Rapid Pest Risk Analysis for Acute Oak Decline

Disclaimer: This document provides a rapid assessment of the risks posed by the pest to the UK in order to assist decisions on a response to a new or revised pest threat. It does not constitute a detailed Pest Risk Analysis (PRA) but includes advice on whether it would be helpful to develop such a PRA and, if so, whether the PRA area should be the UK or the EU and whether to use the UK or the EPPO PRA scheme.

STAGE 1: INITIATION

1. What is the name of the decline-disease?

Acute Oak Decline (AOD) in the UK, is a decline-disease (Manion, 1982; Denman *et al*., 2014). Amongst the biotic factors, at least two species of bacteria and at least one insect species are involved.

Bacterial species implicated to date:
Brenneria goodwinii
Gibbsiella quercinecans

Insect species implicated to date:
Oak buprestid beetle *Agrilus biguttatus* (Fabricius, 1777)

Synonyms:
Agrilus pannonicus (Piller & Mitterpacher, 1783)
Agrilus subfasciatus (Ménétriés, 1832)
Agrilus morosus (Gory & Laporte, 1837)

Common name(s) of pests implicated in AOD:
The name Acute Oak Decline (AOD) originated in the UK (Denman and Webber, 2009). However, similar decline-diseases in the UK and Europe are called oak decline, but some are also referred to by a specific name, for example, T-disease (Donabauer, 1987). There are some common-names for some of the components of AOD.

Common name of bacteria involved in AOD: None

Common names of the insect involved in AOD: Jewel beetle, oak splendour beetle, two-spotted oak buprestid

Taxonomic position of putative causal organisms associated with AOD:

Taxonomic position of bacteria involved in AOD:
Kingdom - Bacteria; Phylum - Proteobacteria; Class – Gammaproteobacteria; Order - Enterobacteriales; Family - Enterobacteriaceae; Genus – ***Brenneria*** : Species – ***goodwinii***

Kingdom - Bacteria; Phylum - Proteobacteria; Class – Gammaproteobacteria; Order - Enterobacteriales; Family - Enterobacteriaceae; Genus – ***Gibbsiella***; Species – ***quercinecans***

Taxonomic position of the insect involved in AOD:
Kingdom - Animalia; Phylum - Arthropoda; Class - Insecta; Order - Coleoptera; Family - Buprestidae; Genus – ***Agrilus***; Species – ***biguttatus***

2. What is the status of Acute Oak Decline in the EC Plant Health Directive (Council Directive 2000/29/EC) and in the lists of EPPO?

Acute Oak Decline is not listed in the EC Plant Health Directive nor is it currently on the EPPO Alert List. Neither the buprestid, *Agrilus biguttatus*, nor the bacterial species implicated in AOD in the UK (*viz. Brenneria goodwinii* and *Gibbsiella quercinecans*), are listed on the EPPO Alert list.

3. What is the reason for the rapid assessment?

Acute Oak Decline is a relatively new condition of oak trees in the UK, thought to have started 20 - 30 years ago (Denman *et al*., 2014). Recent research has shown that it is a spreading decline-disease in the UK (Brown, 2014) that affects native species of oak (*Quercus robur* and *Q. petraea*) and is now considered to pose a threat to the long term health and survival of native oak species in certain parts of England (Denman *et al*., 2014). As a result it has been identified as a decline-disease of concern to the UK during a review of tree health and plant bio-security action plans (LWEC, 2013) and is included on the Defra Plant Health Risk Register. A risk assessment is required to help inform the decision on whether any statutory action is justified.

STAGE 2: RISK ASSESSMENT

4. What is the present geographical distribution of Acute Oak Decline?

In order to estimate the geographical distribution of AOD it is necessary to provide some background information about the decline-disease so that distribution can be considered in that context.

The causes of decline-diseases such as oak decline, involve assemblages of both biotic and abiotic factors (Manion, 1982; Delatour, 1983; Schlag, 1994; Gibbs and Greig, 1997; Steiner, 1998; Thomas, 2008). Recently, Denman and Webber (2009) emphasised the need for a more discerning analysis of the decline-disease known as 'Acute Oak Decline' (AOD), characterised by a rapid decline in native oak trees over three to five years often, and not uncommonly resulting in tree mortality. Denman *et al.* (2014) provide four key descriptors that identify AOD in the UK: (1) Weeping patches of dark fluid visible on oak stems; (2) cracks in the outer bark from which the fluid seeps; (3) irregularly oval-shaped lesions in the inner bark and/or cavities behind the outer bark around the seepage point; and (4) the presence of galleries of the buprestid *A. biguttatus* in the phloem and outermost sapwood (in less than 5% of cases studies so far galleries appeared absent but this could be due to unsuitable investigation technique used).

To date, most affected oaks in the UK have been 50+ years old, so the decline-disease appears to be associated with mature or veteran trees although this could reflect a reporting bias and the lack of systematic surveys for AOD which covered all the age classes. However, in 2013 young oak trees with a DBH (trunk diameter at 1.3 m height) of 10-12 cm (possibly 10-20 years old), showing the symptoms of AOD were identified for the first time;

both bacterial species (*B. goodwinii* and *G. quercinecans*) were isolated and evidence of larval galleries was noted (S. Denman, unpublished). Thus, affected trees may be younger than previously thought. In the UK AOD is currently present in England particularly across the Midlands and the Welsh Borders (Denman and Webber, 2009; Brown *et al*., 2014; Denman, 2014).

Similar symptoms have been reported on a range of native oak species in continental Europe but detailed descriptions are lacking, making it difficult to interpret and compare whether AOD in the UK is the same as any of the oak decline decline-diseases reported in Europe (See Denman *et al*., 2014). Oak declines with a similar symptomology to AOD but found elsewhere in Europe are listed in Table 1.

Table 1. Possible distribution of Acute Oak Decline in Europe, based on symptom descriptions and photographs only

Country	References
Austria	Donaubauer, 1987; Cech and Tomiczek, 1988
Belgium	Van Steenkiste *et al*., 2004
France	Jacquiot, 1949; Jacquiot, 1950; Jacquiot, 1976
Germany	Falck, 1918; Krahl-Urban *et al*., 1944; Hartmann *et al*., 1989; Hartmann and Blank, 1992; Kehr and Wulf, 1993; Schlag. 1994
Italy	Scortichini *et al*. 1993
Netherlands	Oosterbaan, A. 1990; Oosterbaan & Nabuurs, 1991
Poland	Kowalski, 1996; Siwecki, 1989; Siwecki and Ufnalski, 1998
Spain	Biosca *et al*., 2003; Soria *et al.*, 1997; Poza-Carrión *et al.*, 2008
United Kingdom	Gibbs and Greig, 1997; Gibbs, 1999; Denman and Webber, 2009; http://www.forestry.gov.uk/fr/INFD-7UL9NQ

Distribution of the bacterial species associated with AOD:
So far the presence of *Brenneria goodwinii* is only known from the UK (England and Welsh borders – Denman *et al*., 2012) and *Gibbsiella quercinecans* is known from the UK (Brady *et al*., 2010) and Spain (as *Serratia* - Biosca *et al*., 2003; Poza-Carrion *et al*., 2008). It is unknown whether both these bacteria are native to these areas or introduced.

Distribution of *Agrilus biguttatus*:
Agrilus biguttatus is considered native to the UK and Europe and is widespread across central Europe, extending east to the Ukraine and south to North Africa (Bily, 1982; Davis *et al*., 2005). Recent range expansion has been reported along the northerly limit, into Denmark (Pendersen and Jørum, 2009).

The beetle is also mentioned as present in the following areas:
Germany (Falck, 1918)
Russia (Starchenko, 1931)
France (Jacquiot, 1950)
Netherlands (Moraal and Hilszczański, 2000)
Hungary (Moraal and Hilszczański, 2000)
Poland (Moraal and Sierpinski, 2007)
Sweden (Sonesson and Drobyshev, 2010)
Denmark (Pendersen and Jørum, 2009)

5. Is Acute Oak Decline established or transient, or suspected to be established / transient in the UK? *(Include summary information on interceptions and outbreaks here).*

Acute Oak Decline is established and spreading in the UK (Brown, 2014; Denman *et al*., 2014). A similar condition appears to be established in parts of Europe where episodic outbreaks cause significant damage and losses (Delatour, 1983; Donabauer, 1987; also summarised in Denman *et al*., 2014).

