Mini Risk Assessment
Metallic Beetle: *Agrilus biguttatus* Fabricius
[Coleoptera: Buprestidae]

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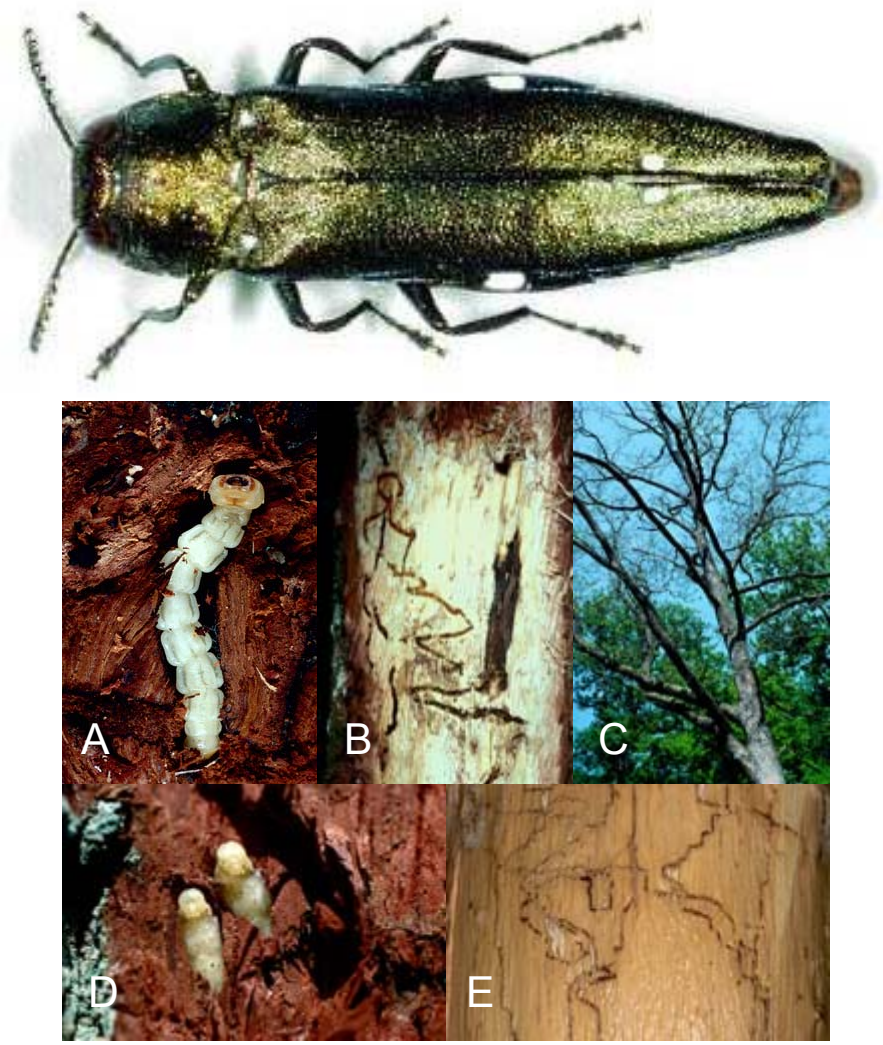

Figure 1. *Agrilus biguttatus*: Adult beetle (top; typical length is 8-13 mm; 5/16-1/2 in.); (A) larva tunneling in *Quercus robur*; (B) cambium necrosis with characteristic "zig-zag" gallery pattern; (C) tree death resulting from *A. biguttatus* infestation; (D) pupae visible in bark; and (E) "stair" gallery pattern. Images are not to scale. [Top photo by Gyorgy Csoka, Hungary Forest Research Institute; photos A-E by Louis-Michel Nageleisen, Département de la Santé des Forêts - France. Images courtesy of invasive.org (2005)].

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Introduction

Agrilus biguttatus is a significant pest of oak forests in eastern and western Europe, Russian Asia, northern Africa, and the Middle East (Jacquiot 1976, Gutowski and Lugowoj 2000, Moraal and Hilszczanski 2000a, b, Vansteenkiste et al. 2004). This insect is commonly known as the oak splendor beetle or two-spotted wood borer and belongs to a family of insects (Buprestidae) that are commonly called flatheaded wood borers as larvae and metallic or jewel beetles as adults. Concerns surrounding *A. biguttatus* are heightened by the recent invasion of a closely related species, emerald ash borer (*Agrilus planipennis*), that has killed thousands of ash trees in Michigan (Haack et al. 2002).

Agrilus biguttatus is not known to occur in the United States but poses substantial risk to natural and urban environments if it were to be introduced. In the Exotic Forest Pest Information System (EXFOR), Ciesla (2003) considers the overall risk posed by the insect to be very high, but this assessment was highly uncertain. The purpose of this "mini-" pest risk assessment is to further evaluate several factors that contribute to risks posed by *A. biguttatus* and apply this information to the refinement of sampling and detection programs.

