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Scoping study

Re-engineering small diameter and coppiced English hardwoods for a variety of end uses

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Executive Summary

The Forestry Commission commissioned BRE to undertake a scoping study (CFS 17/06) on the re-engineering English hardwoods, which is duly reported in this output. The aims of this report are to evaluate the opportunity for re-engineering to provide material from English hardwoods that might be used for a variety of end uses including joinery, furniture and structural applications. This report describes the process of re-engineering timber and the work that has been carried out and is in the public domain with regard to small diameter and coppiced grown material. More importantly it highlights gaps in the existing knowledge that need to be rectified before full commercialisation of this under utilised resource can be achieved.

The cost of the resource is currently low. If a market is found it is low value and often sold for firewood or pulp. Frequently the cost of harvesting is more than the price realised for the product so it is simple not harvested. Even with the cost of re-engineering this material has sufficient headroom to be cost competitive against premium quality timbers of the same species. Being cost competitive it has potential to open markets currently unavailable to products made from premium quality hardwoods due to their retail price, this is an aspirational market for individuals wanting something better than for example the standard veneered particle board product but at an affordable price.

The basic work on re-engineering for joinery has been carried out but other markets can be foreseen but they need further exploration, most notably structural use. Very little work had been carried out for the use of re-engineered small diameter hardwoods for structural applications. The main difficulty with the use of such timber is that it is predominately juvenile timber and, in consequence, there will be a fundamental difference in mechanical and structural properties from mature timber used to derive the stresses in BS 5268[1]. Without being aware that these differences exist serious consequences may arise if the stresses for mature timber are used.

This report also indicates that once the gaps in knowledge have been filled the principle barriers to market up-take are dissemination of the information and demonstration of serviceability. The size of investment needed to be made to carry out re-engineering of timber requires a high degree of confidence in a successful outcome and a viable market. Therefore the producer will need to know how to achieve the desired product and how that product performs over time. These two themes will also need addressing to be sure of success.

It is recommended that the follow specific points are addressed:

- Effects of drying multiple laminates needs investigation to understand the effects of drying stresses upon final performance
- The relationship of lay-up arrangement and the timbers physical properties needs study to:
    1. determine effect upon machining characteristics
    2. the best lay-up arrangements for specific products
    3. the best orientation for lay-up to reduce distortion

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- Determination of structural properties for suitable species to facilitate use in re-engineered substrates
- Ensuring that the data obtained for structural use is compatible with the basis of design in BS5268 and Eurocode 5
- Methods for maximising the timbers visual appeal in the finished product need to be developed

Contents

Introduction

The use of mature hardwoods is a well established business activity and discussions with foresters and hardwood sawmills clearly indicate that there is no difficulty in selling good quality timber from such trees. However, there is a considerable quantity of small diameter or coppiced material standing in woodlands, both public and private that is uneconomical to harvest in the prevailing market. This is primarily due to loss of traditional markets or competition from alternative timber supplies. This has led to poorly maintained woodlands, cessation of harvesting coppiced timber and general neglect. This has clear negative consequences for the rural economy and biodiversity. Neglect leads to poor stem formation and overall lower quality timber. The recent closure of the St Regis pulp mill is still a further blow to this sector of the forestry community.

A study carried out for the Greenwood Community Forest funded by East Midlands Development Agency (BRE report 219 008 – A feasibility study for the creation of green gluing enterprise based in the Greenwood Community Forest and surrounding regions[2]) determined that the average price for small diameter oak was of the order of £25 a green tonne (£30 m^3), standing. At such a price the cost of harvesting and delivery exceeded the price paid. However, that report went on to demonstrate the potential for much of this material in value added applications. However, it only started to demonstrate the full potential of small diameter hardwood. There were factors not considered such as structural applications, maximisation of yields and dimensional stability of large built up sections that are considered to offer as much potential as joinery applications.

The use of modern adhesive technologies can add significant benefits to processing activities to reduce waste and build a more stable product. However, no progress will be made in expanding the market, and hence demands, without a clear demonstration of the potential to take small diameter logs and manufacture real products. These products must be competitive on price, quality and performance and offer an acceptable return to the grower and the manufacturer. The Greenwood Community Forest report started this process but captured a relatively limited audience and there is considerably more that can be done with joinery than the scope of that work allowed. Therefore this scoping study aims to explore what can be achieved across a wider product range that is only limited by the imagination.

BRE has, in its capacity as a research provider with an international reputation for timber research, been party to many uses of small diameter hardwood by commercial producers. However due to commercial confidentially little of this work has reached a wider audience. Therefore, there is scope to draw accumulated knowledge together along with identified gaps in that knowledge to demonstrate to potential producers what can be achieved not only in terms of technical ability but how to make the best of the visual appeal of temperate hardwood.

The resource

The principles for adding value to the resource will be by re-engineering and in essence any timber species can be re-engineered, and products made from them. The main drawback is usually cost; re-engineering entails high processing costs. Therefore, for timber species that have little room to accommodate this cost then the process is often not commercially viable. However, small diameter hardwoods have a potentially high margin for value adding, taking a £30/m^3 resource to several hundred pounds a cubic metre for joinery work. Therefore, whilst mature trees with poor stem form could be included the small diameter logs appear to offer the greatest potential both in size of supply and concentration for cost effective harvesting.

The exact range of species will depend on what is desired to be achieved. Therefore, it is the basic principles of the approach that are important with regard to this scoping study. However, certain species standout as being highly desirable due to reputation (e.g. most people have a idea of oak as conferring quality), technical performance, durability or visual appeal.

Therefore the range of timbers that offer great promise are as follows, though no species should be considered outside the scope:

- Oak – suitable uses include joinery, work surfaces, flooring and structural. The natural durability and visual appearance are also beneficial characteristics
- Sweet chestnut (small diameter and coppiced) - suitable uses include joinery, flooring and structural. The natural durability is an added benefit
- Ash - suitable uses include joinery, work surfaces, flooring and structural. The visual appearance is an added benefit
- Birch – suitable uses include flooring and joinery
- Beech - suitable uses include joinery, work surfaces, flooring and structural.
- Sycamore – uses include work surfaces and joinery
- Alder – uses include joinery and work surfaces
- Hornbeam – uses where a very hard wear resistant surface is require – flooring, work surfaces and joinery.

Some species have properties that can be effectively used for joinery and structural applications whereas others may only be applicable to joinery use. In either case technical performance should be combined with aesthetic qualities to produce a product that not only fulfils the technical requirements but satisfies an aesthetic quality to take the product to the market between the low cost and the premium product..

Appendix A shows the national distribution of some of the species mentioned above. All show good coverage over England with many being well represented within Wales and Scotland. Most of what is known about these species is based on studies from mature or predominantly mature timber. However, it is known that many of the timber characteristics are age dependent therefore certain properties may not be present in timbers that are predominantly juvenile and therefore they need careful exploration and investigation. It is known that structural properties and durability are age related and there may be other properties that need investigating and drawing to the user's attention, though the extent to which the properties vary with regard to mature timber is likely to be species related.

Species	£/m^3		
	Standing	Roadside	Delivered
Ash	4	x	x
Beech	15	x	x
Birch	4	x	x
Oak	30	x	x
Sycamore	15	x	x
Low values hardwoods (Poor stem form)	3	14 -15	30
Mixed hardwoods (Average quality)	1.64	16-18	36.5

Based on users in the East Midland area (2003) x = Figures unavailable

Table 1. Shows the relative cost for hardwoods as standing timber, at roadside and delivered.

Possible product range

The full range of products made by re-engineering is limited only by the imagination. The list set out below gives some indication of possible products, and whilst technically all are practicable, commercially some may not be viable at the present time, but that does not mean they will not be in the future.

- Joinery – windows, doors, work surfaces and other kitchen components,
- Furniture – dining tables and chairs, cabinets and bookcase and furniture boards, garden furniture
- Construction – cladding, flooring, stairs
- Structural – Post and beams (traditional timber frame) including principle members as glulam beams, joists, structural stair parts, structural window and door opening parts
- Decorative – turnery items such as newel posts, columns, raised door panels,

Potential market and resource size

The Market and Business Development Report[3] published in 2003 showed that the size of the market for products made from UK grown timber was of the order of £10million (based on manufacturers selling prices). This figure is forecast to increase between 2004 and 2007 to approximately £11 million, giving a strong indication of the growth within UK sourced timber supply. One strong factor acting in the UK resources favour is the government's timber product procurement policy promoting the better use of the UK resource and its emphasis on environmentally friendly and sustainable sources. Although the supply of imported certificated (FSC and similar) hardwoods is increasing, for certain applications, particularly structural, no improvement is foreseen. Many of the tropical timbers listed in BS5268 for structural use will never gain sustainable certification; therefore UK timber is ideally placed to benefit from this shortfall in the traditional supply of certain tropical hardwoods.

Based on figures from the Greenwood Community Forest project the resource of small diameter hardwood is sustainable. Figures for the harvesting of small diameter timber collected during this project indicated that for the East Midlands area alone 93, 250 m^3 (Nottinghamshire and Derbyshire) was harvested in 2003. The quoted figure did include low volumes of some small diameter pine and Sitka spruce. The figure was based on information generated by local suppliers. If a slightly higher price was paid for the resource the same suppliers thought the supply could be increased by 35% and remain sustainable. They also indicated that 50% of the harvested hardwood was low value small diameter. The East Midlands is a balanced mix of urban and rural land use. Therefore it does not seem unreasonable to assume that other areas of England would have a similar resource pattern though mix of species would vary, with around half of the potential hardwood supply comprising of small diameter logs.

One nationally growing market ideally suited for re-engineered products produced from small diameter logs has been identified as the restoration market. Re-engineered products have distinct advantages over traditional solid wood. Large timber section sizes are common in old buildings and whilst these can still be sourced, in most cases in the original species, prices have risen to high levels. Therefore alternatives that offer predominantly the same appearance and performance yet at a lower price are in most cases acceptable (excluding the requirements of English Heritage). One problem for restoration work in houses equipped to meet the requirements of the modern family is central heating with ambient room temperatures of 18 to 20°C and low relative humidity. As mentioned many of the timbers used in old houses were large, installed green and allowed to dry naturally with time as internal conditions were frequently only marginally better that the prevailing external conditions. In a centrally heated house the internal condition can result in rapid drying that results in both drying degrade (surface checking) and distortion. These can be mitigated to some extent by the re-engineering process. Using dry laminates eliminates such problems, or re-engineered green the lay-up arrangement and glues lines can be designed to significantly reduce surface degrade and distortion.