Bacterial component of AOD:

Both bacterial species associated with AOD in the UK were un-named or unknown to science prior to the recognition of the decline-disease. *Gibbsiella* is a newly erected genus to accommodate *G. quercinecans* (Brady *et al*., 2010) a bacterial species almost exclusively associated with the necrotic lesions on AOD affected oaks and not yet reported to be associated with any other tree (or plant) genera. In contrast, the genus *Brenneria* is well known and characterised; it houses species that cause diseases on other tree genera. The species found consistently from lesions on AOD trees, *Brenneria goodwinii*, is a newly described species (Denman *et al*., 2012). The origins of both these bacterial species in the UK are unknown at present. A native origin is not excluded at this stage.

Whilst characterising *G. quercinecans* strains from affected native oak in Britain, Spanish bacterial strains isolated from declining trees of *Q. pyrenaica* and *Q. ilex* in Spain (Biosca *et al*., 2003) were obtained from Spanish colleagues. These were shown to be *G. quercinecans* (Brady *et al.*, 2010). *Gibbsiella quercinecans* is thus also present in Spain. However, since both bacterial species are new to science and only recently described their status as native or introduced organisms in the UK and continental Europe is unknown.

***Agrilus* component of AOD:**

The oak buprestid beetle associated with AOD is considered a native species in the UK, with earliest records of the insect going back to 1888 (Fowler, 1888; Levey, 1977). Until quite recently *A. biguttatus* was considered a vulnerable endemic species in the UK (Shirt, 1987), developing on recently dead or dying hosts (Alexander, 2003). Distribution records over the last 25 years suggest an increase in both its abundance and geographical range in England (Allen, 1988; Hackett, 1995; Alexander, 2003). The frequent association with oak decline sites has led some authors to consider *A. biguttatus* as a pest species opportunistically colonising weakened oak in the UK (Gibbs and Greig, 1997) and across its European range (Moraal and Hilszczanski, 2000; Evans *et al*., 2004; Van Steenkiste *et al*,. 2004). A recent range expansion has been reported along its northerly limit into Denmark (Pedersen and Jørum, 2009), and increasing abundance was described in the Netherlands in the mid-1990s (Moraal and Akkerhuis, 2011).The British population is at the north-westerly limit of this range, and until the 1970s was regarded as a relic of *A. biguttatus* distribution, occurring in just a few ancient woodland sites such as the New Forest and Sherwood (Fowler, 1888;

Allen, 1973; Alexander, 2003). However, increasingly frequent, casual observations since the mid-1980's suggest an expanding geographical range in Britain (Foster, 1987; Allen, 1988; Hackett, 1995). Recent records now reveal a distribution as far west as Wiltshire and Gloucestershire, (S. Denman unpublished) and as far northwest as Manchester (Keith Alexander, pers. comm.; and Figure 1). Since *A. biguttatus* is a thermophilic species (Brown *et al*., 2014) its distribution in the UK may be explained by altitudinal and longitudinal threshold isotherms. But, the cryptic larval stage of the life cycle and crown feeding habit of adults, do make sightings difficult and many records are probably based on the presence of the D-shaped exit holes of the adult beetle, left on the trunk of colonised trees. It is thus possible that absence in the westerly extents of the UK including Cornwall and Wales, and to the north in Yorkshire, Cumbria, Durham and Northumberland, may merely be explained by failure of detection, although, a more likely explanation is the controlling effect of temperature.

Of particular note is that the distribution of AOD in the UK covers a strikingly similar range to that of *A. biguttatus* (Compare Figure 1 with Figure 2). The majority of trees exhibiting symptoms of AOD in the UK have *A. biguttatus* galleries in the vascular tissue (>90% co-occurrence; Denman *et al*., 2014) and increasing reports suggest that *A. biguttatus* is well established and increasing in range and abundance (Figure 2).

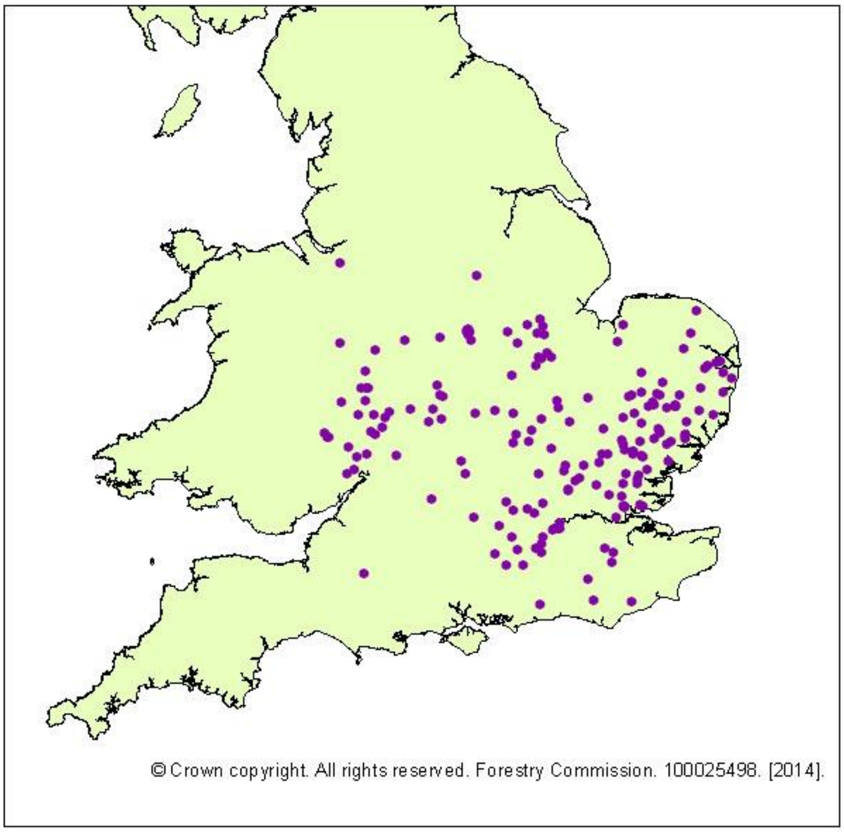
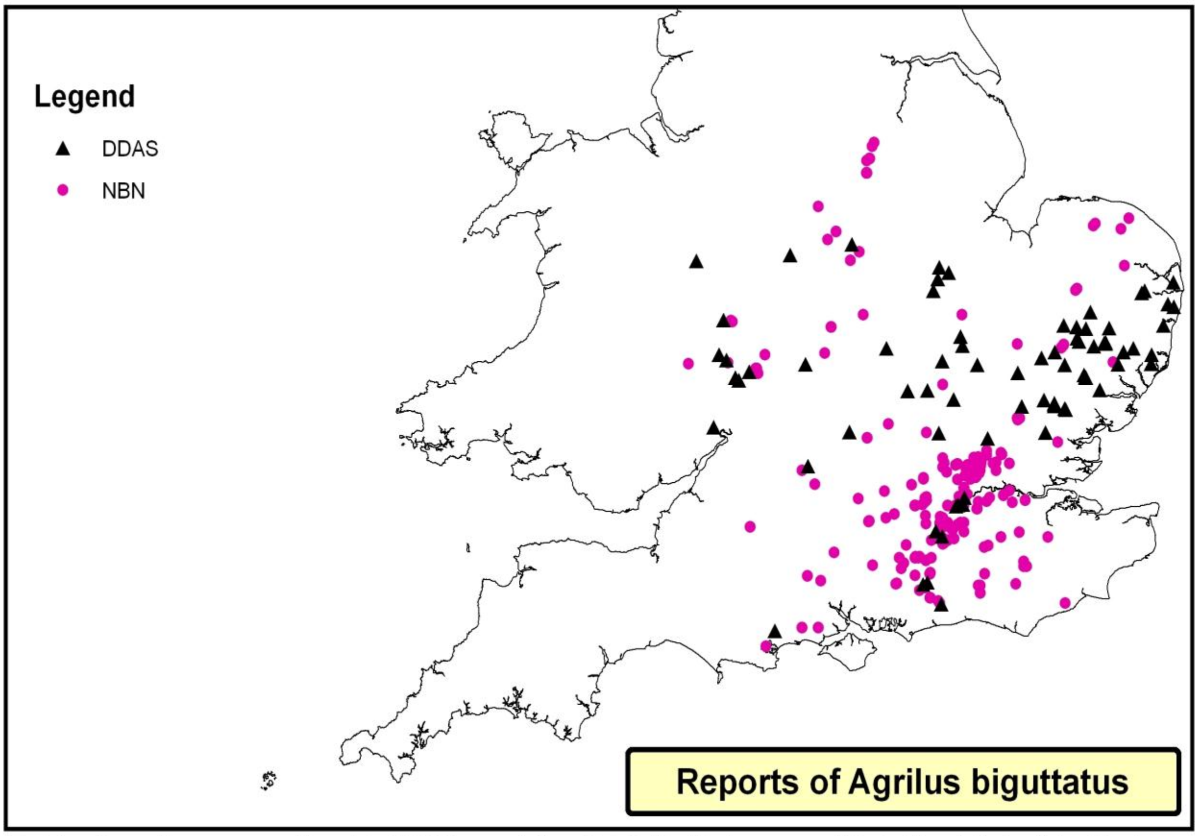


