, 1984; Parish et al., 1994; Hinsley & Bellamy, 2000; Fuller et al., 2001). Species that nest in holes in trees, such as pied flycatcher and tree sparrow (Appendix Table 8), are especially likely to benefit from the presence of hedgerow trees.

Whittingham et al. (2001) have shown that farmland-nesting chaffinches rely on hedgerow trees (especially oaks and willows) for nestling food, because they feed on arboreal caterpillars in much the same way as tits, rather than finding arthropods in the agriculturally managed field layer. Consequently, the presence of these feeding habitats may be one reason why chaffinches have maintained their numbers on farmlands whilst other species have declined.

The concentration of moths and flies next to hedgerow trees, which probably benefits bats foraging within agricultural landscapes, is also likely to benefit insectivorous birds and would be expected to increase their feeding efficiency.

Important attributes of hedgerow trees

Attributes of hedgerow trees that are important for invertebrates and other animal species, are listed in Appendix Table 9 and are compared with trees growing in closed woodland and in parkland and wood pasture. Key attributes are discussed below.

<u>Tree species diversity</u>

Different tree species host widely different numbers of herbivorous insect species, and presumably associated predator and parasitoid species and other invertebrates. For example, oak supports more than 420 insect species, whereas ash supports 60-70 species and sycamore only 40-50 species (Kennedy & Southwood, 1984; Brandle & Brandl, 2001). Therefore the species composition of hedgerow trees will have a large influence on the numbers and types of insects living in the hedgerow.

Hedgerows contain more wild and adventitious fruit trees (apple, pear, plum, bullace) and other (non-timber) species such as buckthorn, elm and broad-leaved lime, than managed woodland or even woodland edges in intensively farmed areas. These trees species have been lost from woodlands through management and from semi-natural areas, because of succession and a lack of grazing & disturbance (Vera 2000), but they support a wide range of host-specific insects and their fruit is an important food resource for invertebrates, birds and small mammals. Hedgerows are probably the most important remaining habitat and refuge for some of these tree species (e.g. Plymouth pear *Pyrus cordata* and rare *Sorbus* species), which cannot persist in closed canopy woodland or have been selected out of managed woodlands.

<u>Tree age</u>

Older trees are of greater value for invertebrates and vertebrates compared with young trees (although there are some young tree invertebrate specialists). Large mature trees provide a wide range of resources (e.g. flowers, fruits, roosting and nesting opportunities) and a variety of niches not provided by young trees, especially sources of standing dead wood, rot holes and the fungi and other organisms associated with decay (Ranius & Jansson, 2000). Hedgerows have the potential for a mixed age-structure of trees, maximising the numbers and diversity of associated fauna.

Foliage & canopy biomass

Hedgerow trees, by virtue of their large size, increase the total biomass of food resources available to tree-feeding insects and other invertebrates, which should lead to generally higher population numbers and consequently more food for birds, bats and small mammals.

Flowers, fruit & seeds

Many hedgerow shrubs and trees come into leaf and flower earlier in the year than shrubs and trees growing in woodland, and this is likely to provide valuable food resources for insects and other invertebrates during the spring (Clements and Tofts, 1992; Corbett & Mole, 2005).

The open, sunny aspect of hedgerow trees and freedom from competition with other trees is likely to promote much more abundant flowering and greater fruit set than on trees growing in woodland (Vera, 2000). This should benefit a wide range of nectar & pollen feeding insects during the spring and early summer, and fruit- and seed-feeding invertebrates, mammals & birds in late summer and autumn.

Dead wood

Old and veteran trees in hedgerows are recognised as very important habitats for saproxylic beetles, flies and fungi (Kirby & Drake, 1993; Alexander, 2004; Clements & Alexander, 2004), but they are often relatively isolated compared with ancient trees in wood pastures, parklands and along forest edges. As a result, invertebrate species that they potentially could support are frequently missing because of local extinction and lack of re-colonisation.

The adults of many saproxylic insects, particularly flies and beetles, feed on nectar and pollen and an abundance of flowering plants in the vicinity is important for maintaining viable populations. The adults of many dead-wood beetles are often to be found on hawthorn blossom in May (Cooter & Barclay, 2006). The number of flowers can be limiting in closed woodland, but wood pastures, parks and hedgerows usually have many more flowers and, depending on management, a succession of plant species flowering through the spring and summer (Pollard et al., 1974; Clements and Tofts, 1992).