1. **Ecological Suitability. Rating: High.** *Agrilus biguttatus* is present in much of eastern and western Europe, Russian Asia, northern Africa, and the Middle East. Appendix A provides a detailed list of countries reporting this buprestid. In general, *A. biguttatus* occurs in climates ranging from warm and dry to more temperate with adequate rainfall to support forest trees. The currently reported distribution of *A. biguttatus* suggests that the pest may be most closely associated with biomes characterized as: desert and xeric shrublands; Mediterranean scrub; temperate broadleaf and mixed forests; and temperate coniferous forests.

Consequently, we estimate that approximately 68% of the continental US would have a climate suitable for establishment of *A. biguttatus* (Fig. 2). See Appendix A for a more complete description of this analysis.

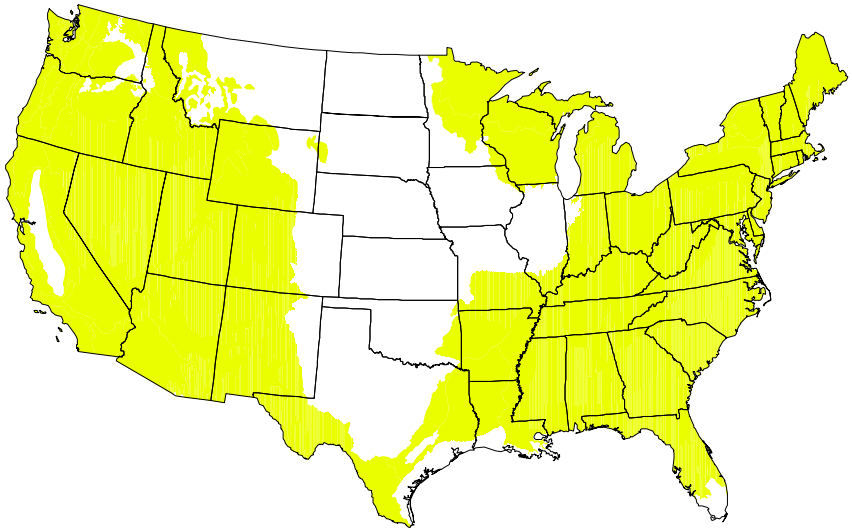

Figure 2. Predicted distribution (green) of *Agrilus biguttatus* in the contiguous US.

Figure 2 illustrates where *A. biguttatus* is most likely to encounter a suitable climate for establishment within the continental US. This prediction is based only on the known geographic distribution of the species. Because this forecast is based on coarse information, areas that are not highlighted on the map may have some chance of supporting populations of this exotic species. However, establishment in these areas is less likely than in those areas that are highlighted. Initial surveys should be concentrated in the higher risk areas and gradually expanded as needed.

2. **Host Specificity/Availability. Rating: Medium/High.** *Agrilus biguttatus* feeds primarily on oak but reportedly has over a dozen host plants within the plant family Fagaceae (Table 1). Reports of *A. biguttatus* feeding on poplar are probably based on misidentifications of *A. ater*. Oaks and other suitable hosts are common and often dense.

Table 1. Host plants of *Agrilus biguttatus*.

Host(s)	**Reference(s)**
beech (*Fagus* sp.)	(Key 1991)
beech, European (*Fagus sylvatica*)	(Hellrigl 1978, Moraal and Hilszczanski 2000a, b, Ciesla 2003)
chestnut, European or sweet (*Castanea sativa*)	(Hellrigl 1978, Key 1991, Moraal and Hilszczanski 2000a, b, Ciesla 2003)

Host(s)	Reference(s)
oak (*Quercus* sp.)	(Jacquiot 1976, Foster 1987, Key 1991, Hackett 1995a, b, Moraal and Hilszczanski 2000b, Hilszczanski and Kolk 2001, Ciesla 2003, Denton 2004, Vansteenkiste et al. 2004)
oak, cork (*Quercus suber*)	(Hellrigl 1978, Moraal and Hilszczanski 2000a, Ciesla 2003)
oak, downy (*Quercus pubescens*)	(Hellrigl 1978, Moraal and Hilszczanski 2000a, Ciesla 2003)
oak, durmast (*Quercus petraea*)	(Hellrigl 1978, Hartmann and Blank 1992, Blank 1997, Gutowski and Lugowoj 2000, Moraal and Hilszczanski 2000a, Ciesla 2003, Vansteenkiste et al. 2004)
oak, English (*Quercus robur*)	(Hellrigl 1978, Hartmann and Blank 1992, Blank 1997, Gutowski and Lugowoj 2000, Moraal and Hilszczanski 2000a, Ciesla 2003, Vansteenkiste et al. 2004)
oak, European	(Vansteenkiste et al. 2004)
oak, European turkey (*Quercus cerris*)	(Hellrigl 1978, Moraal and Hilszczanski 2000a, Ciesla 2003)
oak, holly (*Quercus ilex*)	(Hellrigl 1978, Moraal and Hilszczanski 2000a, Ciesla 2003)
oak, northern red (*Quercus rubra*)	(Moraal and Hilszczanski 2000a, b, Ciesla 2003)
oak, Pyrenean (*Quercus pyrenaica*)	(Echevarria Mayo and Echevarria Leon 1998)
poplar[1] (*Populus* sp.)	(Hellrigl 1978, Moraal and Hilszczanski 2000a, Ciesla 2003)

1. Dubious host record, possibly a misidentification (*A. biguttatus* may have been confused with *Agrilus ater*) (Hellrigl 1978).