Figure 1: *Map showing distribution of Acute Oak Decline in the UK* (*31 March 2014*)



The information used here was sourced through the NBN Gateway website and included the following resources: Biological Records Centre, National Trust, Natural England, Countryside Council for Wales, Royal Horticultural Society, Leicestershire & Rutland Coleoptera, Suffolk Biological Records Centre, Kent & Medway Biological Records Centre, Norfolk Biodiversity Records Centre , Worcester Biological Records Centre, Herefordshire Biological Records Centre, Tullie House Museum (Accessed March 2011). The NBN and its data contributors bear no responsibility for the further analysis or interpretation of this material, data and/or information. Copyright © Crown Copyright. All rights reserved NERC 100017897 2004. Additional points are included from Forest Research Disease Diagnosis and Advisory Service (DDAS) . © Crown copyright. All rights reserved. Forestry Commission. 100025498. [2011].

Figure 2: *Map showing known distribution of Agrilus biguttatus in the UK*

(▲) Records from Forest Research (Advisory databases)
(●) National Biodiversity Network Gateway records

6. What are the natural and experimental host plants affected by Acute Oak Decline; and of these, which are of economic and / or environmental importance in the UK?

Known Host Species Range of AOD:

Known natural hosts of AOD in the UK and suspected host species in Europe recorded to date are in the genus *Quercus* and are listed in Table 2.

Table 2. Natural hosts associated with symptoms of Acute Oak Decline in Europe

Host		Family	Location	Reference
Scientific name	Common name			
Quercus robur	English oak	Fagaceae	Austria, Belgium, France, Germany, Poland, Netherlands, UK	Donaubauer, 1987; Cech and Tomiczek, 1988; Jacquiot, 1949; Jacquiot, 1950; Jacquiot, 1976; Van Steenkiste *et al*., 2004; Kowalski, 1996; Oosterbaan & Nabuurs, 1991, Denman and Webber, 2009; Denman *et al*., 2014
Q. petraea	Sessile oak	Fagaceae	Austria, Belgium, France, UK	Donaubauer, 1987; Cech and Tomiczek, 1988; Jacquiot, 1949; Jacquiot, 1950; Jacquiot, 1976, Denman and Webber, 2009; Denman *et al.*, 2014
Q. cerris	Turkey oak	Fagaceae	Italy, UK	Scortichini *et al*. 1993; Denman *et al*., 2014
Q. ilex	Holm oak	Fagaceae	Spain	Biosca *et al*., 2003; Soria *et al.*, 1997; Poza-Carrión *et al.*, 2008
Q. pyrenaica	Pyrenean oak	Fagaceae	Spain	Biosca *et al*., 2003; Soria *et al.*, 1997; Poza-Carrión *et al.*, 2008

Oak species known to be associated with AOD and present in the UK (host species) are, for the most part, common and widely distributed (see Figures 3-6).

Known Host Species Range of the Bacteria Associated with AOD

As the origins of *Gibbsiella quercinecans* and *Brenneria goodwinii* remain uncertain, the full range of natural host plants is also unknown. To date *G. quercinecans* is reported from the UK and Spain and *B. goodwinii* from the UK only. *Gibbsiella quercinecans* has been isolated from *Q. petraea*, *Q. robur*; *Q. cerris, Q. fabri*) in the UK and from *Q. pyrenaica* in Spain.

Known Host Species Range of the *A. biguttatus* Associated with AOD

Natural hosts of *A. biguttatus are Q. robur* and *Q. petraea* but occasional hosts include: *Q. pubescens, Q. ilex, Q. suber, Q. pyrenaica* and *Q. cerris* together with *Fagus sylvatica*, *Castanea sativa* and very rarely Q. *rubra* (Bily, 1982; Moraal and Hilszczanski, 2000; Davis *et al*., 2005). Additionally the newly-emerged adult beetles feed primarily upon oak foliage, but have also been recorded on sycamore and beech (Wachtendorf, 1955; Habermann and Preller, 2003).

Experimental Host Range of AOD

AOD is a decline-disease thus Koch's postulates are not the most appropriate test to apply, [consideration must be given to Leach's principles or similar (Leach, 1940)]. AOD has yet to be proven experimentally.

Bacteria associated with AOD

In vitro inoculation tests on *Q. robur* and *Q. petraea* have caused variable amounts of necrosis but overall analysis of results to date indicate significantly larger lesions formed in the inoculated material than in the wound controls (S. Denman unpublished).

The naturally susceptible economically and / or environmentally important hosts present in the UK are: *Quercus robur*, *Q, petraea*, *Q. ilex*, *Q. cerris.*

Distribution maps of the host and potential host species are shown (Figures 4-7)

Figure 3: *External and internal symptoms of AOD*

(a) Typical external stem symptoms of AOD showing bark crack between the bark plates and dark fluid seeping from these
(b) Necrotic inner bark (red arrow) and gallery (blue arrow) are typical internal symptoms and signs of AOD