Microclimate
Hedgerow trees generally have an open, sunny aspect, which in spring and summer will often provide a more favourable thermal environment for invertebrates, compared with trees growing in woodland. Larger hedgerow trees also provide shelter (Merckx et al, 2009a,b) and, beneath the canopy, more extensive shade that may benefit certain species at particular times. Consequently, the presence of hedgerow trees increases the diversity of microhabitats for other organisms.

Hedgerow trees, however, are also more exposed to strong winds and adverse temperatures compared with trees growing in woodland and perhaps wood pasture and parkland. This may have a negative effect on foliage feeding invertebrates (e.g. wind and heavy rain are important causes of mortality in aphids, Dixon 2004).

Adjacent habitats
The amount of other ‘natural’ habitat adjacent to hedgerows and hedgerow trees is usually very limited and this affects invertebrate colonisation and dispersal (Marshall & Moonen, 2002). Adjacent land use, the type and management (e.g. pesticide use) of the crop growing next to the hedgerow has a large influence on the invertebrates living in the hedgerow (Pollard, 1968).

Management
Hedgerow trees are vulnerable to pesticide drift from adjacent crops, as is the main body of the hedgerow, but the canopy of tall trees might escape the worst effects of pesticide exposure. Similarly, whereas the main body of the hedgerow might be cut and flailed intensely, and at the wrong time of the year for many invertebrates and other animals, the canopy of hedgerow trees above the reach of farm

machinery, will remain undisturbed. Consequently, hedgerow trees often retain berries and seeds through the autumn and winter, after they have been lost from the body of the hedgerow. In this respect, a hedgerow tree offers a 'vertical refuge' out of reach of the more damaging aspects of management that are applied to the main body of the hedgerow.

6. Discussion and main implications

This desk-based study has concentrated on the key questions of the relative recruitment and loss rates of isolated hedgerow trees in Great Britain and, within this context, has provided an evaluation of the ecological value of this tree resource. Arising from the final project Workshop held on 24 July 2009, other aspects such as the wider roles of trees in the landscape and some consideration of further work needed on ecological values are included in this discussion section.

The modelling component has provided both predicted figures for the rates of recruitment of hedgerow trees needed to retain the current population and has also indicated the level of sensitivity of these parameters to changing assumptions, including management and human intervention. Conclusions from various sources, commencing with the concerns expressed in the 1951 Forestry Commission study and subsequently in recent Countryside Surveys and by the Tree Council (Stokes & Hand, 2004), all agree that isolated hedgerow trees are in sharp decline. In bringing these sources together, the present study is the first to model the extent of the decline and to provide quantitative indications of the necessary recruitment rates to halt and, if possible, to reverse the decline.

Simulations from the model suggest that concerted action is needed both to accelerate recruitment of isolated hedgerow trees and, equally important, to reduce the rate of mortality in the older cohorts of those trees.

The numbers of hedgerow trees needed 'just to stand still' are demanding:

- Annual recruitment of around 30,000 trees is needed to stabilise the current population of 1.6 m isolated hedgerow trees;
- The total of 1.6 m trees is already reduced from the 1.675 m trees recorded in the CS2000 survey (this is reduced from the originally published figure of 1.8 m trees) and the much higher numbers in earlier surveys (Appendix Table 1);
- Data sources indicate that only 15,000 trees are currently being recruited annually. On this basis, the model projects a drop in total hedgerow trees to as low as 1.05m trees over the next 50 years;
- Discussion at the Workshop held on 24 July revealed that, in some areas of the country, mortality of older trees is accelerating as a result of felling of trees for Health & Safety reasons. There are increased concerns arising from the *Poll vs Bartholomew* judgement of a duty of care to provide expert inspection and judgement on the stability of a given tree, with decisions on whether to fell based on a suitably high level of inspection expertise. Concerns were expressed that application of the precautionary principle rather than expert inspection could lead to premature felling and accelerate the downward trend noted in surveys and in the model.
- The dominance of ash and oak in hedgerow tree populations may compromise future recruitment and survival trends, especially in relation to climate change. However, little information is available to assess whether this is a significant factor.