See Appendix B for maps showing where various hosts occur in the continental US.

3. **Survey Methodology. Rating: Low.** Sampling for *A. biguttatus* will be exceptionally difficult because there are no known baits or traps for this insect. Neither beat- nor sweep-sampling is effective to collect adults (Foster 1987, Allen 1988)**.** In Europe, surveys have relied heavily on visual inspection of known hosts, primarily oaks, for D-shaped exit holes (Foster 1987, Hackett 1995a, b, Jones 1996, Denton 2004). These characteristic holes are created as adults emerge from trees.

   For visual surveys, the number of trees that must be examined to detect *A biguttatus* depends on the frequency of infested trees in a stand and the desired confidence of detecting the beetle when it is present. Assuming that (i) visual surveys are accurate enough to locate the beetles on a tree when the tree is inspected, (ii) a stand has a large number (e.g., >1000) of potential host trees, and (iii) potential host trees are selected at random for inspection, binomial statistics can be used to determine the number of trees that must be examined to achieve a desired probability of finding at least one infested tree when the beetle is present. Figure 3 illustrates how the number of required samples changes as the proportion of trees with *A. biguttatus* and/or the desired probability of detecting at least one

infested tree changes. In general, more samples are required as the desired probability of detection increases and as the proportion of plants with insects decreases (i.e., the insects become rarer in the environment).

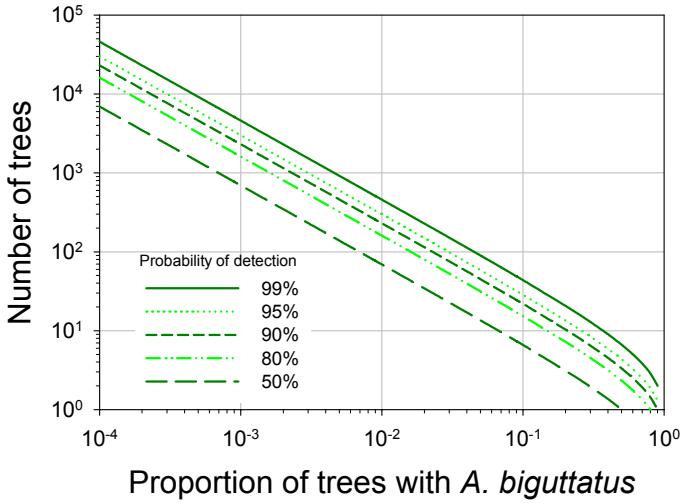

Figure 3. Required number of trees to be inspected to detect *A. biguttatus* in relation to the proportion of trees that are infested and the desired probability of detecting this insect. This figure assumes random sampling from a large environment.

Adults have been collected in a haphazard approach, typically with the intent of confirming the presence of the species not quantifying its abundance. Single adults have been painstakingly stalked though the woods (Allen 1988). Anecdotal evidence suggests beetles are most active when in sunlight (Godfrey 1987, Allen 1988, Smith 1994).

Significant research is needed to identify possible attractants for *A. biguttatus*. Limited evidence suggests *A. biguttatus* might be attracted to stressed trees (Moraal and Hilszczanski 2000a, Vansteenkiste et al. 2004). If additional research confirms this observation, a trap-tree method might be developed similar to the approach used for monitoring *A. planipennis*, the Emerald ash borer (USDA 2005b). For *A. planipennis*, girdling is used to stress a tree (i.e., the trap tree). Tanglefoot is spread above girdle to trap incoming adults. At the end of the season, trees are felled and bark is stripped to examine for the presence of developing larvae.

4. **Taxonomic Recognition. Rating: Medium.** This pest closely resembles indigenous buprestid species (Ciesla 2003) and could also be confused with other exotic *Agrilus* spp in the US: *A. planipennis*, *A. cuprescens* (=*aurichalceus*), *A. cyanescens*, *A. derasofasciatus*, *A. hyperici*, *A. pilosovittatus*, and *A. sinuatus* (Haack et al. 2002). An observer who is unfamiliar with these species might get them confused. A dubious host record in the literature reflects the potential difficulty with identification. According to Hellrigl (1978) *A. ater* may have been

misidentified and mistaken for *A. bigutattus* on *Populus* sp. (see 'Host Specificity'). *Agrilus biguttatus* has not been reported on *Populus* elsewhere. Conspicuous life stages (pupa and adult) may be positively identified by close examination of morphological characters by a taxonomist.

For a detailed description of the morphology and taxonomy of *A. biguttatus*, see Appendix C.