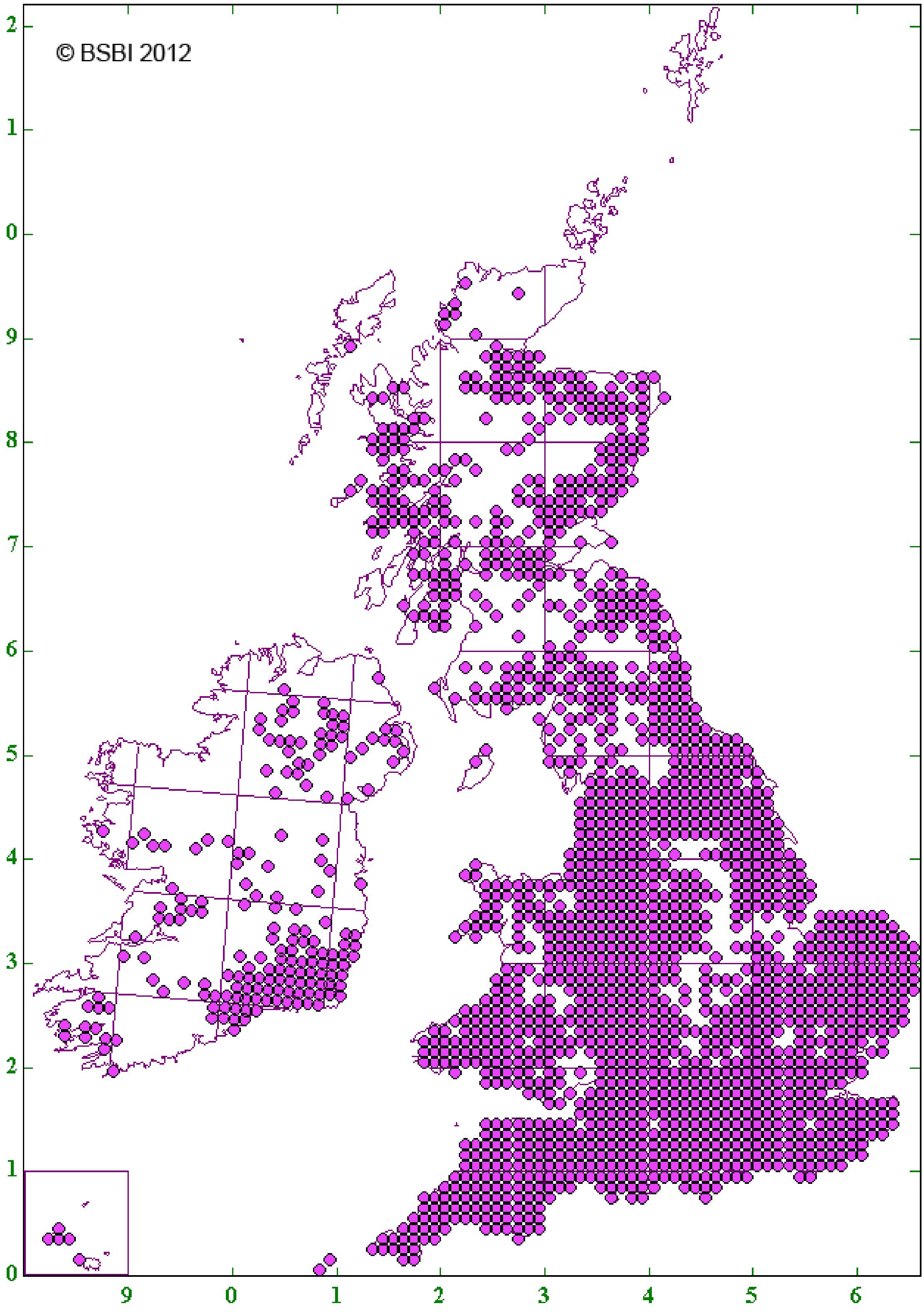


Figure 4. *Hectad map showing distribution of* **Quercus robur** *in GB and Ireland* (*Source – BSBImaps* http://www.bsbimaps.org.uk/atlas/map_page_dc4.php?spid=1640.0)

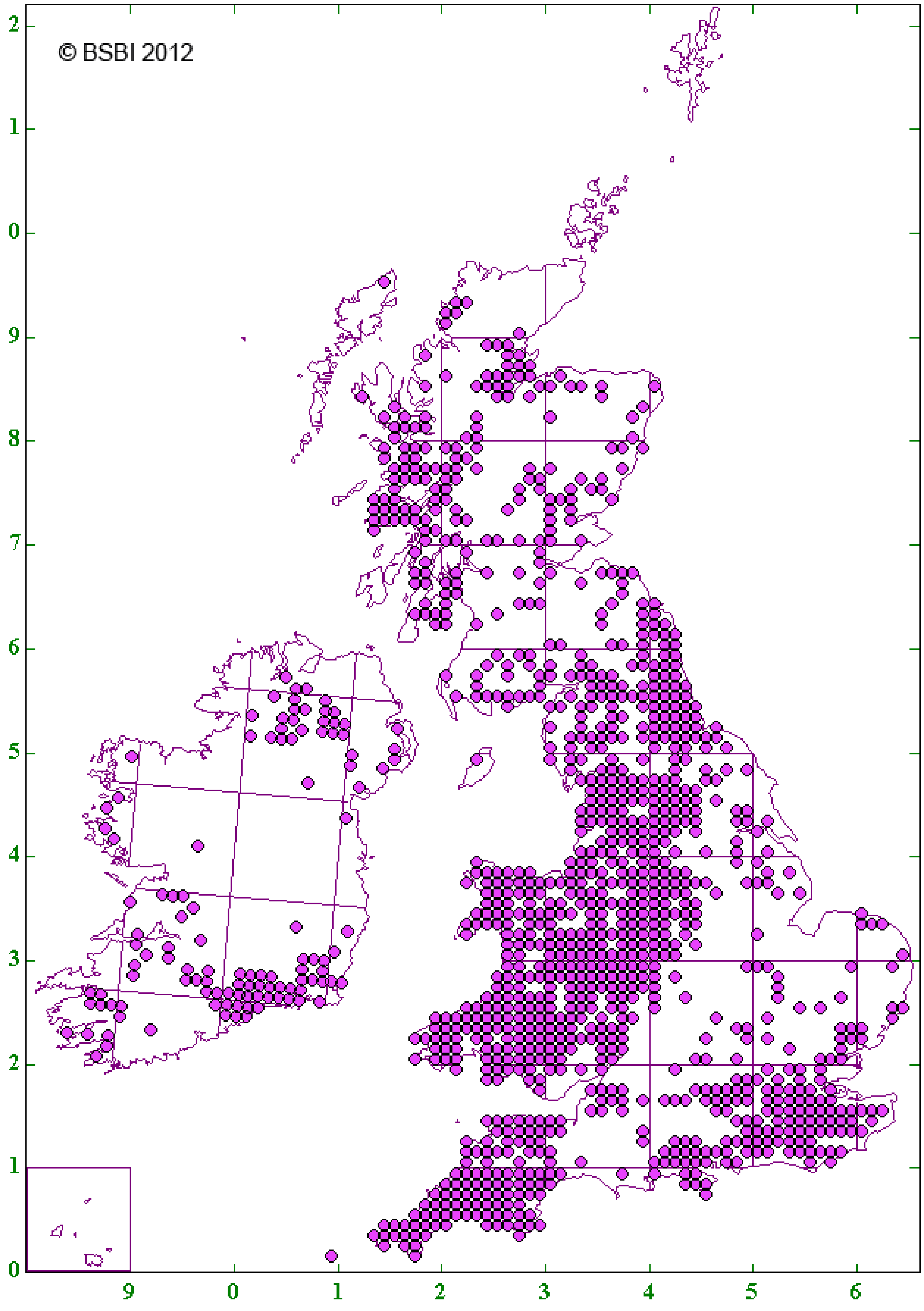


Figure 5: *Hectad map showing distribution of* **Quercus petraea** *in GB and Ireland* (*Source – BSBImaps* http://www.bsbimaps.org.uk/atlas/map_page_dc4.php?spid=1638.0)