Flooring for restoration work is a strong possibility where the degree of defect cutting is selective or discretionary and can be used to introduce "character" in to the floor boards. These can be engineered to meet the customer's needs. The visual appearance of the natural timber would be a strong marketing point over other possible alternative materials.

Applications

Basic principles of re-engineering

As already mentioned the main method of adding value to a small diameter log is re-engineering and the principle steps are as follows:

Primary processing

This follows standard sawmilling activity; the logs are felled and converted following normal sawing procedures, the dimensions of the planks produced being dependent on the log size or those required for the product.

Dry or green gluing

It is usual within the timber processing industry to carry out most gluing operations in the dry state but modern adhesive technology makes possible successful gluing at moisture contents up to and above fibre saturation. The difference in approach is a matter of choice for the producer and both have advantages and disadvantages.

If green gluing is carried out correctly and lay-up arrangements are addressed, reductions in the amount of distortion occurring on drying can be achieved. However, failure to address the lay-up arrangements correctly can add significantly to distortion. One of the major unresolved issues with green gluing is effective drying where more than two laminates are joined. Work to date shows that two laminates can be effectively kiln dried and three laminates can be effectively air dried but the drying potential of a greater number of laminates needs to be more fully explored before definitive recommendations can be made. The difficulty is extracting moisture that is bounded on more than one side by a glue line. In a three laminate or more arrangement the pathway for moisture exiting the timber is limited to the sides and ends. Effective drying regimes need to be established. Part kiln drying may be possible for large section material, such that the moisture content is reduced to level at which air drying can successfully complete the process, so reducing overall energy input costs.

When drying before gluing, distortion of the material can occur which can either render the material unfit for further processing or require additional processing to remove the distortion. The major advantage of gluing in the dry state is that large sections can be produced at a moisture content appropriate to the intended environment for end use. These large sections may be required for structural reasons or a processing step before secondary sawing to joinery blanks.

Defect cutting

Defects usually refer to any undesirable characteristic present in the plank that is not wanted in the final product. Normally this refers to knots, wane, slope of grain and decay or discolouration. The planks are cross cut either side of the undesirable feature leaving sections of clear timber for later rejoining. Whilst there is no practical limit, other than the finger jointing capability, to how small the sections are, visually isolated finger joints may not be detectable, but many joints occupying only a short length of timber do become obvious and therefore the market requirements dictate the acceptable length between joints or the frequency of finger joints within a given length. It has not been demonstrated if a better result is obtained by randomly mixing the lengths of defect cut material or if it is better to rejoin them in the original sequence. It is possible that the overall result will be the same but this needs further investigation.

Finger Jointing

There are a variety of possible finger joint deigns depending on the end use of the product from finger joints for structural applications to finger joints to be used in joinery, the later leaving a clean joint line on the visual face.

Laminating

Finger jointed boards can be laminated, either on the edge or face depending on the product, and built up in to the final production blank for the article being manufactured.

Basic steps in defect cutting and laminating

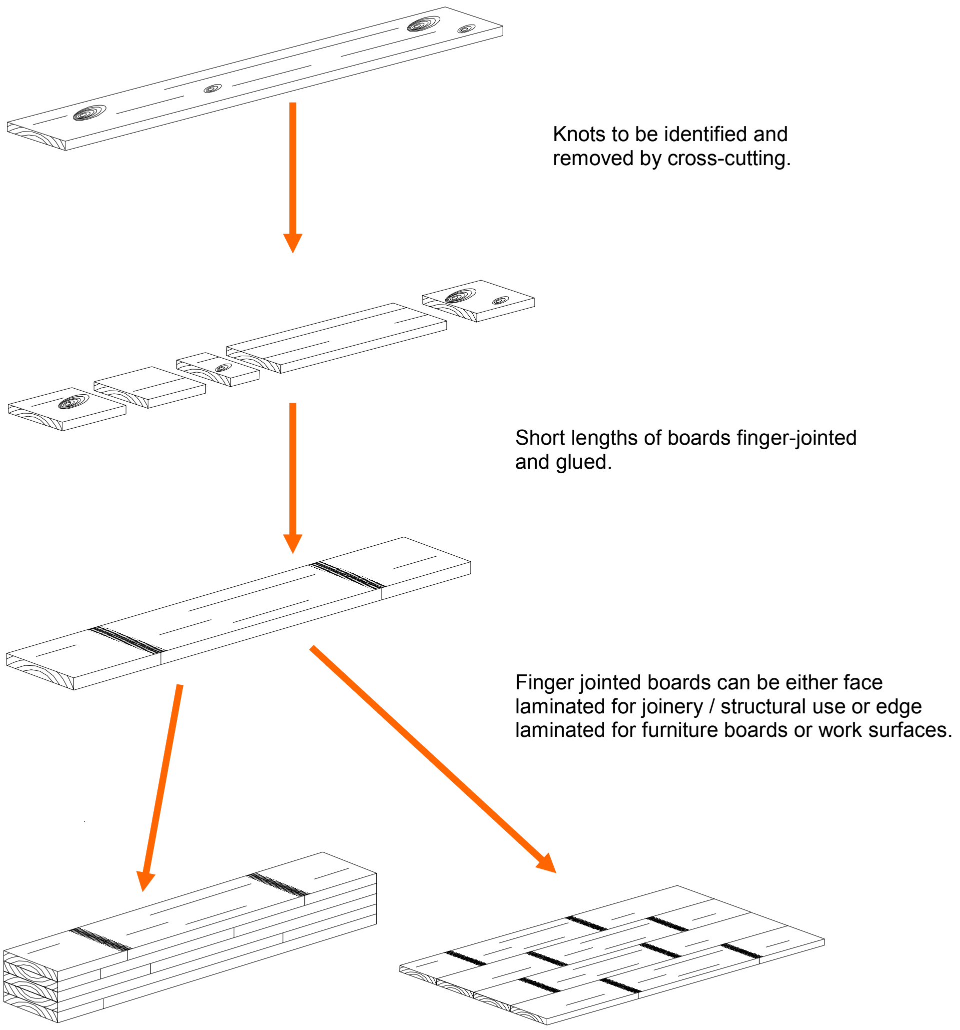

Figure 1. Steps in defect cutting and laminating

Re-engineering for joinery uses

This area of re-engineering offers probably the greatest immediate area of success. As mentioned in the introduction BRE has previously carried out a limited study into the re-engineering of hardwoods for joinery applications. That has been able to establish a reasonable base-line for the incurred costs of re-engineering against possible value added potential.

The report (BRE 219 - 008) carried out a costing exercise for the production of oak joinery planks (size 50mm x 100mm – 4 finger joints per 2m run), in that exercise the following costs were taken into account.

Equipment:

- Capital machinery costs
- Machinery depreciation costs
- Machinery maintenance cost
- Machinery utilisation factor (70%)
- Machinery throughput
- Power consumption (kW/h)
- Machinery accommodation costs
- Kiln drying (£20/m^3) and capital cost of kilns

Handling:

- Forklift truck use

Product:

- Adhesive (£6/kg)
- Product dimensions
- Product shrinkage during drying
- Planing the finished product
- Number for finger joints per 2m run
- Number of laminations

Raw material:

- Logs (£30/m^3)

Primary processing costs:

- Log to batten conversion cost (£30/m^3) – assuming a log to batten conversion rate of 30%. Whilst a log to plank conversion rate of 30% was achieved only around 50% of the planked material was utilised in the finished product.

The cost per m^3 of joinery blanks was:

- Small enterprise = £355
- Medium and large enterprise = £334

Comparison with premium quality joinery and flooring oak:

Joinery = £1200 m^3

Flooring = £1040 m^3

The costings were based on 2003 prices.

This shows the considerable head room available for adding value based on a joinery market. However, the costs are very product specific and hence will vary according to the exact nature of the product being produced. The overall value of the final product, due to the presence of finger joints, may not be as high as premium joinery quality timbers. This difference allows for product placement perhaps not comparable with the highest quality joinery but opens the possibility for customers to be able to afford better than the normal product if not the premium quality items. Taking the example of flooring; the cost of premium oak flooring may be outside of the scope of the customer or housing developer and the normal standard choice would be between softwood flooring or 18mm particleboard. The re-engineered flooring may be more expensive than the softwood or particleboard but may encourage the purchaser to outlay on a mid value product, costing significantly less than for the premium flooring, as they would have a product greatly superior to the standard flooring both in wear quality and aesthetic appeal. Such a purchase could negate the need for other floor coverings, due to high visual quality. The same case could be made for work-surfaces. Instead of a 38mm particle board work surface with a melamine face customers could aspire to a range of hardwood work surfaces for less than those made from a premium quality hardwoods.

Using the visual appearance to enhance value

One of the major selling points of any article manufactured from hardwoods is the attractive nature of the timber. The complex interaction of the wood vessels and related micro-structure is hard to simulate in synthetic product. Some timbers are by their nature more pleasing to the eye than others but most hardwoods have a visual appearance more pleasing that the bulk of the commercial softwoods.

"Making the Grade – A guide to appearance grading of UK grown hardwood timbers[4]" has been beneficial in drawing attention to the natural beauty of hardwood timbers, showing grading and assessment methods for a range of UK grown hardwoods.

Re-engineering by defect cutting reinforces this document allowing a better visual rating and distortion free board to be produced emphasising the natural look of the product. Taken to its logical conclusion, by re-engineering it should be possible to move some of the lower grades as demonstrated in Making the Grade to the higher grades, though this may not be the best use of the technology.

The main thrust of re-engineering small diameter or coppice grown material will be to produce a similar attractive joinery blank to one obtainable from larger trees but at a competitive price to increase the market range for hardwood products. Once again there is the potential to appeal to an aspirational market that wants to move from the basic timber product to one that makes more of statement and has different appeal. This market has started to be addressed; increasing volumes of re-engineered hardwood furniture products from Eastern Europe have entered the UK market. However, though producing a hardwood product at a reasonable cost (below that of solid hardwood furniture) due to the manner of manufacture the visual appearance of the product has been lost. One of the main reasons for this is that the lengths of timbers for finger jointing and laminating have been standardised for ease of production and they are in the main comprised of small section laminating stock. This combined with poor matching of grain loses all sense of the visual quality of the timber. Too successfully re-engineer timber to keep its visual impact great care needs to be taken in matching grain characteristics and colour between adjacent pieces to be joined. The size of the feed stock also needs to be such that it allows the natural beauty of the wood to show without the presence of the finger joints or glue lines becoming obtrusive.

Case study

Figure 2. Shows a sweet chestnut window produced from coppiced grown timber from the Welbeck Estate in Nottinghamshire. It was manufactured as part of the Greenwood Community Forest project.