5. **Entry Potential. Rating: Low.** No interceptions of *Agrilus biguttatus* have been reported by USDA APHIS in the Port Interception Network-309 database (USDA 2005a). "*Agrilus* sp." have been intercepted at least 22 times between 1985 and 2004 (incomplete records complicate the accuracy of this count). Annually, only about 1.2 (±0.3 standard error of the mean) interceptions have been reported nationally (USDA 2005a). The majority of interceptions have been associated with dunnage (68%), crating (13%), grape leaves (*Vitis* sp) (5%), or unspecified cargo (5%). These materials were typically found in general cargo (60%), ship holds (13%), baggage (13%), or miscellaneous (7%). The majority of interceptions were reported from San Francisco, CA (17%), Alabaster, AL (12%), Houston, TX (12%), Erlanger, KY (12%), Long Beach, CA, and Chicago, IL (8%). These ports are the first points of entry for infested material coming into the US and do not necessarily represent the final destination of infested material. Movement of potentially infested material is more fully characterized in the next section.

   Some interceptions of *Agrilus* spp. might have been identified simply as "Buprestidae; species of." Between 1985 and 2004, unspecified Buprestidae have been intercepted on average at 4.21 (±0.88) times per year (USDA 2005a). Again, incomplete records complicate the accuracy of this count. Like *Agrilus* sp, the majority of these interceptions were associated with wooden crating, dunnage, or pallets (66%). The remainders were loosely associated with plants or plant products. Similar to *Agrilus* sp, most interceptions were reported from California (28%), Texas (24%), Florida (15%), and Georgia (6%). Interception records for specimens identified to family level must be analyzed with caution. It is probable that most of these interception were not *Agrilus biguttatus*. Nevertheless, even if they were, the apparent rate of entry would still be low compared with other insect pests.

   Previous interception records of the pest may not accurately characterize the frequency at which this pest actually arrives in the US. Because *A. biguttatus* is a wood borer, larvae may be difficult to detect during routine quarantine inspections at ports of entry. Adults may be more easily detected on the surface of logs or wood products. Further, evidence suggests that interceptions records are occasionally incomplete for some forest pests. Thus, a high degree of uncertainty is associated with the low rating.

6. **Destination of Infested Material. Rating: Medium-High.** When an actionable pest is intercepted, officers ask for the intended final destination of the conveyance. Materials infested with "*Agrilus* sp." were destined for 11 states (USDA 2005a). The most commonly reported destinations were California (25%), Alabama (21%), Texas (13%), Illinois (8%), and Tennessee (8%). We note that portions of each of these states have climates and hosts that would be suitable for establishment by *Agrilus biguttatus*, although suitable climate in Illinois appears to be limited to the southern tip of the state. Materials infested with "Buprestidae; species of" were destined for 17 states (including Hawaii). California (28%), Texas (24%), Florida (15%), Georgia (6%), Arizona (4%) and Illinois (4%) were the most commonly reported intended destinations (USDA 2005a).

7. **Potential Economic Impact. Rating: High.** *Agrilus biguttatus* is an important pest of oak in much of Europe, particularly in Belgium, Germany, Hungary and Poland (Moraal and Hilszczanski 2000a, b, Hilszczanski and Kolk 2001, Vansteenkiste et al. 2004). Significant tree mortality and oak decline have been reported in these regions. Over 20,000 ha (nearly 50,000 acres) of oak mortality has been attributed to this insect in the Voronej region of Russia. Considerable damage also occurred in several regions of France between 1945-1949 following notably hot and dry summers (Jacquiot 1976). Moraal and Hilszczanski (2000a, 2000b) documented the emergence of hundreds of adults from a single oak trunk, with each specimen leaving a D-shaped exit hole ranging in size from 2-4mm. A heavy infestation has been described as, "38 exit holes per $0.5m^2$ of bark" (Moraal and Hilszczanski 2000a). In addition, zig-zag pattern galleries over 150 cm long have been reported.

   The potential economic impact of *A. biguttatus* in the US is difficult to measure because this species typically occurs in mixed populations with other pests of oak within its native range. The severity of damage varies depending on host availability, stand composition, and forest health, among other factors (Ciesla 2003, Vansteenkiste et al. 2004). Establishment and spread by this insect could jeopardize valuable oak forests, domestic and foreign forest product industries, and the nursery trade. Significant economic losses may result from infestation of live tree hosts, or feeding damage may impact quality of timber, pulp and other forest products (Ciesla 2003). Phloem feeding by this destructive wood borer can kill a tree or predispose it to further attack by other secondary pests (Hartmann and Blank 1992, Blank 1997, Moraal and Hilszczanski 2000a, b, Ciesla 2003, Vansteenkiste et al. 2004).

   Control measures could be costly and ineffective given the elusive nature of *A. biguttatus*. Feeding larvae are generally well protected while tunneling inside the host. A thorough understanding of the biology of *A. biguttatus* as well as conditions that favor attack by this pest, will be essential for successful detection and control efforts (Ciesla 2003, Vansteenkiste et al. 2004).