Ecological values directly applicable to isolated hedgerow trees have been difficult to assess and quantify. As indicated in the summary of the literature review, there is remarkably little verifiable and direct study on the absolute and relative roles of hedgerow trees as ecological features of the landscape. Despite systematic review of the literature for invertebrates (the main aim of the review), the number of strictly relevant studies was disappointingly low. However, where there were quantitative and statistically sound studies, the indications were that isolated hedgerow trees have distinct and, sometimes, unique ecological values that would contribute significantly to the ecosystem services offered by this resource. Key findings were:

- Presence of trees within a hedgerow is likely to encourage a wider range of invertebrate species than would otherwise be the case, but this conclusion is inferred rather than supported by direct study. Inference is mainly from extrapolation from studies of woodland edges and trees in parklands and wood pastures.

- Studies of moths by Merckx et al (2009a, b, c) and of Diptera by Peng et al (1992) have shown clearly that abundance and diversity of the two invertebrate groups are enhanced by proximity to hedgerow trees, with further linkage to the width of the hedge and field borders. Some of the value is provision of ‘safe’ corridors for movement of the organisms through the landscape rather than direct exploitation of the trees for nutrition or breeding.
- Inferences on interactions of BAP priority species with hedgerow trees suggest that many species benefit from the presence of this ecological resource. However, there are very few studies that would allow direct conclusions on enhanced management for these BAP species to be made.
- Bats and nesting birds benefit from hedgerow trees both as roosts/breeding sites and as connecting features to facilitate movement through the wider landscape.
- The paucity of quantitative data on the ecological value of hedgerow trees indicates that further, targeted research should be carried out. A structured framework for such studies could be based on the evaluation of the *Important attributes of hedgerow trees* carried out within the present study.

Simulations of the recruitment and loss rates of isolated hedgerow trees, therefore, provide a quantitative measure of the scale of losses and the necessary replacement rates to be able to maintain or increase this valuable resource. While the ecological roles and values of hedgerow trees are regarded as positive, albeit with relatively few specific studies to quantify this contribution, there are many other attributes of hedgerow trees that support their retention in the landscape. Some of these were discussed at the Workshop on 24 July 2009 and a short summary of the main points is provided below.

Landscape values

Other than the ecological values that have been the subject of review in this project, a related but highly valued attribute of hedgerow trees is the perception of how they fit into the wider landscape. This has been the subject of Landscape Character Assessment through the Countryside Agency with Natural England, Scottish Natural Heritage and Countryside Council for Wales. Information is brought together by the Landscape Character Network (http://www.landscapecharacter.org.uk/), whose aims are:

The Landscape Character Network (LCN) is an informal network with a dual focus on Landscape Character Assessment (LCA) and the European Landscape Convention (ELC). LCA is an important tool for enhancing local distinctiveness and promoting sustainable development. The ELC is the first international agreement on landscape, devoted to the protection, management and planning of all landscapes in Europe. The network is open to anyone with an interest in landscape.

The British countryside has been divided into a series of National Character Areas, reflecting the particular landscape characteristics of each area. Some of these are highly relevant to the current topic of hedgerow trees and have been highlighted by Stokes & Hand (2004). For example, at the time of their review Stokes & Hand indicated that 38 areas (roughly 25% of the countryside) had hedge trees, shelterbelts and field boundaries as essential features of the landscape. Some examples included:

- Blackmoor Vale and Vale of Wardour, Somerset – small, rectilinear pasture fields with hedge oak trees;
- Marshwood and Powerstock Vales, Dorset – pasture vale landscape with ribbons of woodland, regular field patterns and abundant hedge oaks;
- South Hampshire lowlands – oaks prevalent in hedges and woodlands, creating impression of well-wooded landscape;
- South Suffolk – main hedge tree is elm (with hornbeam) and areas with ash.
- Essex – oak is common. Ancient coppice woods and patterns of copses connected by hedges joining together to give a wooded skyline.