Figure 2. Re-engineered coppiced sweet chestnut window

Basic production data:

- The logs were in the size range 150mm to 200mm.
- Primary conversion to planks was carried out at BRE
- The planks were defect cut and finger jointed using a polyurethane adhesive whilst still in the green state (60 to 70% moisture content).
- The planks were only partially dried, this was due to the time constraints of the project, the final moisture content (around 22%) was in excess of that normally recommended for joinery.
- The partially dried material was planed and laminated to make the joinery blanks
- The joinery blanks were machined to make the window components and finally fabricated into the window at BRE.
- The finished window was allowed to air dry.

Though at construction the timber components were at 22% moisture content the window dried almost distortion free, with only slight movement on the opening casement.

Representatives of the Princes Trust, whilst visiting BRE, showed great interest in the potential for this approach to joinery manufacture. BRE later received a request from the Trust seeking further information on the process as this approach to widow joinery had been suggested for two of the Trusts upcoming projects. One was a youth centre and the second a 700 unit development near Torquay following the principles established at Poundbury. However, this approach was not adopted as there were still too many gaps in the knowledge between demonstration and production. If these projects had been in a position to use the re-engineering approach it would have been a significant boost to the development of such products and markets. What is does emphasis it that the gaps in the current knowledge need to be filled before the market place has confidence to move forward into adoption and production.

One company has adopted a re-engineering approach to the manufacture of a range of timber productions from coppiced material. Inwood Developments is Sussex have established a niche market for structural and non-structural products mainly based on sweet chestnut. Though involved in the manufacture of re-engineered timber products from coppiced sweet chestnut they concede that they could produce a far more extensive range of products from more timber species if the basic information was available.

Identified issues that need addressing:

- Drying of green glued joinery blanks of more that two laminations
- Best orientation of laminates for specific applications (dry and green glues) internal, external and boundary conditions (doors and windows with one external face and one internal face).
- Best laminate orientation to reduce drying distortion when green gluing.
- Determination of best methods of colour and grain matching between finger joints and laminates

Small diameter hardwoods for structural use

Unlike joinery applications structural applications require a far higher degree of rigour in demonstrating fitness for purpose, and derivation of stresses that allow engineers to design safely with the material. The assumption that timber from small diameter or coppiced logs is the same as timber from mature trees is erroneous and indeed dangerous, there are significant difference in juvenile wood properties that will impact upon structural properties and therefore this needs careful exploration and quantification. John Brazier (PRL) demonstrated in the 1970's that juvenile fast grown timber from ring porous species had significantly different properties from mature timber of the same species.

Therefore, it is unsafe to use stresses derived for mature timber (oak and sweet chest in BS5268 and soon to be in BS EN1912[5]) when designing structural components made from small diameter or coppiced material. The situation is compounded when designing structural elements as glued laminated components (glulam), as would need to be the case with small diameter hardwoods and coppiced grown material. The most frequent approach is to design to BS5268: Part 2 - Section 3 or Eurocode 5[6] / BS EN1194[7]. In either case the calculations are based on strength classes with stresses derived from mature timber. In BS5268 the design is based on modification factors to strength and stiffness which add to the basic stresses given in the strength classes. Therefore not only will the basic properties be wrong but they will be compounded by the modification factors, eroding safety still further.

There are two approaches that can be adopted:

- Full scale test – under BS5268 section 8 full scale testing of structural components can be carried out, the minimum requirement is for one beam to be tested, but the low number tested attracts a reduction factor in the beam's permitted performance. Up to five beams can be tested allowing, if successful, the full design potential to be used. However, this approach has two drawbacks that could act as barriers to use of small diameter hardwoods or coppiced material for structural purposes. The cost, even when only one beam is tested is high and increases with the number tested. If only one beam is tested and fails to meet the required performance the designer gets little additional information from the testing process that could be used to rectify the design deficiencies. However, if five beams are tested there is usually sufficient data generated to allow for design modifications. Full scale testing is usually a method of last resort and is not advised as a general design approach.

- BS EN1194, where appropriate strength class data does not exist, permits the determination of structural characteristic values by test, and allows this data to be used in the design process. This is the more desirable approach for small diameter and coppiced hardwood. However, a significant cost is still incurred and again this could be a barrier to using this material, as every producer wishing to design in this timber would need to carry out individual testing. A far better approach would be to have the basic characteristic values for a number of species derived collectively to reduce cost and ease this barrier to use.

When studying the differences between juvenile and mature timbers the most obvious difference is in stiffness. Brazier demonstrated that fast grown oak and ash (12 rings per 25mm) had improved strength, which should be regarded as a bonus, but significantly reduced stiffness when compared to mature timber of the same species. When designing in timber strength is not usually the limiting factor that is usually stiffness, the serviceability criteria. Therefore to have a reduced stiffness is something that needs to be known at the design stage, as it can be accommodated in the design by an increase in the section depth.

The main factor contributing to low stiffness in juvenile timber is the high micro-fibril angle; this is compounded in coppiced grown material by the incidence of high slope of grain. The effect of both micro-fibril angle and slope of grain have on stiffness is shown in Appendix B.

Case study

Kent County Council was in the process of redeveloping a community centre at Shornwood, near Canterbury; as part of the design they wished to demonstrate the potential of locally grown coppiced sweet chestnut. The initial basis of design was to BS5268: Part 2 – Section 3, which requires stresses based on a strength class. The grade stresses in BS5268 for sweet chestnut are for mature timber and they fail to meet the minimum hardwood strength of D30 – though they are just below it terms of strength and density and above for stiffness. The engineer's basis of design was to use the D30 strength class but to have the design verified by test; BRE was asked to carryout that verification. Five test beams each 6.5m long, 175mm wide and 490mm deep were produced to carry a uniformly distributed service load of 35kN per metre. These were subjected to 24 hour load testing to monitor deflections and finally broken to establish strength.

The structural engineer was concerned about the strength of the beams making the assumption that the means stiffness quoted in BS5268 was greater than that required by the strength class. To maximise yield of the coppiced material no quality control was exercised on slope of grain, which in places was high.

Testing followed the procedures in Section 8 of BS5268 and clearly demonstrated that the basis of design was incorrect but for reason that the strength requirements were fully met. However, the recorded deflections over the 24 hour period for all five beams considerably exceeded the acceptable levels for survivability, and were deemed to be unsafe.

In this situation corrective action needed to be taken to make the design work appropriately for the intended use. From the data produced BRE was able to calculate the actual stiffness of the beam (around 9000 N/mm^2 as opposed to the value in BS5268 and used in the design of 11300 N/mm^2). This allowed a new beam depth to be calculated to meet the survivability criteria. In addition BRE were able to highlight areas of high slope of grain within the laminates that should be excluded from the final production beams thereby improving performance still more (Figure 3).

To use timber from small diameter logs or from coppiced material specific structural design data is needed and currently does not exist. To have every design load tested is a significant barrier to the use of this material. There is a limited number of species that would be regularly used for structural purposes;-oak, sweet chestnut, ash and beech, and it would not be too onerous to derive stresses for this species.

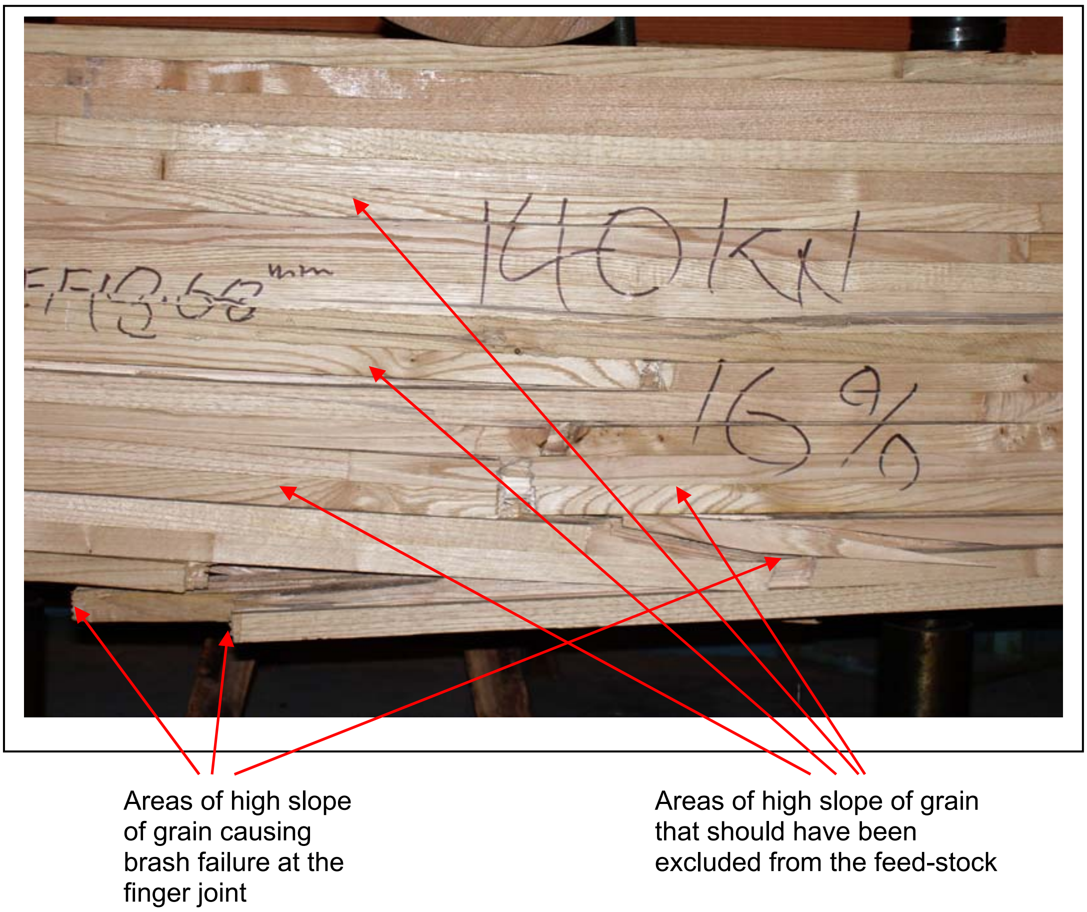

Figure 3. Showing areas of high slope of grain that should not have been included in the sweet chestnut beam and the effects upon performance.

One of the largest potential market areas for structural material made from laminated small diameter hardwood is architectural structural joinery, such as windows, staircases, internal and external balconies, post and beam work. Items that have a highly decorative and architectural impact whilst requiring to meet a structural criteria: proof of design. Whilst this may seem a limited market it was the driving criteria behind the American Hardwood Export Councils (AHEC) decision to ask BRE to derive structural stresses for four of their temperate hardwoods (American white oak, American red oak, white ash and yellow poplar). AHEC's commercial decision was based on the frequency of enquires made regarding this type of application. Therefore, this seems a market that could be well suited to re-engineered small diameter hardwood. In many cases an engineered timber product is better suited to this type of application.