8. **Potential Environmental Impact. Rating: High.** In general, newly established species may adversely affect the environment by reducing biodiversity, altering forest composition, disrupting ecosystem function, jeopardizing endangered or threatened plants, degrading critical habitat, or stimulating use of chemical or biological controls. *Agrilus biguttatus* is likely to affect the environment in many of these ways.

   In Europe, *A. biguttatus* is an environmental concern (Key 1991). In England, the insect will attack ancient oaks that are dominant features of landscapes. Loss of broad-leaved forest stemming from "coniferisation" or clear cutting infested trees is feared. Dead trees are an integral part of an ecosystem, and removal of dead or dying trees to manage *A. biguttatus* would alter the function of the system (Key 1991). Use of insecticides (particularly in urban areas) and biological controls would likely be pursued, just as they were for *A. planipennis* (Haack et al. 2002).

   Agrilus biguttatus has a moderate host range, feeding on phloem of deciduous forest tree hosts including oak, beech and chestnut [see 'Host Specificity']. Appendix D summarizes federally listed threatened or endangered plant species (USDA NRCS 2004) found within plant genera known to be hosts (or potential hosts) for *A. biguttatus*. Plants listed in Appendix D might be suitable hosts for *A. biguttatus*, and thus, could be adversely affected by this insect.

9. **Establishment Potential. Rating: High.** Our initial predictions suggest that nearly 70% of the US has a climate that could support populations of *A. biguttatus* (Fig. 2). Known Fagaceous host plants are common in these area that are climatically suitable for establishment. Thus, upon arrival into the United States, the chances for establishment are relatively high if the insect is introduced. Available pest interception records suggest that the arrival rate of this insect is low, but interception records may not reflect the true frequency with which this insect might arrive.

   See Appendix E for a brief description of the biology of *A. biguttatus*.

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Appendix A. Geographic distribution and comparison of climate zones. To determine the potential distribution of a quarantine pest in the US, we first collected information about the worldwide geographic distribution of the species (Table A1). Using a geographic information system (e.g., ArcView 3.2), we then identified which biomes (i.e., habitat types), as defined by the World Wildlife Fund (Olson et al. 2001), occurred within each country or municipality reported. An Excel spreadsheet summarizing the occurrence of biomes in each nation or municipality was prepared. The list was sorted based on the total number of biomes that occurred in each country/municipality. The list was then analyzed to determine the minimum number of biomes that could account for the reported worldwide distribution of the species. Countries/municipalities with only one biome were first selected. We then examined each country/municipality with multiple biomes to determine if at least one of its biomes had been selected. If not, an additional biome was selected that occurred in the greatest number of countries or municipalities that had not yet been accounted for. In the event of a tie, the biome that was reported more frequently from the entire species' distribution was selected. The process of selecting additional biomes continued until at least one biome was selected for each country. Finally, the set of selected biomes was compared to those that occur in the US.

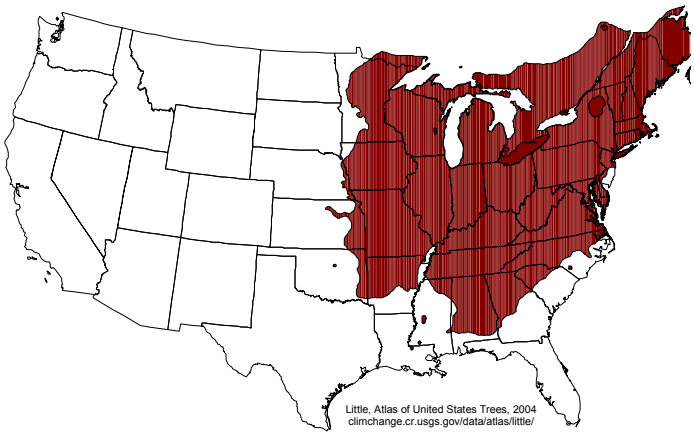
Table A1. Reported geographic distribution of *Agrilus biguttatus*.

Locations	**Reference(s)**
Algeria	(G. Curletti, personal communication)
Asia Minor (Turkey)	(Hellrigl 1978)
Azerbaijan	(Moraal and Hilszczanski 2000a, Ciesla 2003)
Belarus	(Moraal and Hilszczanski 2000a, b, Ciesla 2003)
Belgium (Buggenhout Forest, Soignes Forest, lowland region near Flanders)	(Vansteenkiste et al. 2004)
Czech Republic	(Moraal and Hilszczanski 2000a, Ciesla 2003)
England	(Moraal and Hilszczanski 2000b, Ciesla 2003)
England (Berkshire)	(Key 1991, Smith 1994)
England (Berkshire-Kilmester Farm)	(Alexander and Foster 1999)
England (Berkshire-Maidenhead)	(Verdcourt 1992)
England (Bushy Park)	(Hackett 1995a)
England (Epping Forest)	(Hackett 1995a, b)
England (Gloucestershire-Toddington Manor)	(Denton 2004)
England (Hampshire-Pamber Forest)	(Else 1994)
England (Hampshire-south)	(Key 1991)
England (Hampstead Heath)	(Foster 1987, Allen 1988, Verdcourt 1992, Smith 1994, Hackett 1995b)
England (Hampstead Heath-Ken Wood and North Wood)	(Hackett 1995a)
England (Hampstead)	(Godfrey 1987)
England (Hertfordshire)	(Key 1991)
England (Hertfordshire-Bishop's Wood)	(Smith 1994, Hackett 1995a)
England (Kent-Darenth Wood)	(Hackett 1995a)