These, and other, examples show that trees in hedgerows remain essential features of the landscape which are not just visual but provide links between local and regional landscape types. Issues of retention or extension of these National Character Areas are further drivers for more focussed policy for managing the dwindling population of hedgerow trees.

Lichens as ecological indicators

Although recognised as potentially valuable indicators of both air quality and local tree quality in this review, no specific assessment of lichen species abundance and diversity has been carried out. Robert Wolton (Consultant) recommended that this should be included in any future work on isolated hedgerow trees. One of the interesting areas for further work is the relative capacities of trees within the hedgerow compared with wayside trees (i.e. along roads but not within the hedgerow itself) to support priority lichen species. The lack of shade tolerance by lichen species are likely to be key determinants of their associations with hedgerow trees, particularly in relation to the height of the understorey body of the hedge in relation to the amount of exposed trunk of the potential tree hosts.

Felling of hedgerow trees

During discussion at the Workshop, concern was expressed at the number of mature trees being felled for Health & Safety reasons next to public highways. Several examples known to participants at the Workshop were cited, including the felling of around 20,000 trees in Devon, felling in Wales (noted by CCW) and in Northern Ireland. There appears to be no national policy or guidance on decision making in relation to whether trees should be felled on safety grounds and it was also felt that more trees than are justified by initial examination tend to be felled simply because the contractors are already 'on site'. Further examination of CEH data on mortality rates of trees on roadsides versus other linear features would yield valuable information on the relative loss rates in these different locations. However, the CS2007 data do not include the reasons for tree mortality and, therefore, direct measures of loss rates from human intervention would need to be gathered by other means. In this respect, The Tree Council is collecting evidence from known problem areas.

Improvement in datasets and future monitoring

While there are excellent data from a number of sources, notably Countryside Surveys and Forestry Commission National Inventory of Woodlands and Trees, these all suffer from the relatively long periods between each cycle and the difficulty of ensuring precise positional information to enable local and regional rates of change to be quantified. This increases the level of uncertainty and Ben Ditchburn (Forestry Commission) indicated that increased precision is now a high priority for future FC surveys. In particular, the forthcoming FC Inventory of Woodlands and Trees should be able to increase sample size for inclusion in the hedgerow model five-fold. He also reported that by 2011 the European Space Agency will be making available cloud-free satellite imagery at 4m pixel resolution on a year by year basis. Using the latest image analysis software the rates of change in numbers and, probably, condition of hedgerow trees should be quantifiable over much shorter intervals and with complete location precision. Therefore, the use of remote sensing should be an important part of any future surveys, particularly since techniques such as Lidar are now being refined to enable tree height and volume to be estimated (excellent progress in UK and Norway were noted).

Bats

The roles of hedgerow trees as corridors for dispersal and to facilitate foraging by bats was also noted. In particular, the 'darkness quality' provided by canopy shading is likely to extend the foraging period by bats in the early evening as well as proving perches for some species. Karen Haysom from the Bat Conservation Trust indicated that the BCT have a student at UEA looking at the relationship between Bat Monitoring Scheme data and landscapes, and that the student might be able to look at the impact of the number and size of hedgerow trees on bat abundance.

Overall Conclusions

Rates of change of isolated hedgerow trees are in serious decline and, even with a recruitment rate of 30,000 trees per annum will only retain the current estimated total of 1.6 m trees identified in the CS2007 survey.

Evidence from a range of sources indicate that isolated hedgerow trees have high biodiversity values, some of which is uniquely associated with this resource. However, there are few quantitative studies to give greater precision to these conclusions, particularly in assessing the relative roles of isolated hedgerow trees compared with trees in lines (either in hedges or in other linear features).

A number of other attributes of hedgerow trees support the conclusion that they carry high value in the landscape and these were discussed at the end of project Workshop held at Alice Holt on 24 July.