Recent conversions with BRE Wales clients (a company specialising in public house refurbishment) indicates that the price of traditional oak beams is increasing and products that have a similar look and performance are attractive alternatives in their market This would apply to products such as flooring and bar counters as well as large structural items. This suggests that there are ready markets that will accept re-engineered products so long as the two criteria of performance and price are acceptable. This fits with the experience of AHEC though possibly in different markets.

Identified issues that need addressing:

For structural use the identified issues that need to be addressed are:

- Understanding the basic material properties and how they differ from mature timber.
- Characterisation of structural properties and subsequent derivation of stresses for identified species, to be used on small diameter and coppiced grown material only
- Kiln drying of green glued laminated beams to understand the effects on structural integrity due to drying stresses
- Kiln drying of green glued laminated beams to understand the effects upon dimensional stability and section lay-up
- Comparison with BS5268 and BS EN1194 for mature timber to be sure the basis of design is not undermined.

Reduced degrade and yield maximisation.

Re-engineering of small diameter or coppiced timber as mentioned previously can reduce distortion; another major advantage with regard to quality is the reduction in the occurrence of drying checks that appear on the surface of large section timbers. Traditionally large section hardwoods have been used green and allowed to dry naturally in-situ, leading to drying stresses being generated. The drying differential is considerable as the surface dries whilst the centre of the timber is still swollen, the only way for these stresses to be relived is for the timber to check, the degree of checking being dependent on the difference between the surface conditions and centre. The same degree of surface degrade does not occur where built-up laminated timber is used, even where that timber is in the green state. Figure 4 shows two sections of timber, one a built up section of three laminates of oak (worked in to an acorn) and the other a block of solid sweet chestnut. In both cases the timbers had a moisture content of around 30% (approximating to fibre saturation point). They were then allowed to dry at ambient room temperature (18 to 20°C) over a period of 2 years.

Over this time period the obvious visual degrade is striking in the sweet chestnut. It has developed a large surface check penetrating down to the centre of the block, whilst the laminated oak shows no obvious signs of degrade. Though not obvious the laminated block has relieved some of the drying stress down one of the glue lines and having determined why this has happened it is believed possible to overcome this slight degrade. The cause of this minor degrade is believed to be due to the nature and properties of the laminates used in the construction of the turning blank. The two outer laminates were harder and denser than the central laminate which was of lower density and in consequence was softer. The glue line had relieved the drying stresses not by a bond failure but by peeling off the surface fibres of middle laminate. Therefore this was a failure of material selection rather than of the principles of laminating However, it is this degree of knowledge that is needed and care must be brought to the laminating process for successful industry applications.

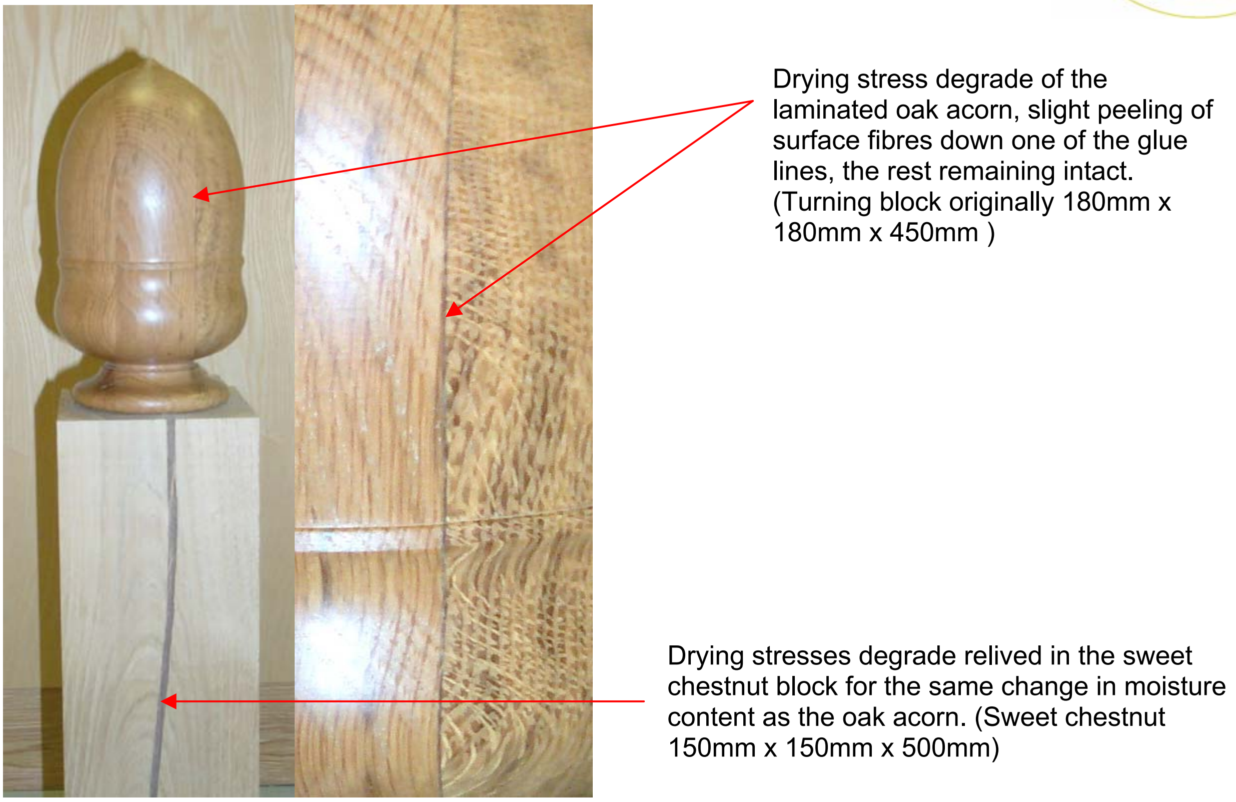

Figure 4. Showing the drying degrade of the solid sweet chestnut block (150mm x 150mm) and the green laminated oak acorn.

Figure 4 also illustrates the potential to increase the yield of the converted timber. Of the material that is converted into planks for re-engineering only 50% gets incorporated into the finished product. The percentage used could be increased for certain other uses. In Figure 4 the acorn has been produced from a turnery blank manufactured from reclaimed defect cut material that would have been classified as waste or residue. The three laminates contain areas of contorted grain, or excessive high slope of grain associated with large knots, which if included in the defect cut planks could induce distortion on drying, Figure 5 shows the basic idea for reclaiming portions of defect cut sections. The benefit for using such difficult timber is that it is usually has a highly decorative figure which is improved by the turning process or other wood working activities. This approach has use in components for stair parts such as newel posts and finials due to the possible highly attractive figure in this timber.

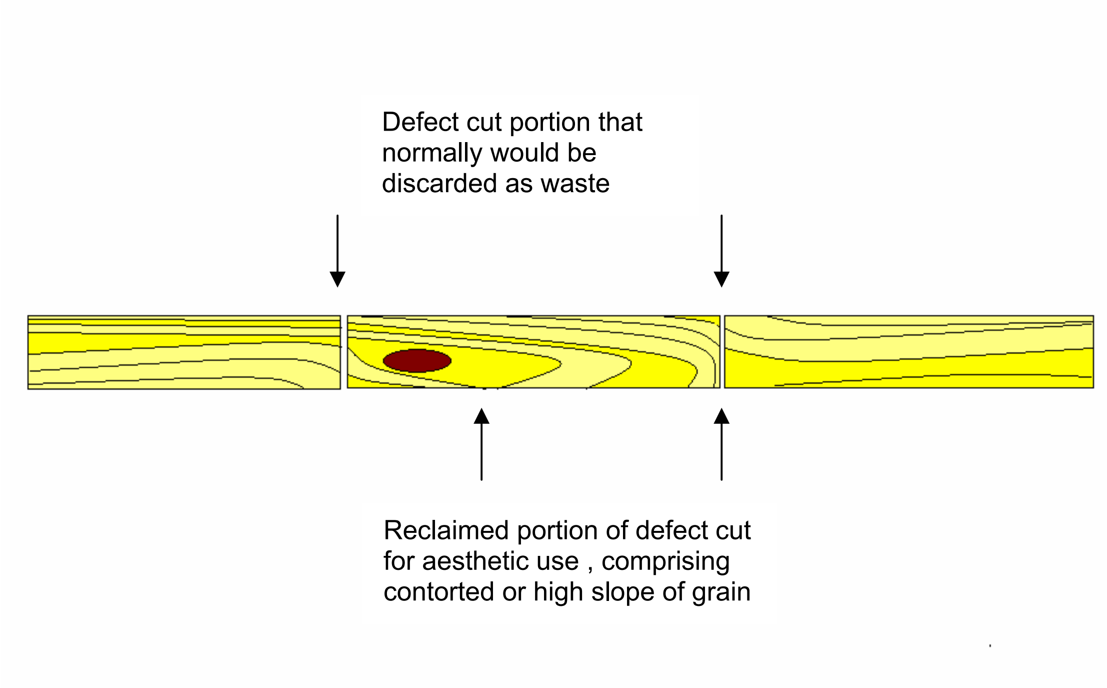

Figure 5. Shows the portion of defect cut material that can be reclaimed that has application for decorative use.

Identified issues that need addressing:

The grain in this material is far more severe than in normal timber, therefore great care needs to be exercised when laminating such material to ensure that the benefits of re-engineering are gained. Areas that need to be addressed are:

- Understanding the interactions of the basic timber properties and how they influence the glue line behaviour and understanding the influence on working properties.
- Best lay-up arrangements to introduce dimensional stability
- Best lay-up arrangements to reduce drying degrade.
- Define best lay-up arrangements to allow the best visual appearance of the wood to show through
- Better understand the interactions of various physical properties of the timber when used in a laminated section and their influence on machining characteristics.

Additional benefits that can accrue from an improved commercial basis for small diameter and coppiced hardwoods.

Development of a viable commercial market for such timber should bring benefits other than the better use of an under utilised resource. The definition of a viable commercial market in this instance is one in which all parties gain financially, that includes the grower of the resources as well as the manufacturer of the products. The two additional main benefits that can be gained with regard to better use of the resource are:

- Improvements to the rural economy
- Environmental benefits of a well managed woodland

Both these topics are important to our future sustainable society and can benefit from increased sustainable product markets that provide a profitable return on the resource. They are not the main driving force behind this scoping study, which is to consider the knowledge and demonstrate potential for such timbers so that such profitable markets can be achieved, they need to be recorded as important gains in their own right.