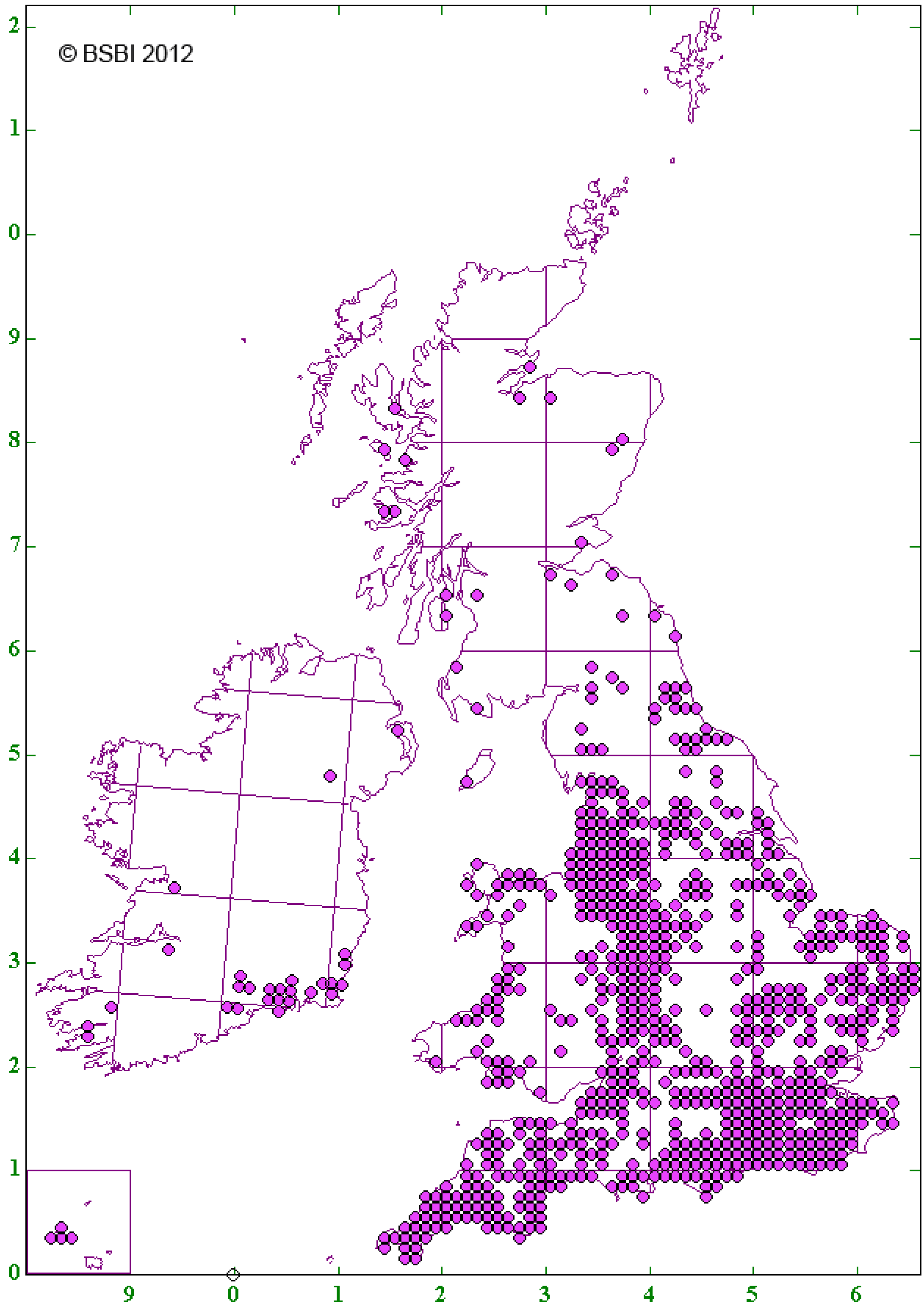


Figure 6: *Hectad map showing distribution of* **Quercus cerris** *in GB and Ireland* (*Source – BSBImaps* http://www.bsbimaps.org.uk/atlas/map_page_dc4.php?spid=1635.0)

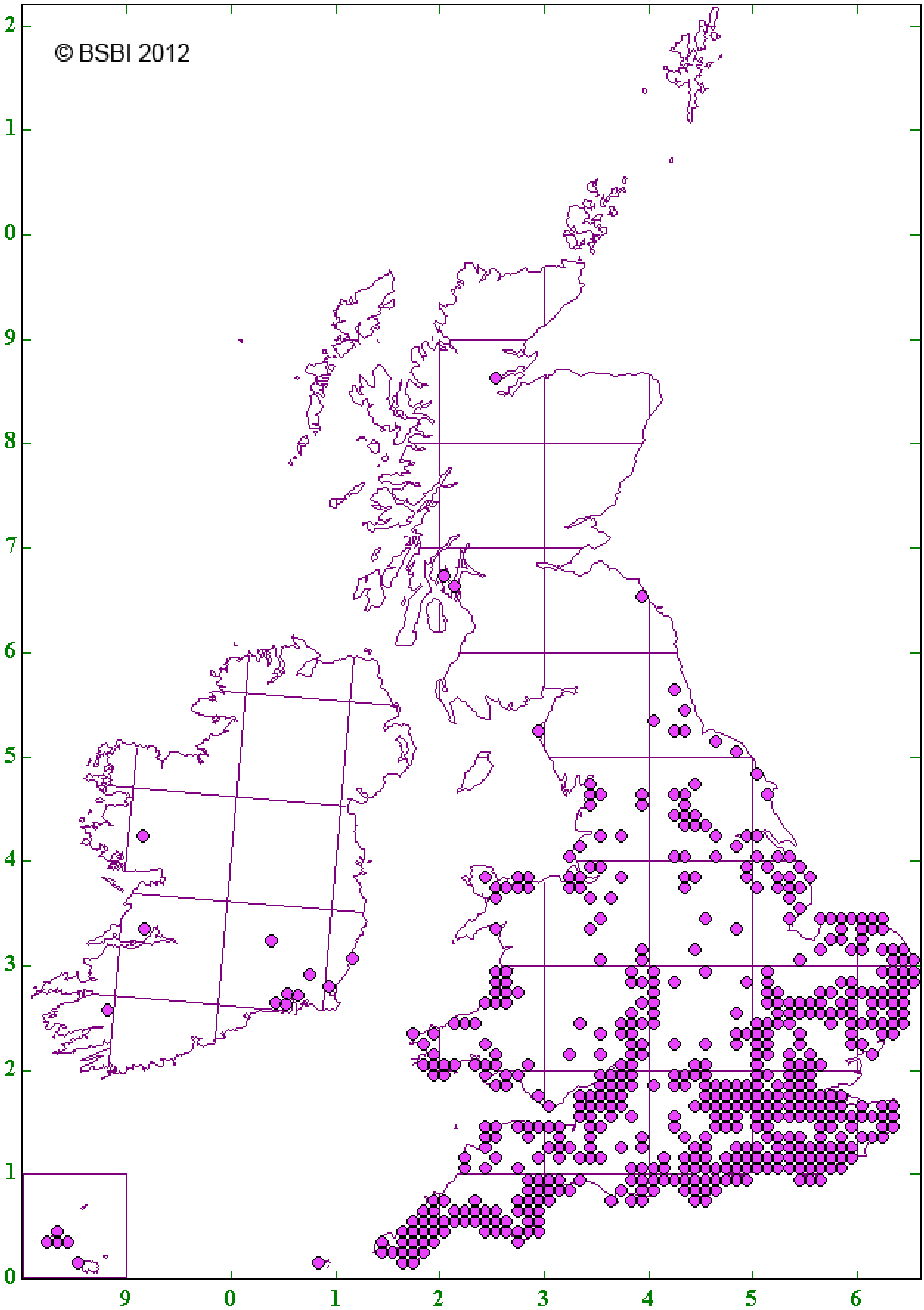


Figure 7*: Hectad map showing distribution of* **Quercus ilex** *in GB and Ireland* (*Source – BSBImaps* http://www.bsbimaps.org.uk/atlas/map_page_dc4.php?spid=1637.0)

7. If Acute Oak Decline needs a vector, is it present in the UK?

Certain elements or agents associated with AOD may be vectored, such as the bacteria associated with AOD. Because there is a significant co-occurrence (>90%) between *A. biguttatus* larval galleries and trees with symptoms of AOD (Denman *et al*., 2014), it seems reasonable to consider that *A. biguttatus* may vector the bacteria associated with AOD.

Vectoring bacteria associated with AOD: To date, twenty adult beetles of *A. biguttatus* have been dissected and analysed for the presence of AOD bacteria in the gut of the beetle. *Gibbsiella quercinecans* was isolated from a single adult beetle (Brown, 2014). There is insufficient data to conclude whether *A. biguttatus* plays a role in vectoring either/both species of bacteria in the disease epidemiology, but there is evidence that the beetle can carry the bacterium *G. quercinecans*. The incidence of beetles carrying bacteria still requires robust testing and evidence of transmission from the beetle to the tree must be shown before it can be concluded that the beetle is a vector. There is no convincing evidence in the literature of vectoring of bacteria or other pathogens by any *Agrilus* species.