7. Recommendations for future work

The following recommendations arise from this study and from the discussions at the Workshop on 24 July:

6. An integrated approach to hedgerow tree management is urgently required. This should address the reasons for the serious decline in the numbers of trees and also develop strategies to plant new trees or encourage growth/regeneration from within the hedge. The new model developed in this study should be used to guide an evolving strategy, particularly with respect to regional trends and relative predicted contributions of different tree species.
7. The shortage of quantitative studies directly addressing the ecological roles of isolated hedgerow trees is a concern and should be addressed through more focused ecological studies. Work by Thomas Merckx and colleagues demonstrate that such studies are feasible and have high explanatory and predictive value. Scoping of a research programme to address the contributions of trees within hedgerows relative to isolated woodland and parkland trees and trees within linear features, using the tree attributes in Appendix Table 9, should be carried out. This could be used to guide future research effort on the ecological values of hedgerow trees. While invertebrates would remain as keynote indicators, their interactions with birds and bats within a quantitative framework would add value to a future research programme. Similarly, the microclimate attributes of trees within and in proximity to hedgerows should be linked to research on lichens as environmental indicators within this habitat type.
8. Future survey and monitoring techniques should maximise the use of new remote sensing techniques both to aid quantification of trees within the hedgerow environment and to increase the frequency of assessment. In this way, trends in numbers can be assessed at a range of geographic scales and linked to the management and modelling recommendations above.
9. Data on tree species numbers within hedgerows are heavily skewed to oak and ash. Further research is needed, particularly related to future climate change scenarios, to determine whether this species mix is likely to be resilient and whether efforts to increase species composition should be increased.
10. Policies that determine whether tree felling for Health & Safety reasons is appropriate and justified should be reviewed, by research on the level of such felling and linkage to the National Tree Safety Group, leading to preparation of guidelines which link to the emerging policy in recommendation 1. Advice on risks from trees already exists and the different sources should be assessed to ensure that all available sources are easily accessible and consideration given to revising, updating and re-publishing key sources. Some of the previously available sources are indicated in Section 9.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Scientific references to the literature review on ecological values of hedgerow trees: Ecology and model hedgerow literature.doc

Web sources:

Buglife – www.buglife.org.uk
CEH Countryside Survey – www.countrysidesurvey.org.uk
Cornish Hedges – http://www.cornishhedges.co.uk/papers.htm
Countryside Council for Wales – http://www.ccw.gov.uk
Devon Hedges – http://www.devon.gov.uk/devon_hedges.htm
Hedgelink – http://www.hedgelink.org.uk
Natural England – http://www.naturalengland.org.uk/
Tree Council – http://www.treecouncil.org.uk
UK Biodiversity Partnership – http://www.ukbap.org.uk

General references:

Stokes, J. & Hand, K. (2004) The Hedge Tree Handbook. The Tree Council, 96pp

References to tree hazard assessment and management:

Lonsdale, D. (2000) Hazards from Trees – A General Guide. Forestry Commission Practice Guide http://www.forestresearch.gov.uk/PDF/fcpg13.pdf/$FILE/fcpg13.pdf

Research for Amenity Trees - a series of books published by The Stationery Office (formerly HMSO) for DETR (Department of the Environment, Transport and the Regions):
- No. 2 (1994, revised 2000) *Diagnosis of Ill-health in Trees*, by R.G. Strouts & T.G. Winter
- No. 4 (1995) *The Body Language of Trees: A Handbook for Failure Analysis*, by C. Mattheck & H. Breloer
- No. 7 (1999) *Principles of Tree Hazard Assessment and Management*, by D. Lonsdale

Guide for Trees in Relation to Construction (BS 5837). British Standards Institution, London.

Recommendations for Tree Work (BS 3998). British Standards Institution, London (with 1990 amendment).

Tree Work and Employing a Contractor. London Tree Officers' Association, Islington, London UK.

Guide to the Care of Ancient Trees (1996). Veteran Trees Initiative, English Nature, Peterborough.

Veteran Trees: A Guide to Good Management, by Helen J. Read (2000). Veteran Trees Initiative, English Nature, Peterborough.

Forest Operations and Badger Setts. (1995) Forestry Practice Guide, Forestry Commission, Edinburgh.

R. Ferris-Kaan, D. Lonsdale, and T.G. Winter (1993). *The conservation management of deadwood in forests.* Forestry Commission Research Information Note 241.

**Protected Trees* – a guide to tree preservation procedures, a free leaflet issued by DETR and available from your local planning authority or from the Arboricultural Advisory and Information Service

†*Tree Felling - Getting Permission*, free booklet available at any Conservancy office of the Forestry Commission.