The decline in rural employment and the fall in rural populations are well documented and have become a concern of both the present Government and noted land owing figures such as HRH the Prince of Wales. This combined with the drive for environmental sustainable businesses with aims such as local sourcing, low carbon footprints and the recent Stern report on climate change and the economy, can act to aid the development of local product markets.

Whilst the large global scale environmental issues may be hard to appreciate within the context of better utilisation of small diameter hardwoods within the UK and England in particular more local issues can be understood and the benefits to biodiversity of well maintained and appropriately managed hardwood lands are understand. The increased profitability of such woodland could feed through into better management of the resource which impacts directly on the biodiversity.

The Forestry Commission (England) hosted a conference specifically directed at the hardwood markets "New Markets for Old Wood[8]" in 1994. The contributors at that conference highlighted the environmental importance of hardwood woodlands as well as profitability and markets. In the conferences "Background and Objectives" Alan Betts stated:

"In order to place new emphasis on the management of our broadleaved resource, the Forestry Commission in recent years has been at the centre of a number of developments and projects to look more closely at the issues involved. This effort has been mirrored in a number of other organisations which share the same concerns to better manage our stock of fragmented and often declining broadleaved woodlands.

It is in the context of these environmental and economic concerns, and in recognition of the vigorous response to them over the last decade, that the Forestry Commission decided to organise the New Markets for Old Woods conference.

Sir Hector Monroe as part of his keynote address said:

"*The Government very much supports the various initiatives that are being taken to develop new markets for hardwood: Some in the old traditions, such as charcoal which is finding a new lease of life as well as others which are novel, and which I am sure this conference will touch upon in the course of the next two days.*

23 Re-engineering small diameter and coppiced English hardwoods for a variety of end uses.

However, for initiatives to be successful, the key issue is that the growers need information about market opportunities and processors need information about supplies."

From the above it can be seen that profitability and bio-diversity have been recognised for a number of years but since the conference great developments have been made in both technology and markets that can move the debate on from the 1994 position to the present. Sir Hector's comments about new products are interesting, in 1994 BRE had just completed the derivation of structural stresses for oak, followed two years later with similar stresses for sweet chestnut, and these should not be viewed as new products but simply reclaiming markets that had been lost. Since that time glulam and re-engineered timber products have increased from almost no market share to a now established market penetration, in certain sectors taking the majority market share. Therefore with the initial steps BRE has taken in re-engineering and being in a position to identify the areas of concern that still need addressing, it is possible to make the aspirations of the conference a reality.

Demonstration and dissemination

For the re-engineering of small diameter and coppiced grown hardwoods to be rapidly adopted by manufacturers there needs to be dissemination of detailed knowledge and procedures on re-engineering. Much of what has already been achieved is subject to commercial confidentially or is highly specific, therefore work needs to be carried out so that the results generated can be open for all to use. Business initiatives will need kick starting in appropriate regions to deliver the re-engineered material.

Knowledge and its dissemination is one significant strand for encouraging up-take. However, the investment costs are high and therefore practical demonstration, not only of the potential but also of the serviceability of products made from such timbers, needs to be demonstrated. To build confidence that the products made by re-engineering perform to an acceptable standard and justify the investment made in them. BRE has been able to demonstrate some of the potential such as laminated joinery blanks and simple windows. However, serviceability still needs to be demonstrated. The material that has been produced has never been placed into a built environment, which is the best showcase for such products.

To demonstrate both serviceability and use within a construction context it is proposed that a re-engineered timber based demonstration building is constructed, both to show case what can be achieved and as a weathering facility to demonstrate serviceability. It is envisaged it would be comprised of a range of products and approaches both structural and non-structural.

The product range could include:

- A range of structural applications – products including laminated post and beam walls, laminated studs, glulam beams, laminated floor joists and roof components
- Decking
- Cladding
- Windows
- Flooring
- Furniture
- Stair parts
- Work surfaces

This list of possible products for inclusion in a demonstration building is not considered exhaustive.

Conclusion and recommendations

1. There is potential to significantly add value to small diameter hardwoods and the initial work in demonstrating this has been carried out.
2. There is a range of issues where the current knowledge is lacking or is insufficient for the move from demonstration to successful marketing to be made without them being resolved.
3. The resource is plentiful to support a developing industry based on it, and the aim would be for the resource price to raise in-line with demand. Thereby increasing profitability for growers.
4. Demand for mature solid wood (especially oak) is increasing leading to higher prices for premium timber, further widening the possible headroom for re-engineering of small diameter material to be profitable.
5. Re-engineering can be carried out either with the timber in the green state or dry depending on the needs of the final product.
6. Structural use has been demonstrated but the current approach, by test, is both random and expensive. Widely available information of the properties for structural; use would make the process simpler and cheaper for producers.
7. Increases in yield and reduction of waste can be achieved, but the material reclaimed has quite specific end uses.
8. Dissemination and demonstration are key features in developing the market for the resources and a purpose built demonstration building is recommended in achieving this aim.
9. It is recommended that the following issues are addressed initially:
    - Effects of drying multiple laminates needs investigation to understand the effects of drying stresses upon final performance
    - The relationship of lay-up arrangement and the timbers physical properties needs study to:
        i. determine effect upon machining characteristics
        ii. the best lay-up arrangements for specific products
        iii. the best orientation for lay-up to reduce distortion
    - Determination of structural properties for suitable species to facilitate use in re-engineered substrates
    - Ensuring that the data obtained for structural use is compatible with the basis of design in BS5268 and Eurocode 5

- Methods for maximising the timbers visual appeal in the finished product need to be developed

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6. British Standards Institution, Eurocode 5: Design of timber structures – Part 1.1 General rules for buildings, DD ENV – 19995 -1-: 1994, London
7. British Standards Institution, Timber structures,- Glued laminated timber – Strength classes and determination of characteristic values, BS EN 1194: 1999. London
8. New Market for Old Woods- Betts. A and Claridge J.- Proceedings of a conference at the University of Surry, The Forestry Authority of England, Great Eastern House, Tenison Road, Cambridge, CB1 2DU.1994