8. What are the pathways on which Acute Oak Decline is likely to move and how likely is it to enter the UK?

Entry into the UK: Two of the key agents associated with AOD *viz*. species of bacteria and *A. biguttatus* are already present in the UK. However, further entry of the bacteria and *A. biguttatus* (as larvae) could occur on importation of roundwood (i.e. fully barked logs with no further treatment) or firewood. Volumes of oak firewood imported currently amount to 325 tonnes and the origin of this wood is from the EU (Forestry Commission UK Firewood Import Report 2014, unpublished). Currently there is no information available about the volumes of roundwood entering the UK more information about the country of origin and volume of material imported is required so that the risk can be assessed more accurately. The likelihood of the bacteria and *A. biguttatus* transferring to UK oak trees could be high dependent upon the proximity of the trees to the imported material but in the absence of more information, the risk is assessed as moderate.

Entry to the UK could also occur on plants for planting, especially trees imported for landscaping. Trees with a girth of 12 cm recently tested positive for AOD (S. Denman unpublished). There could be a significant risk as many thousands of bare-rooted or root-balled oak trees are imported from the EU annually (for example the number of oak plants notified to Fera through the notifications system on e-Domero from 17 Jan 2013 to 20 May 2014 was 658,983 E. Birchall, Personal communication) but in the absence of more information, the risk of carrying the bacteria as well as *Agrilus* is assessed as moderate.

✓***(put tick in box)***

Bacterial component of AOD

	Very unlikely	Unlikely	Moderately likely	Likely	Very likely
Host plants for planting:			✓		
Timber / wood			✓		
Soil			✓		
Ground water/river			✓		
Rain					✓
Wind			✓		
Vectors			✓		
Tools				✓	

***Agrilus* component of AOD**

	Very unlikely	Unlikely	Moderately likely	Likely	Very likely
Host plants for planting*:			✓		
Timber / wood			✓		

*Note: plants for planting refers to landscaping and includes trees of stem diameter > than 10 cm. However, when making these assessments there is a high level of uncertainty because there is such limited information about the organisms associated with AOD.

9. How likely is Acute Oak Decline to establish outdoors or under protection in the UK?
✓***(put tick in box)***

AOD is already established outdoors in parts of the UK, but establishment under protection is very unlikely because the plants are not grown under protection.

Persistence of the bacteria in AOD: Nothing is known about the persistence potential of the bacteria in natural media, but *G. quercinecans* was able to survive high temperatures (45°C) during *in vivo* growth studies, with 50°C being the lethal temperature. Both *G. quercinecans* and *B. goodwinii* are able to survive low temperatures since they are stored at -20°C under laboratory conditions (S. Denman unpublished data).

Persistence of *Agrilus* in AOD: *Agrilus* is a thermophilic species and its distribution is likely to be curtailed by low temperatures (Brown *et al*., 2014). It has been demonstrated that open oak stands i.e. with no understorey, are more vulnerable to attack (Starchenko, 1931; Habermann and Preller, 2003). Furthermore, *A. biguttatus* is a phototactic species and stems exposed to increased light and warmth attract ovipositing females and may facilitate faster development of larvae. This in turn limits larval exposure time to predators and parasitoids, and to host defence mechanisms. Attack by *A. biguttatus* is often seen on trees on recently opened ride edges (S. Denman, unpublished information) and these may be favoured spots. Lethal upper and lower temperatures for this beetle are not known.

	Very Unlikely		Unlikely		Moderately likely		Likely		Very likely	
Outdoors:	Very Unlikely		Unlikely		Moderately likely		Likely		Very likely	✓
Under protection:	Very Unlikely	✓	Unlikely		Moderately likely		Likely		Very likely	

10. How quickly could Acute Oak Decline spread in the UK?
✓***(put tick in box)***

AOD: Brown (2014) demonstrated that AOD spreads from tree to tree on affected sites. The rate of development of newly infected trees varied between sites, but the greatest increase was observed at open sites where up to 1.43 times as many trees were infected after 3-4 years of monitoring than at the outset. Between 1-3% of monitored trees died annually while on average 40% of symptomatic trees showed remission (Brown, 2014).

Bacterial component of AOD: No data are available on this aspect. However, the spread of the bacteria is likely to be accelerated once the cracks develop in the outer bark (a diagnostic symptom of AOD) and fluid seeps from the cracks since the bacteria have been shown to be present in this fluid (S. Denman unpublished information).

***Agrilus* component of AOD:** *Agrilus biguttatus* is widespread across central Europe, extending east to the Ukraine and south to North Africa (Bily, 1982); (Davis, *et al*. 2005). The British population is at the northerly limit of this range. Increasingly frequent observations since the mid-1980's suggest an expanding geographical range in Britain (Foster, 1987); (Allen, 1988); (Hackett, 1995). Recent records now reveal a distribution as far west as Wiltshire and Gloucestershire, and as far north as Manchester (K. Alexander pers. comm.). Despite the apparent expansion in range and abundance of *A. biguttatus* there is also the likelihood that under-recording of the buprestid may have been a factor in the past. An increased awareness of the beetle may account for some of the additional records over the last two decades.

In addition a warming climate may be the cause of the apparent increase in the British *A. biguttatus* population (Alexander, 2003; Broadmeadow and Ray, 2005); but this is difficult to assess given the current lack of knowledge of its thermal requirements and thermal tolerance range. The abundance of susceptible host material is also likely to play a key role in the abundance and distribution of the beetle (Hackett 1995). *A. biguttatus* is reported to require stressed host material for colonisation and is unable to attack healthy trees. An abundance of suitable host material created through the Great Storms of 1987 could account for some of the increase in abundance with stress very likely continuing as a result of the major droughts in 1990-92 and 1995-97, which were widespread and protracted (Marsh *et al*., 2007). Drought stress impairs the ability of oak trees to resist attacks from secondary organisms, including wood-boring buprestids (Jactel *et al*., 2012; Wargo, 1996). The generalised decline of oak is believed to have been intensified across Europe by drought, in combination with other stress factors such as severe defoliation by caterpillars (Thomas,

2008) and, together with temperature, these stress factors are likely to be important in affecting expansion of the range of *Agrilus*. The Forest Condition Survey also recorded a decline in the health of oak (measured on the basis of crown density) between 1987and 2004 (Hendry *et al*., 2004).

Establishment or Spread in the UK

Likely pathways for spread within the UK: The infection biology of AOD is not fully understood but it appears that the majority of infections are initiated on the stems of trees suggesting an aerial mode of dispersal. The bleeds on affected trees have been shown to contain both species of bacteria (Plummer and Denman, unpublished) which are also present in the necrotic tissue of AOD affected trees. On this basis potential pathways include:

1. Spread via pruning equipment (Goodwin, 2005). Although this is unproven it could be a possible pathway for spread.
2. Vectoring by *Agrilus* or other animal, bird or insect species (see for example Rizzi *et al.,* 2013).
3. If soil or water is contaminated with bleed fluid, there is potential for spread by people, animals or vehicles and also in waterways as well as wind or rain.
4. Infected planting stock (and associated planting medium), as well as bark and slab-wood from affected trees may also act as a pathway.

Pathways for the *Agrilus* component of AOD: Adult *Agrilus* beetles are able to fly but flight distances are unknown. Flight-mill experiments with a related beetle, the emerald ash borer (*Agrilus planipennis*), predicted that 20% of mated females could fly >10km over several days (Taylor *et al*., 2010). This was based on a laboratory experiment and may be different in the field, but it suggests that *Agrilus biguttatus* beetles could travel several km. Larval and pupal forms of the beetle can be moved in fully barked logs and firewood.