Locations	Reference(s)
England (Leicestershire)	(Key 1991)
England (London)	(Moraal and Hilszczanski 2000a)
England (London-Arnos Park and Broomfield Park)	(Hackett 1995b)
England (London-north)	(Smith 1994, Hackett 1995a, Jones 1996)
England (London-SE)	(Jones 1996)
England (Middlesex)	(Key 1991)
England (North Hampshire)	(Key 1991)
England (Nottinghamshire)	(Key 1991)
England (Oxleas Wood)	(Hackett 1995b)
England (Queen's Wood in Haringey)	(Hackett 1995a)
England (Richmond)	(Hackett 1995b)
England (Rutland)	(Key 1991)
England (southern)	(Hackett 1995a, Moraal and Hilszczanski 2000a)
England (Surrey)	(Key 1991)
England (Surrey-Ashstead Common)	(Allen 1988, Morris 1991, Verdcourt 1992, Hackett 1995a)
England (Surrey-Bookham Commons)	(Hackett 1995a)
England (Surrey-Mitcham Common)	(Morris 1991, Verdcourt 1992)
England (Surrey-Richmond Park)	(Allen 1988, Morris 1991, Verdcourt 1992, Hackett 1995a)
England (Surrey-Thursley Common)	(Else 1994)
England (West Kent)	(Key 1991)
England (West Sussex)	(Key 1991)
England (West Sussex-Broad Halfpenny)	(Else 1994)
England (West Sussex-Kingspark Wood)	(Allen 1988, Else 1994)
England (West Sussex-Plaistow)	(Verdcourt 1992)
England (Windsor Great Park)	(Allen 1987, Verdcourt 1992)
England (Windsor)	(Allen 1988, Hackett 1995a)
England (Windsor-Windsor Forest)	(Godfrey 1987)
Europe (except Denmark and Finland)	(Moraal and Hilszczanski 2000b)
Europe (except Finland)	(Hellrigl 1978, Moraal and Hilszczanski 2000a)
France	(Moraal and Hilszczanski 2000b, Ciesla 2003)
France (northern Alsace)	(Moraal and Hilszczanski 2000a)
France (Vosges, Loire Valley, region of Paris, Normandy)	(Jacquiot 1976)
Germany	(Moraal and Hilszczanski 2000b, Ciesla 2003)
Germany (Baden-Wurttemberg, Rheinland-Pfalz)	(Moraal and Hilszczanski 2000a)
Germany (northern)	(Hartmann and Blank 1992, Moraal and Hilszczanski 2000a)
Germany (Schleswig-Holstein)	(Anon. 2005)
Hungary	(Moraal and Hilszczanski 2000a, b, Ciesla 2003)

Locations	Reference(s)
Middle East	(Moraal and Hilszczanski 2000a, b)
Morocco (Tangiers, Akfadou Forest, Bab-bou-Idir in the middle Atlas Mts.)	(Curletti 2005)
Netherlands	(Moraal and Hilszczanski 2000a, b, Ciesla 2003, Moraal 2003)
Northern Africa	(Moraal and Hilszczanski 2000a, b)
Northern Africa (presumably Algeria, Morocco, and Tunisia)	(G. Curletti, personal communication, Ciesla 2003)
Northwest Africa	(Hellrigl 1978)
Persia (Iran)	(Hellrigl 1978)
Poland	(Moraal and Hilszczanski 2000a, Ciesla 2003)
Poland (widespread except mountains regions, Niepolomice Forest District near Krakow; Lower Silesia; two Forest Districts in the Odra river Valley)	(Moraal and Hilszczanski 2000a, b)
Poland (Bialowieza Primeval Forest)	(Gutowski and Lugowoj 2000)
Poland (Regional Forest Directories of Wroclaw, Radom, Poznan, and Zielona Gora)	(Hilszczanski and Kolk 2001)
Russia	(Moraal and Hilszczanski 2000a, b, Ciesla 2003)
Russia (Caususes)	(Hellrigl 1978)
Russia (near east)	(Ciesla 2003)
Russia (region of Voronej)	(Jacquiot 1976)
Russia (Siberia)	(Moraal and Hilszczanski 2000a, b, Ciesla 2003)
Spain (Madrid)	(Echevarria Mayo and Echevarria Leon 1998)
Ukraine	(Moraal and Hilszczanski 2000a, b, Ciesla 2003)

Appendix B. Host distribution (partial) for *Agrilus biguttatus* in the continental US.