Appendix A – Distribution of selected tree species within the UK

Information courtesy of Cambridge University

Figure 1. Distribution of Acer pseudoplantanus

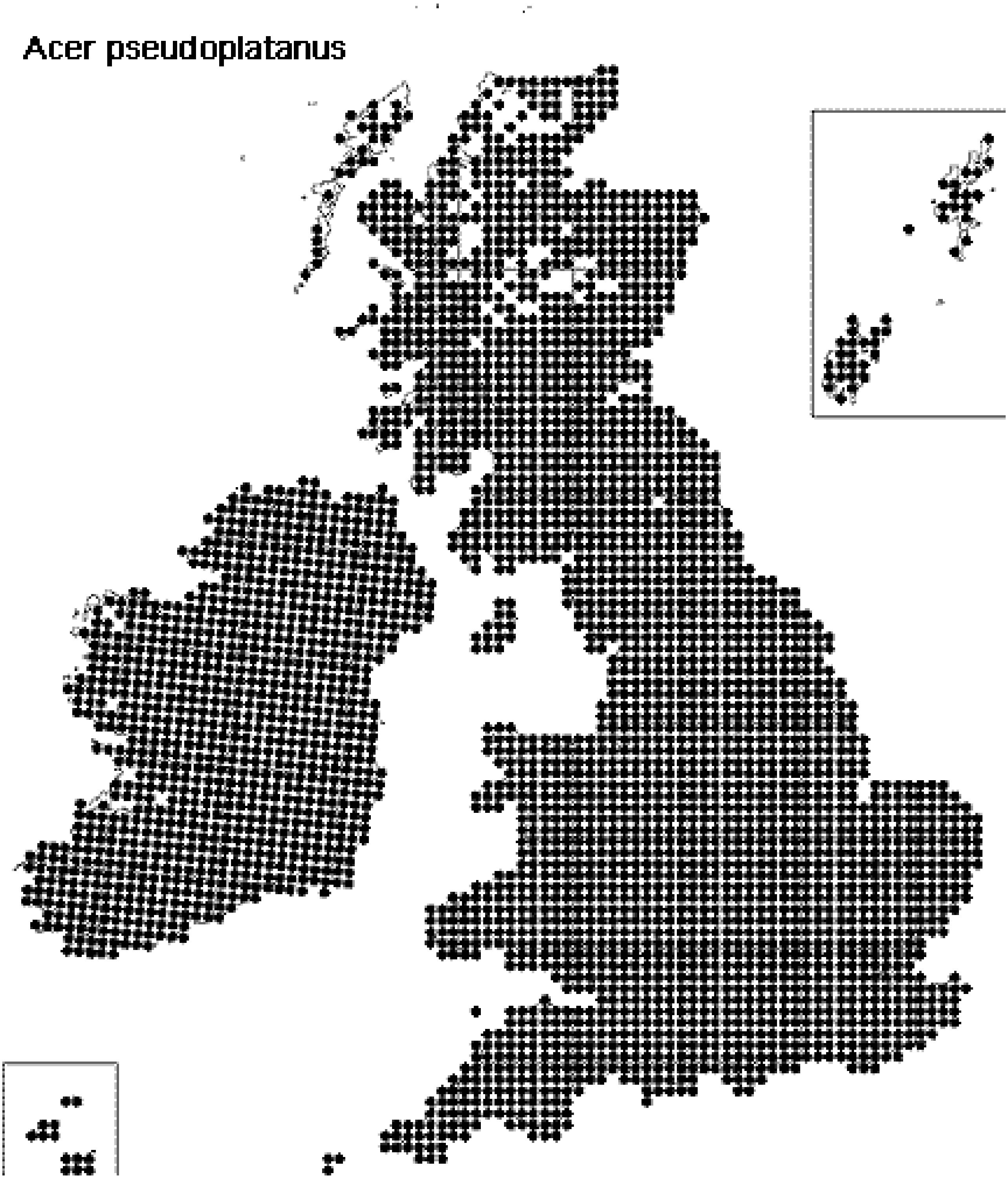


Figure 2. Distribution of Alnus glutinosa