Based on observations the Natural Rate of Spread of AOD in the UK is assessed as:

AOD:	Very slowly		Slowly		Moderately	✓	Quickly		Very quickly	
Bacteria:	Very slowly		Slowly		Moderately	✓	Quickly		Very quickly	
Agrilus:	Very slowly		Slowly		Moderately	✓	Quickly		Very quickly	

11. What is the area endangered by Acute Oak Decline?

Much of the UK is at risk due to the distribution of the host species, although there are environmental factors that could limit the distribution of the *Agrilus* species and the two bacteria. Figures 1-4 illustrate the distribution of the known host species including host species affected by a similar condition in Italy and Spain. However, bearing in mind the associations of *A. biguttatus* and bacteria with AOD, and the thermal sensitivity of *A. biguttatus*, temperature requirements are likely to influence the limits to the distribution of *A. biguttatus* more than the bacterial component see Figure 8. The distribution of *A. biguttatus* is likely to be limited by temperature which will constrain the development of larval stages. These constraints may be due to latitude or altitude. In addition the distribution presented in figure, has a restriction focusing the predicted area in regions of low rain fall where hosts are likely to be more susceptible to beetle infestation.

Figure 5: CLIMEX prediction for the establishment of *A. biguttatus* in Great Britain using 5 km^2 climate data.
Darker shaded areas predict a greater chance of establishment (EI). Pink data points include *Agrilus* sightings.

European CLIMEX Model

Development of the CLIMEX model for *Agrilus biguttatus* used the Mediterranean template as a starting point, as the species is described as thermophilic and drought stress is thought to increase the availability of susceptible host trees. Due to the limited available information on developmental requirements for *A. biguttatus* the model was primarily built using the available distribution data. As *A. biguttatus* occupies a much wider range than that described by the template the first steps in building the model involved the removal of the hot-wet and cold stresses. Much of the documented range of the species has wet summers and the related species, the Emerald Ash Borer (*A. plannipennis*) has been recorded overwintering at temperatures far below zero (Croswaite *et al*., 2011; Vermunt *et al*., 2012). Following this, adjustments were made to the development temperatures. The threshold for heat accumulation and development has not been documented for any *Agrilus* species in laboratory conditions but estimates are available from studies of emergence and pupation of members of the *Agrilus* genus (not active feeding and development). They predicted a threshold between 8 and 10 °C air temperature for *Agrilus anxius* emergence from hosts and 17.8 °C when *Agrilus bilineatus* pupae were incubated in the laboratory (Akers and Nielsen, 1984; Haack *et al*., 1981). The lower estimate is likely to be a reasonable approximation as heat accumulation is likely to occur faster within the sheltered environment of the bark than in the open (Vermunt *et al.*, 2012). For the model the threshold was lowered to 13 degrees and day degrees adjusted to 550 in order to fit the northern boundary of the recorded distribution (in Norway and Sweden). The fit of the model in the Mediterranean was improved by adding heat stress at a rate of 0.01 above 29 °C. Finally, to adjust the model to favour areas with drought stressed hosts, moisture index maximum was reduced to 1.2

Climate data:
Global data: The 10 arc minute interpolated climate surface CliMond CM10_1975H_V1.1 (https://www.climond.org/) was used to develop the *A. biguttatus* model. It is a dataset of long-term monthly climate means (across 50 years and centred on 1975) for: precipitation; maximum temperature; minimum temperature; and relative humidity at both 9 am and 3 pm. CLIMEX uses these monthly means to calculate weekly values for use in its modelling.

Great Britain data: A grid at 5 km resolution was obtained from Richard Baker at FERA. This contained the same parameters for use in CLIMEX.

Map and data by courtesy of: 2011 Report for: Framework for the future deployment of modelling in support of Plant Health, sub-contract PH0441 WP11: Climex mapping of AOD and *Agrilus biguttatus* in the UK. Nathan Brown, Dominic Eyre, Richard Baker, Mike Jeger and Sandra Denman

12. What is the economic, environmental or social impact of Acute Oak Decline within its existing distribution? (Europe)
✓***(put tick in box)***

Owing to the uncertainty of whether the conditions described in Europe are AOD or not, the economic, environmental and social impacts are not quantified here.

13. What is the potential of Acute Oak Decline to cause economic, environmental or social impacts in the UK?
✓***(put tick in box)***

AOD: An important current impact of AOD is tree mortality, particularly of oak trees in their prime and veteran trees. Monitoring indicates that on average 1% of symptomatic trees on a site die annually (Brown, 2014). The knock on ecological effects as well as loss of potential income to high quality timber production, through early death is significant. About 40% of trees monitored showed some form of remission through the development of lignified callus-like tissue laid over the necrotic areas in tree trunks and over galleries (Denman *et al*., 2014). There will be an energy cost to the tree to do this which may weaken the tree making more vulnerable to attack from other organisms but it will also reduce overall health and vitality. It is unknown whether the lignified callus-like tissue has an effect on the quality or value of the timber. It is also unknown whether the trees that show this 'healing' go on to recover fully, become re-infected, or whether the tissue necrosis reactivates. Good silvicultural management and care for underlying tree health may be sufficient to reduce susceptibility induced by predisposing factors such as drought, root decay and defoliation, and prevent mortality that might be caused by additional stresses placed on the tree, giving AOD infected trees a chance to recover. Symptomatic trees have a changed metabolism (S. Denman and J. Draper unpublished information) and this is also likely to have an impact on the ecological status and function of the tree.

The significance of oak in the landscape in the UK, its value as a timber tree and the environmental and social values of oak mean that AOD is likely to have very high impacts in all these areas. With the occurrence of defoliating insects including the fairly recently introduced oak processionary moth (*Thaumetopoea processionae*) the cumulative effects of are likely to be very damaging to oak.

Bacterial component of AOD: The bacteria are only known from oak with symptoms of AOD. They have not been recorded from any other host or substrate. No other information about their presence as endophytes or saprophytes is available.

***Agrilus* component of AOD:** *Agrilus biguttatus* is a well-known native insect in Continental Europe and England in the UK. It colonises oak trees that are predisposed/susceptible to colonisation.

Until recently *A. biguttatus* was considered a vulnerable endemic species in the UK (Shirt 1987), developing on recently dead or dying hosts (Alexander 2003), but is now considered by some authors as a pest species opportunistically colonising weakened oak in the UK (Gibbs and Greig 1997). There are concerns that the population levels in the UK (and in some parts of Europe) have increased reaching damaging levels its ecological status requires revision (see Brown *et al*., 2014). *A. biguttatus* attacks compromised oak, and is considered as a key factor affecting tree mortality during periods of oak decline in Europe (Falck, 1918; Starchenko, 1931; Hartmann and Blank, 1992). Recent investigations show that >90% of trees (n>50) exhibiting symptoms of AOD in the UK, have *A. biguttatus* galleries in the vascular tissue (Denman *et al*., 2014) prompting the need to better understand the role of the beetle in the decline.

Economic:	Very small		Small		Medium		Large		Very large	✓
Environmental:	Very small		Small		Medium		Large		Very large	✓
Social:	Very small		Small		Medium		Large		Very large	✓

14. What is the potential of Acute Oak Decline as a vector of plant pathogens?

AOD as a vector of plant pathogens: Acute Oak Decline is a complex decline-disease. However, some plant pathogens may play a part in the decline-disease and influence its outcomes. For example, the exact cause of tree mortality is unknown but it is likely to be accelerated if the roots of trees are infected with pathogenic fungi such as certain *Armillaria* spp. (Denman *et al*., 2014).

Bacteria as a vector of plant pathogens: No information is available.

***Agrilus* as a vector of plant pathogens:** Only a single isolate of *Gibbsiella quercinecans* was isolated from one out of 15 adults of *A. biguttatus*, which does not prove that the buprestid is a vector but indicates that it can carry at least one of the two known bacterial species associated with AOD. More evidence is required to confirm whether the beetle is a vector or not.

STAGE 3: PEST RISK MANAGEMENT

15. What are the risk management options for the UK?

(Consider exclusion, eradication, containment, and non-statutory controls; under protection and/or outdoors).