Map 1.Northern red oak (*Quercus rubra*)

Appendix C. Taxonomy and morphology of *Agrilus biguttatus*

Agrilus [=*Buprestis*] biguttatus was originally described by Fabricius in 1777. A revised morphological description was published by Staig (1940).

Synonyms

Buprestis biguttatus (=*biguttata*), Fabricius, 1777
Agrilus pannonicus Piller & Mitterpacher, 1783
Agrilus subfasciatus Ménétriés, 1832
Agrilus morosus Gory & Laporte, 1837

A complete list of proposed or unavailable synonyms appearing in literature is also documented by Jendek (2002) and Silfverberg (1977).

Diagnostic features

For complete accuracy, the following description is quoted from Staig (1940).

Female.

"Form narrow and elongate, subparallel between the head and the narrowed apical third of the elytra, rounded in outline at the sides of the prothorax and somewhat sinuate along the sides of the elytra, which ark a little constricted about the middle, gently rounded out behind the middle and from there straightly convergent towards the regularly rounded (arcuate) apices which are slightly expanded, entire, and finely serrulate with a short gap near the outcurved ends of the sutural margins. Markedly flattened above and convex beneath.

The front of the head flattened and with a central depression. The prothorax not quite as broad as the elytra, cylindrical, transverse, and obliquely carinate on the sides, the sinuous carinae (side rims of pronotum) extending from the posterior angles obliquely downwards to the deflected sharp anterior angles. The pronotum slightly convex across the front, centre and base, and furrowed between these parts; almost straight in front and the base bisinuate. The scutellum with a ridge across the base. The elytra long and narrow, at the base slightly broader than the thorax, and the sides sharply convergent from the middle to the apices; flattened over the disc, convex along the sides, and with two incurved basal hollows between the prominent long shoulders and the flattened scutellar area ; the elytral surface more shagreened than rugulose in appearance, and with two small white-haired spots adsutural and towards the apex. Abdomen with six white-haired spots ventrally. Coloration bright metallic bronze green with localised suffusion of violet. The under-surface finely and more or less closely punctate with considerable confluence of the punctures on the thoracic parts.

The short **head** is brilliant bronze green and rugulosepunctate. Upon the vertex there is an impressed median longitudinal line which is continuous on the perpendicular front; it intersects the median longitudinal sulcus of the frons and becomes obsolete where the sulcus forms a broad frontal depression or fovea. A straight line between the uppermost parts of the antennal sockets marks off the frons from the narrow clypeus which is a narrow subquadrate area between the antennal sockets and which is widely emarginate before the small lobate labrum. The prominent oval eyes are vertically placed and wide apart; their finely faceted corneal surfaces are dull green with darker patches

and some small golden spots. The short antennae are metallic dark bronze green and are serrate, except the first three segments and the last or eleventh which are club-shaped; the first or basal segment is the largest, the second and third are about equal in size. The antennae are inserted in large pyriform excavations between the clypeus and the lower portions of the eyes, the sockets being directed, obliquely towards the lower ends of the eyes, where the narrow part of the pear-shaped socket is open at the narrow gena.

The **prothorax** is cylindrical and transverse and its sides are strongly carinate; the sinuate carinae are directed obliquely downwards and forwards from the posterior angles of the pronotum to the front margin where it meets the proepisternal borders, and there join the margin to form the deflected sharp anterior angles, behind the eyes, at a short distance from their lower ends. The **pronotum** is transverse, its breadth (2 ¼ mm.) is greater than its length, which measures 1 ½ mm.; it is broadest across the middle and the base is slightly narrower than the front. The front of the pronotum is almost straight, very slightly arcuate between the eyes; the base is bisinuate, the middle or scutellar part of the base is broad and straight and the two sinuations or bays are wide but not deep, widely angular; the posterior angles are sharp and obtuse angles. The sides of the pronotum (viewed from above) are rounded and have arcuate narrow rims (the lateral carinae); as the carinae are obliquely placed, the sides are considerably deflected in front and the sharp anterior angles are low down at the gena and at a short distance from the lower ends of the eyes. The disc of the pronotum is not entirely raised, it is a little convex at the front and across the centre and also around the basal sinuations or bays; between these convex parts the disc is furrowed (sulcate), and the sides of the disc are somewhat hollowed about the middle. The pronotum is finely marginate all round, the front portion of the margin being brilliant and most apparent. The surface of the pronotum is transversely and sinuously rugulose, and on the wrinkles there are minute round punctules at intervals apart; there are also some larger punctures in front and within the posterior angles. The general appearance of the surface is that of a shagreened sculpture with slightly rugulose effect. The coloration of the pronotum is metallic bronze green suffused with violet.

The sides or **pleura** (proepisterna and proepimera) are broadly angular, markedly convex beneath and involving the front portion of the lateral carinae, and a little hollowed about the middle; and the dark bronze green surface is closely puncturate and finely rugulose, the punctures bearing very short and fine whitish hairs. The colour and sculpture of the short and narrow mesepisterna and mesepimera and of the narrow and oblong metepisterna (somewhat vertically placed) appears to be the same as that of the propleura.