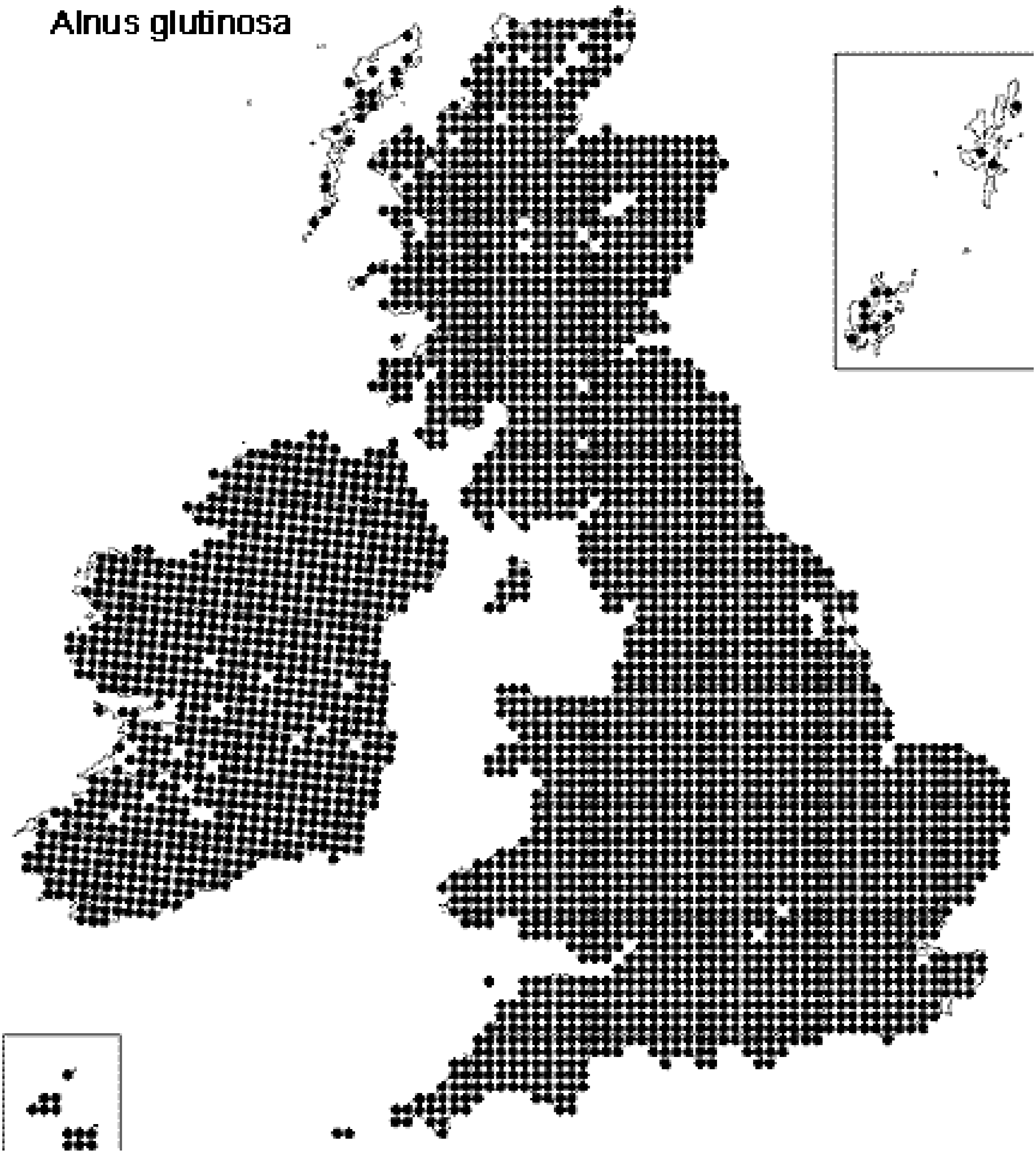


Figure 3. Distribution of Betula pendula

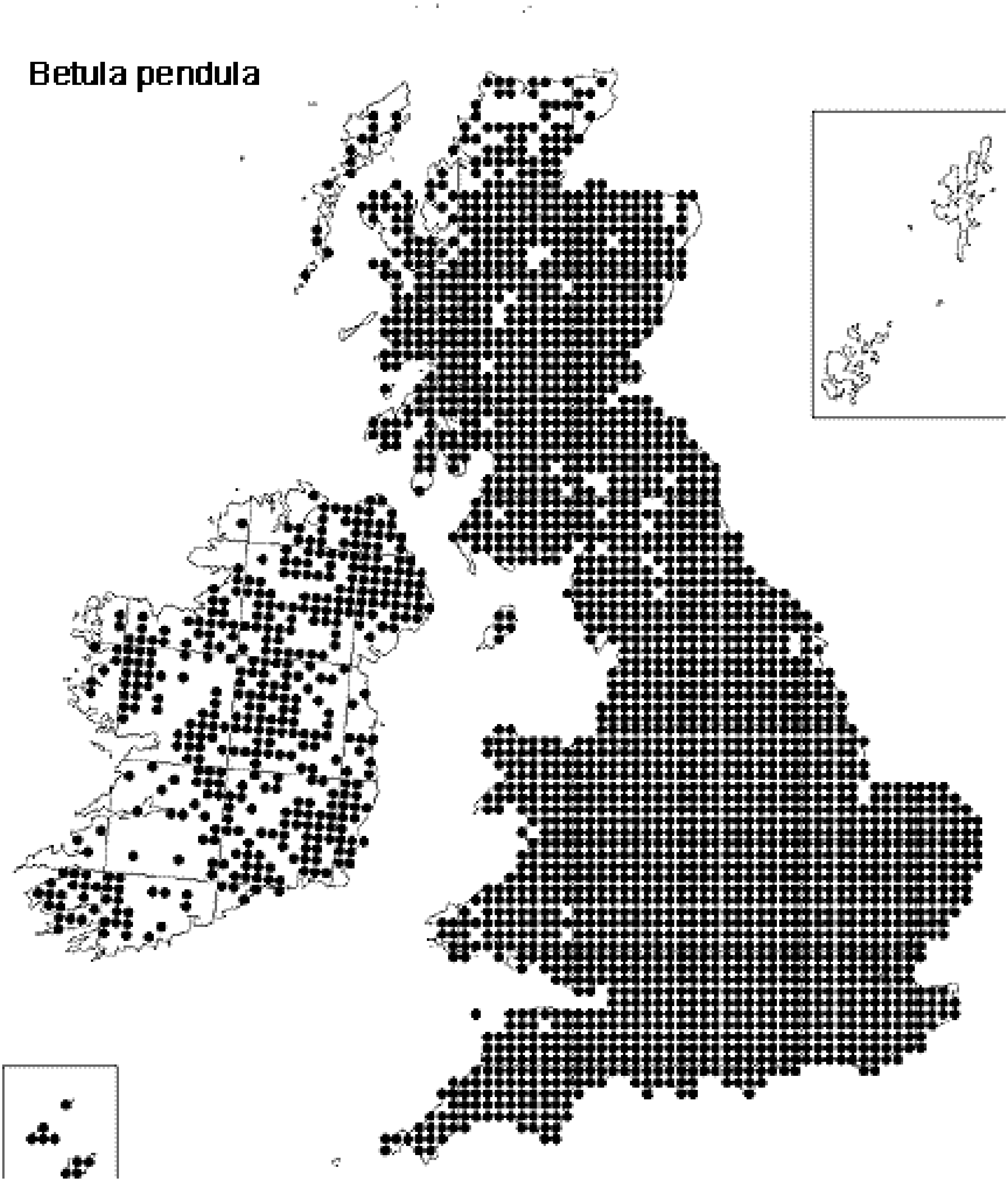


Figure 4. Distribution of Carpinus betlus

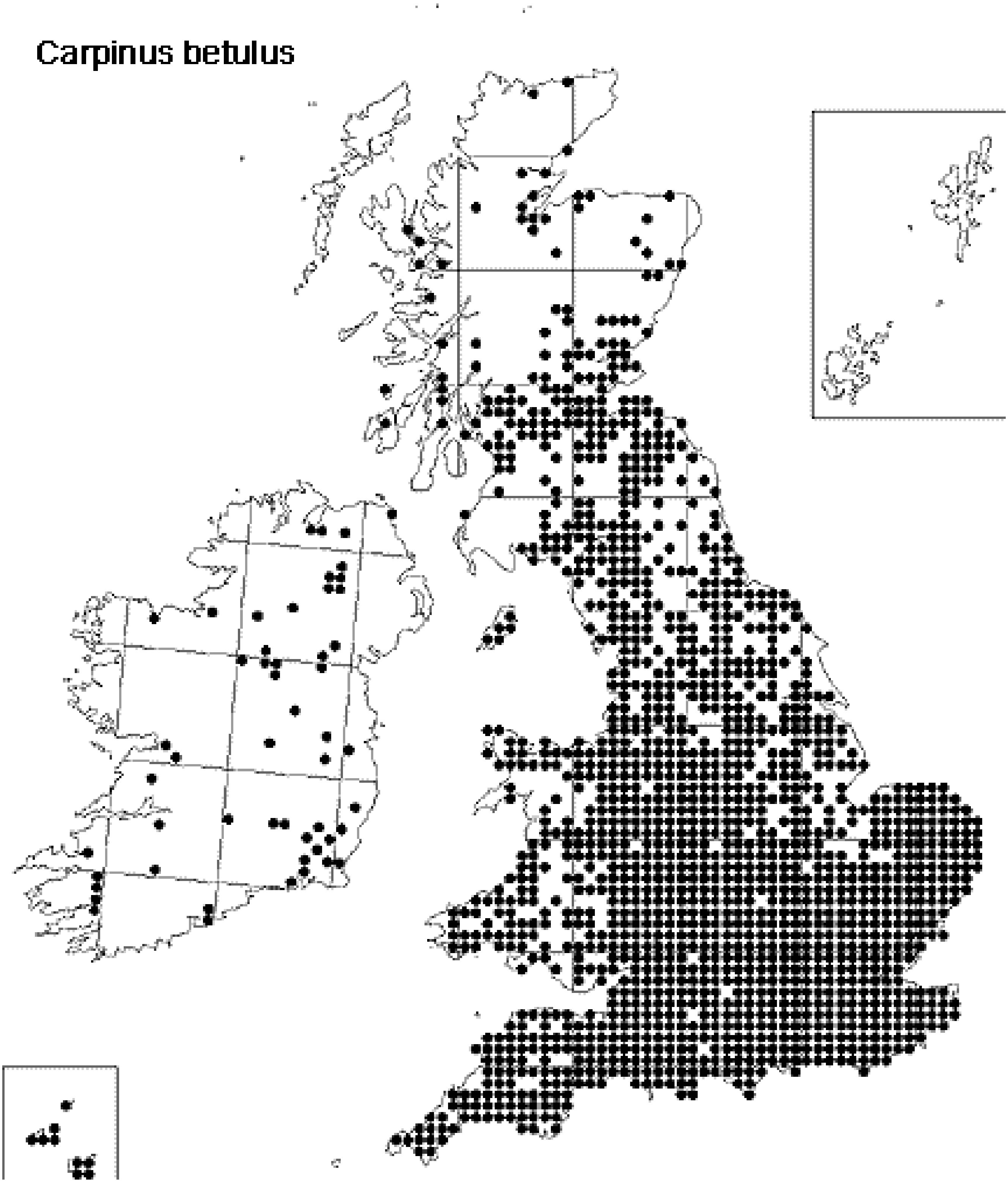
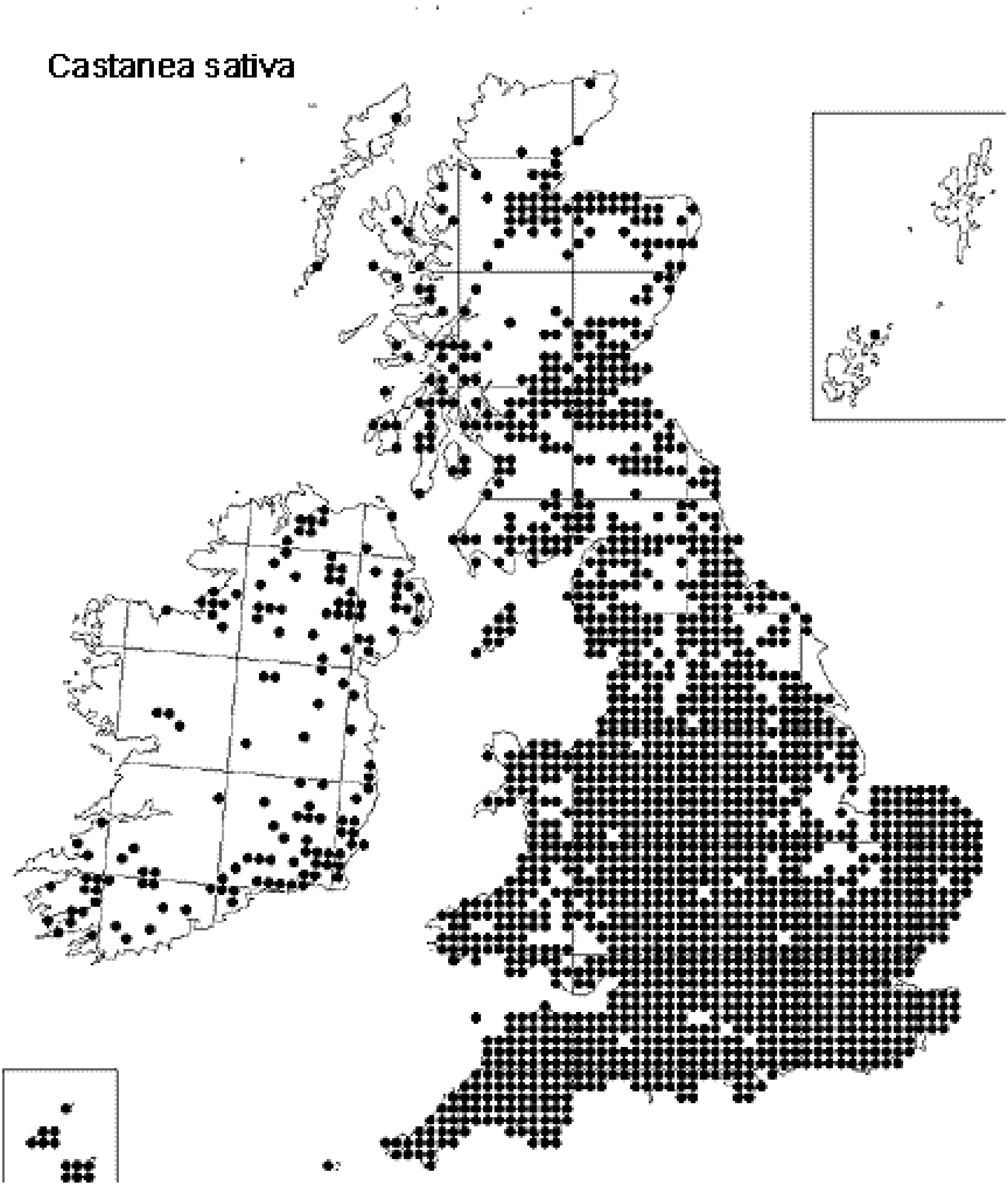