Action for keeping the pest out of the UK
AOD is already present in the UK but appears to be limited to southern England, the Midlands and the Welsh borders. Thus the prevention of spread to unaffected areas needs to be considered. The same applies to the distribution of the bacteria and *Agrilus*. Although a comprehensive study on the distribution of the bacteria has not been carried out, in studies to date the bacteria are only associated with necrotic tissues in AOD symptomatic trees. Nothing is known about alternative hosts or substrates.

Denman *et al.* (2010) and Brown *et al*. (2014) list management options as follows:

(1) Management to prevent the establishment of AOD

- Good silvicultural management and care for underlying tree health may be sufficient to reduce susceptibility induced by predisposing factors such as drought, root decay and defoliation. Additionally, good silvicultural practice may prevent mortality that might be caused by additional stresses placed on the tree, giving AOD infected trees a chance to recover.
- Prompt removal and destruction of the bark of severely declined or recently dead trees should kill larvae or pupae residing in the tree and limit damage to the timber caused by secondary wood boring insects, including longhorn beetles (Cerambycidae) and oak pinhole borer (*Platypus cylindrus*).
- Exercise caution over moving firewood to locations where AOD is not present. Avoid moving firewood from symptomatic trees.
- Predation of *A. biguttatus* by woodpeckers also appears to be important in some areas of the UK (D. Inward, pers. obs), and maintaining environments attractive to woodpeckers may help to control populations of the buprestid in the UK. This is similar to the biotic causes of mortality in EAB where host tree defences were the most important factor causing insect mortality, followed by woodpecker activity (Duan *et al.*, 2010).
- Larvae of *A. biguttatus* are known to be parasitised by wasps including the ichneumonid *Deuteroxorides elevator* (Kenis and Hilszczanski, 2004) and the braconid *Spathius curvicaudis* (Moraal and van Achterberg, 2001). The latter is a native species that locates larvae within the bark before laying multiple eggs on or close to it (Shaw, 1988). With a multivoltine life cycle, the wasp has the potential to respond rapidly to an increasing prey population, yet its importance in this role has yet to be evaluated. The related species *Spathius agrili* has been shown to have significant impacts on *A. planipennis* populations in China, where the wasp and buprestid are native. Parasitism rates of up to 90% have been demonstrated in some ash tree stands (Yang *et al.*, 2010), and the wasp is currently being investigated as a potential biocontrol agent in the USA (Gould *et al.*, 2011).
- Specific management should focus on trees that exhibit a sudden and rapid decline, including significant foliage and twig loss, and signs of *Agrilus* presence (exit holes and galleries beneath the bark). Removal of heavily colonised trees, preferably during planned selective thinning or wider forest sanitation, may reduce population growth of *Agrilus*. Where felling occurs, caution is urged to avoid the creation of open and sunny woodland where sun-warmed stems offer attractive new oviposition sites to female beetles. This can be countered by underplanting with shade-bearing woody species (Wachtendorf, 1955) or mixed species edge planting, especially along the southern side of woodland. Removal of colonised trees should be completed prior to the spring emergence of new adults, and the bark may be removed from stems and destroyed to prevent later emergence of beetles that have completed larval

development. Movement of wood, particularly as firewood, has been identified as an important pathway in the dispersal of many xylophagous insects (Haack *et al.*, 2010). The destination of any infested material should be considered due to the unknown effect of moving this beetle beyond its currently restricted distribution, but also to minimise the risk of spread of the bacterial AOD components. Smaller branch material is not utilised by *A. biguttatus* and can remain *in situ*, and trees standing dead for more than a year will be unlikely to yield any further individuals.

- Direct chemical control of the beetle would have a wide reaching impact on the wider insect fauna and is likely to be difficult due to its cryptic life cycle, spent primarily beneath the bark. Pyrethroid insecticides, applied externally to the stem, have been used experimentally with some effect (Habermann & Preller, 2003). Application of the insecticide prior to adult emergence gave good control of beetles in their pupal chambers within the outer bark, but did not penetrate to affect the feeding larvae in the phloem or sapwood. Systemic insecticides have been successfully trialled in North American ash trees against EAB via soil drenches, trunk injections and spraying of the lower stem. If the tree had not declined too far, control was often effective using these treatments, although success on larger trees was more inconsistent (Herms *et al.*, 2009). Drawbacks include the need for regular repeat applications, and the associated expense, although this might be justified for important amenity trees. However, systemic insecticides used on a keystone species such as oak would cause the mortality of many other non-target invertebrates. In the EU several neonicotinoid pesticides are currently subject to a two-year ban owing to their negative effects on non-target insect species such as bees.
- Informing the public, research, survey and monitoring including risk predictive modelling are the best methods of prevention with legislative support if necessary. Keeping and updating a national database on incidence and occurrence; spread; remission and recovery over a decade would enable evidence based management to be developed and applied. Keeping the public informed and aware but also following up and verifying reports is key.

(2) Management of AOD where the decline-disease is established

- Since AOD is not a quarantine disease in the UK there are no statutory requirements regarding disease management. Management decisions should therefore be guided by prevention of spread and protection of areas not yet affected. Once a better understanding of the significance of *Agrilus* in AOD is obtained, specific evidence based management research can be put in place. Current recommendations are based on the precautionary approach as set out by Denman *et al*. (2010). As *Agrilus* and bacteria appear to be the two key factors in AOD, managing destruction of the bark layers which these agents occupy may be the most important aspect to reducing spread (Denman *et al*., 2014; Brown *et al*., 2014). Removing and burning these layers within a very short time after felling should reduce the risk of spread, and thorough sanitation of footwear and felling equipment is a further precautionary measure. Preventative management would involve alleviation of stress factors upon the tree, but at present there is a lack of understanding of abiotic factors and their effects on AOD in Britain.
- On sites where only a few trees are affected by AOD, eradication can be considered. Recommendations would include felling of symptomatic trees, with immediate burning of the bark and sapwood on site, together with sanitation of felling equipment and footwear. The remaining stumps of symptomatic trees could be buried or burnt *in situ*. Monitoring would be necessary to detect newly developing infections.

16. Summary and conclusion of rapid assessment.
(Highlight key uncertainties and topics that will require particular emphasis in a detailed PRA) General / overall summary and conclusion and then specific text on each part of assessment...

This rapid assessment shows:

Risk for entry is: Unknown for AOD and associated bacteria beyond the UK. With a growing trend to import planting material, particularly large trees for landscape purposes, and roundwood acquired from continental Europe, there is a possibility that bacteria could enter the UK on planting material if the bacterial component was in the latent stage, as well as *Agrilus biguttatus* because the cryptic nature of the life cycle of the beetle is in the bark and inner tissues. Recent evidence in the UK (S. Denman unpublished) has shown *Agrilus biguttatus* galleries in trees with a dbh of 12 cm demonstrating that the beetle can colonise young trees. Hilszczanski and Sierpinski (2006) also mention colonisation of younger trees, in this case, 30 year-old trees in Poland were colonised by *A. biguttatus*. Thus there is a risk of importing both bacteria and *Agrilus* on trees used for landscaping purposes. Although *A. biguttatus* is considered native to the UK different genotypes and/or populations of the beetle as larvae and pupating larvae could re-enter the UK via imported trees.

Risk of establishment is: High

Economic impact is expected to be: Very large over the medium term especially in conjunction with effects of other pests and diseases on oak

Endangered area: Most of the UK – except Scotland at present, but in a changing and warming climate, this country could also be placed at risk.

Risk management:
Practices are suggested to manage the risk (see 15) but most require evaluation to measure their effectiveness.

(for PH Risk Management Work stream to decide) ✓ *(put tick in box)*

17. Is there a need for a more detailed PRA?

Yes ☐ No ☑

Further epidemiological evidence is required before a more detailed PRA could be undertaken.

If yes, select the PRA area (UK or EU) and the PRA scheme (UK or EPPO) to be used.

PRA area: UK or EU? UK PRA scheme: UK or EPPO? UK

18. Given the information assembled within the timescale required, is statutory action considered appropriate/justified?

As the pest is currently established in the UK statutory action is not considered justified.

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