Figure 6. Distribution of Castanea sylvatica



Distribution of Fagus sylvatica

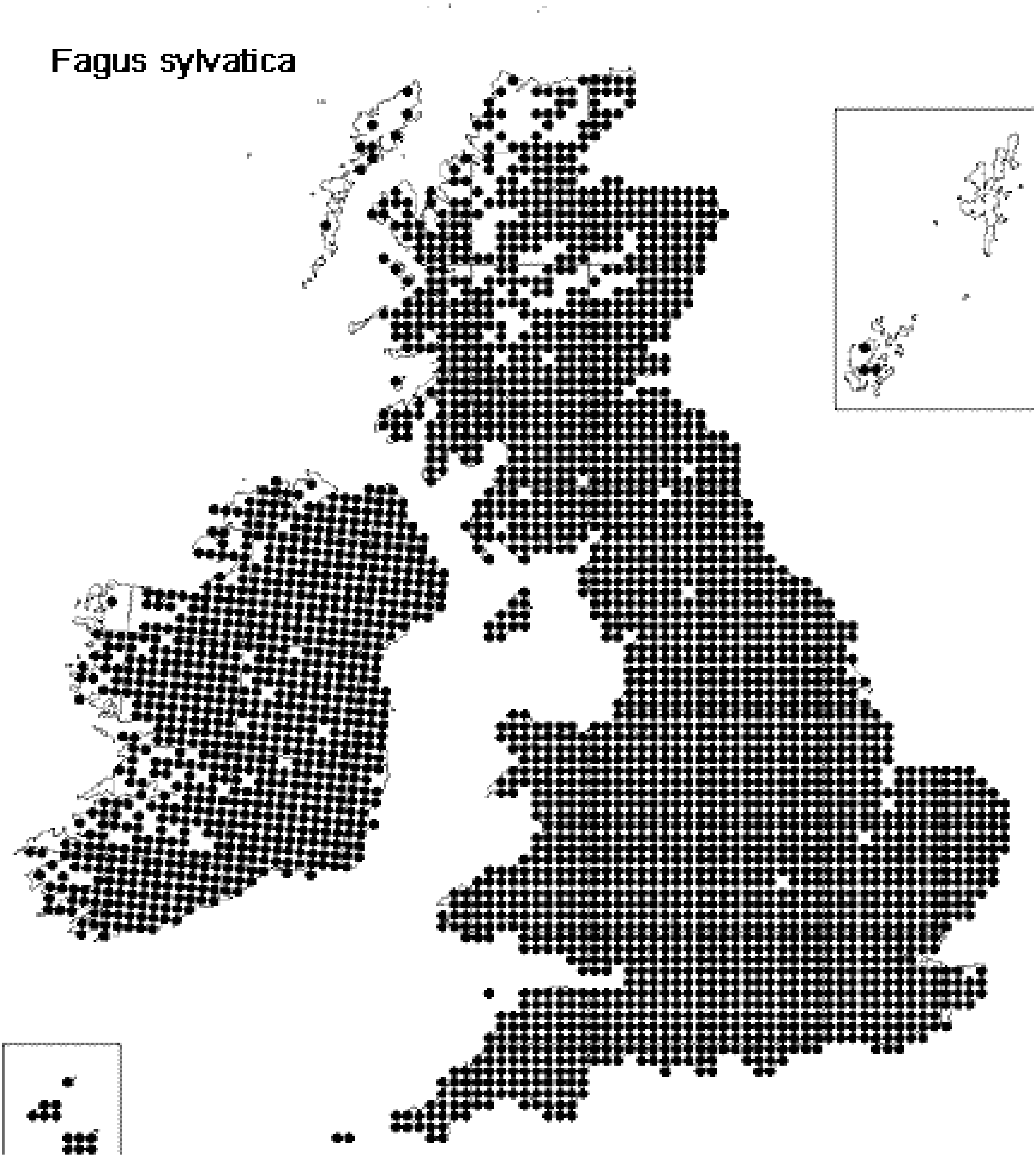


Figure 7. Distribution of Fraxinus excelsior

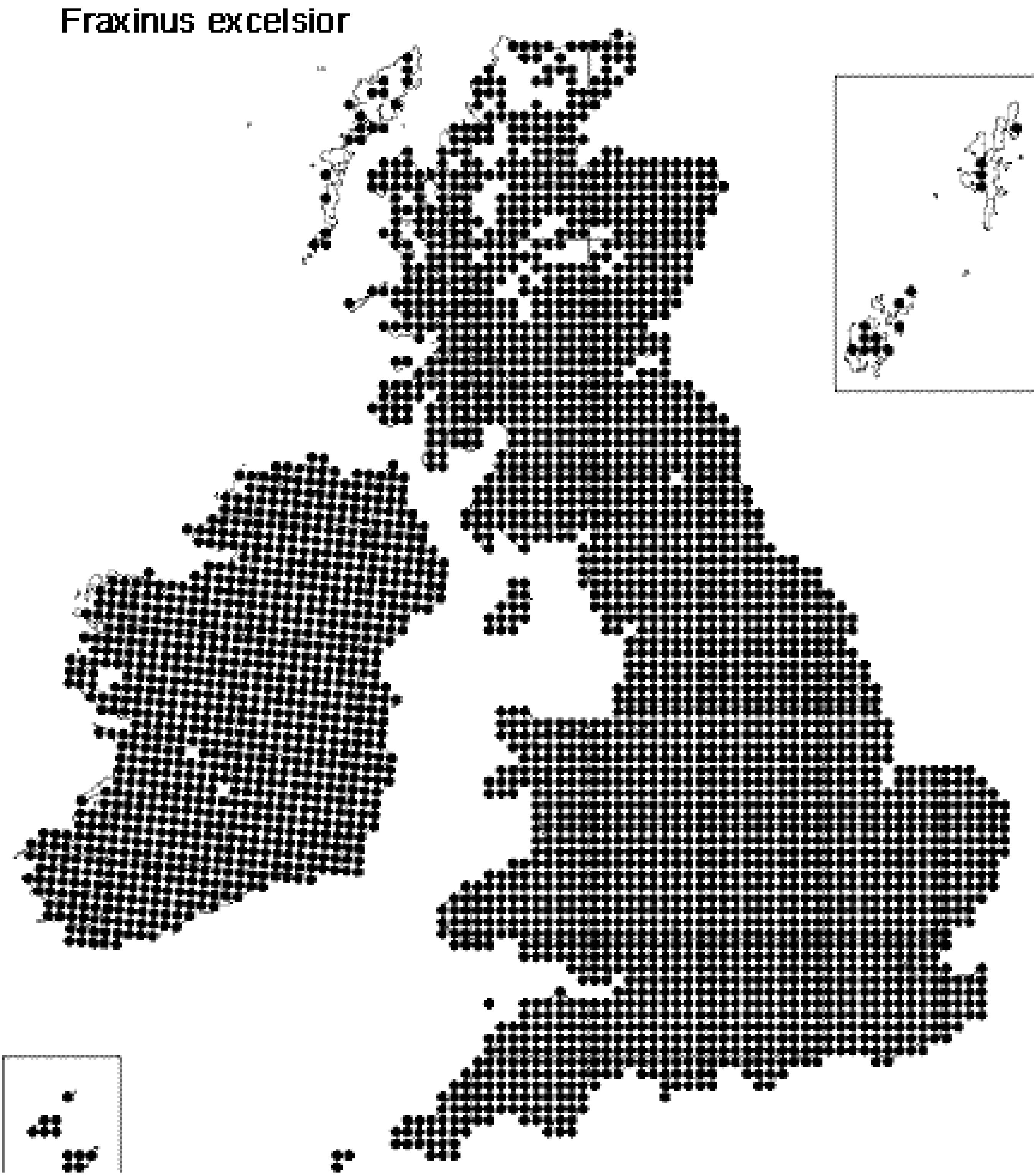
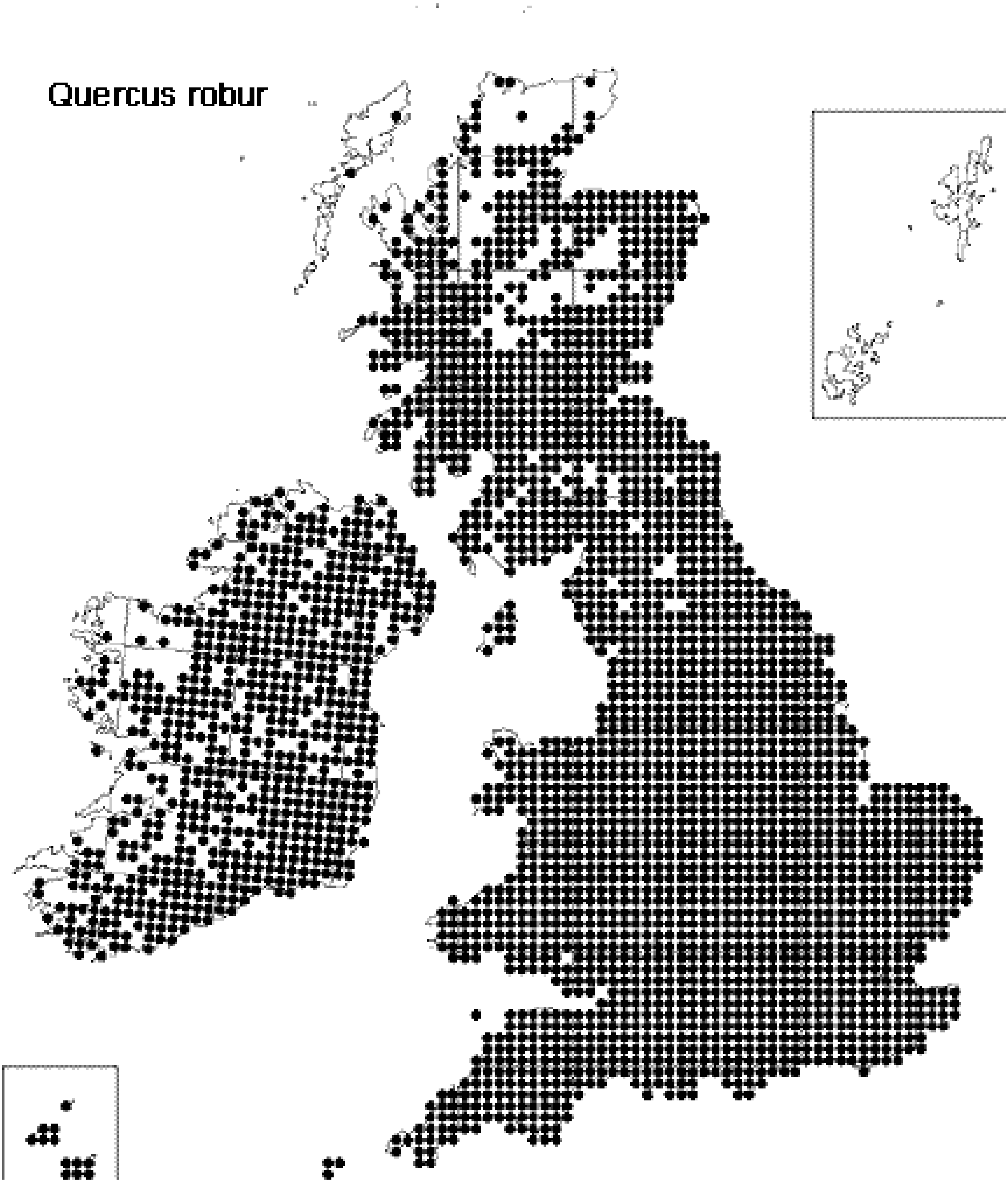


Figure 8. Distribution of Quercus robur



Appendix B – Effects of micro-fibril angle and slope of grain on stiffness

Figure 1. Effects of micro-fibril angle upon stiffness (N/mm^{2})

Figure 2. Effects of slope of grain on upon stiffness (N/mm^2)

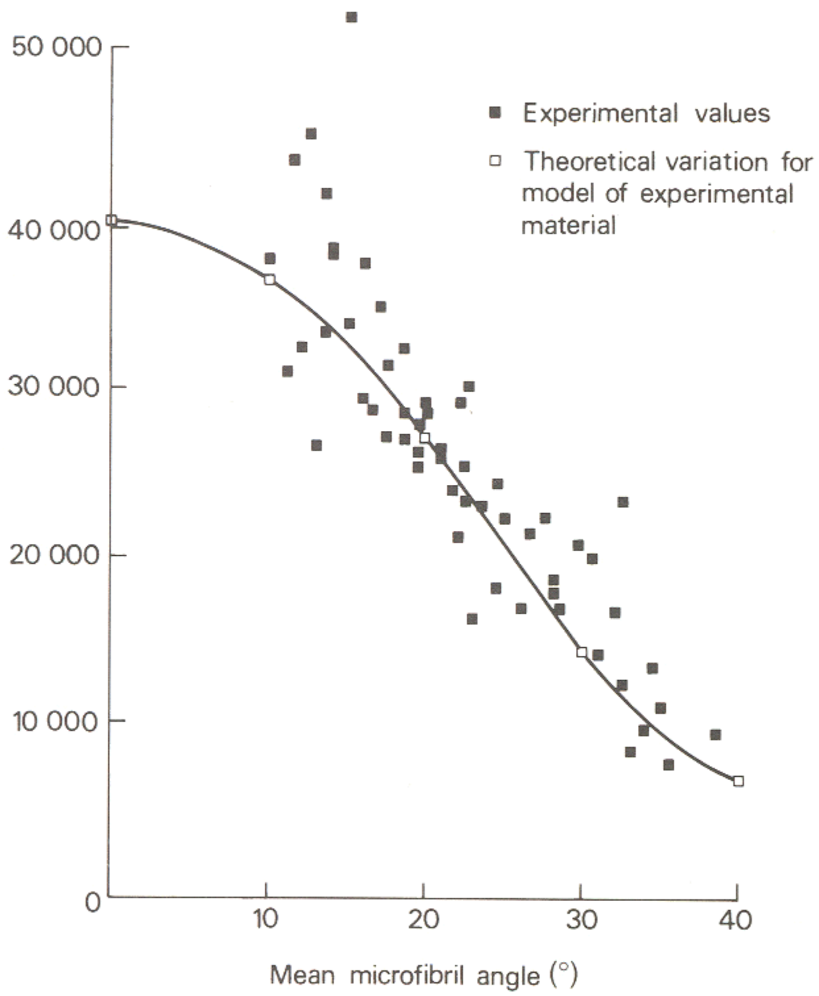


Figure 1. Effects of micro-fibril angle upon stiffness (N/mm^2)

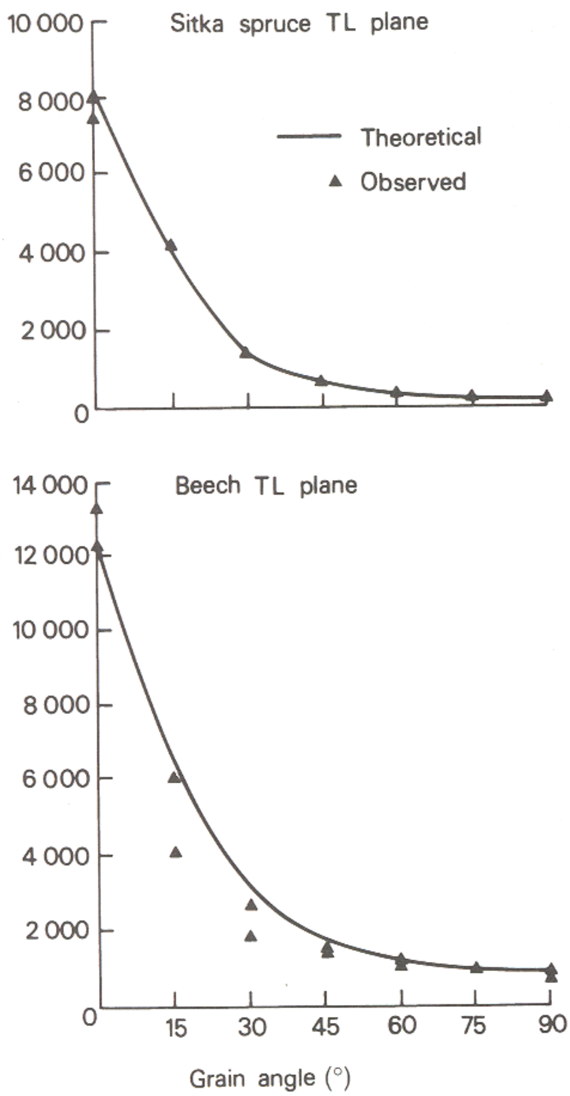


Figure 2. Effects of slope of grain upon stiffness (N/mm^2)