The **prosternum**, dark bronze green, is roughly triangular; its base is emarginate and sinuous and is marked off from the middle portion, by a deep transverse furrow, as a distinct gular part. The base and the middle portion of the prosternum are moderately convex; and the prosternal process, which is lobe-shaped and flattened, reaches the metasternum, the blunt tip of the process being lodged in the emarginate front part of the metasternum. The prosternal surface is irregularly and closely punctate, and many of the punctures are confluent. The lateral parts of the mesosternum are not clearly visible. The metasternum is dark bronze green and irregularly punctate, with very short and fine whitish hairs; but most of the punctures are confluent in broken lines. The surface is convex, except over the ante-coxal area, where it is flattened and depressed. A deeply

impressed median longitudinal line extends from the deep angular notch on the base towards the front, becoming obsolete near the frontal emargination. This line is crossed near the middle by a transverse line which bends abruptly at each side and extends obliquely to the edge of the base, thus reaching the anterior borders of the hind coxae and marking off very clearly the ante-coxal pieces. Where the two lines cross, the metasternum is distinctly hollowed.

The **scutellum** is bright metallic bronze green tinged with violet; it is large and triangular, but the sides are rounded at the base and are deeply incurved towards the apex and upon the large transverse base there is a strong median transverse ridge or carina. In front of the qidge the surface is strigose, behind the ridge it is asperate.

The **elytra** are bright metallic bronze green with violet along the narrowly deflected sides and upon the apices. Between the middle and the apices, and close together at the sutural margins, there are two small and irregular white spots, these being slight depressions with overlying silvery white recumbent hairs of considerable length. The length of the elytra (8 ½ mm.) is more than three times the breadth (2 ½ mm. across the shoulders), which is slightly greater than that of the pronotum across the middle. The elytral base is rather thickly marginate and that of each elytron is sinuous, widely rounded off against the scutellum and having about the middle a wide arcuate projection which is received in the corresponding bay of the pronotal base. The sides, subparallel from the base to the apical third, are sinuate, rounded out behind the shoulder angles, gradually but slightly constricted behind the shoulders to about the middle, gently rounded out behind the middle and from there straightly convergent towards the regularly rounded (arcuate) apices, which are distinctly expanded and entire and finely serrulate with a short gap near the outcurved apical ends of the sutural margins. The sides are also finely marginate with minute denticulation as far as the apical third; there the margin becomes obsolete and is replaced by the denticulation, which is continuous and strongest around the serrulate tips. The suture is finely marginate from the middle of the apices to a point within a short distance from the scutellum, where it becomes obsolete or is hidden from view. The shoulder angles are rounded, the shoulders are prominent and long; and on each elytron, behind the sinuous base and between the shoulders and the flattened scutellar area, there is an incurved hollow (basal fovea). The elytral surface is flattened above, a little hollowed along each side of the suture from the middle towards the apex where the sutural margins are raised, and it is narrowly convex along the sides with marked epipleural deflexion of the shoulder region. The surface is punctate and more shagreened than rugulose in appearance.

The short **legs** are uniformly dark metallic bronze green, brighter on the tibiae, and the leg surface is finely punctulate with very short and fine whitish hairs.

The front and middle coxae are globular and about equal in size; the hind coxae are transverse and a little concave, the inner portions are considerably expanded, the posterior margins are widely arcuate, and the sculpture of the surface is similar to that of the metasternum.

The femora are fairly stout; the front and middle tibiae are curved, and the hind tibiae are almost straight. The first segment of the five-segmented hind tarsi is as long as the second, third and fourth taken together. The tarsal segments have small membranous ventral pulvilli; the claws are cleft and their inner portions are shorter, directed inwards and contiguous.

The **abdomen** is uniformly dark metallic bronze green with a strong suffusion of violet. The proximal sternum (first and second sterna conjoined) is very long, very nearly half the length of the abdomen. The connate first and second abdominal segments have been so completely fused that only a short and rather faint transverse indentation on each side indicates the posterior border of the first sternum. The third sternum is longer than the fourth, which is the shortest, the fifth is one and a half times the length of the third, it is arcuate and its rounded margin is narrowly and evenly bordered by an impressed line. The surface of the abdominal sterna is finely and not closely punctulate , except about the tip of the fifth sternum where larger punctures occur close together. There are six white spots (slight depressions of the surface covered with moderately long overlying silvery-white hairs) on the third, fourth and fifth sterna, one pair on each
and antero-lateral in position."

Length 10 ½ mm.; breadth (across the shoulders of the elytra) 2 ½ mm" (Staig 1940)

Male

"... [Its] length is 11 ½ mm. The anterior tibiae have a small sharp hook at the distal end on the inner side. The suffusion of violet on the elytra is more extensive than in the female metatype" (Staig 1940).

Appendix D. Threatened or endangered plants potentially affected by *Agrilus biguttatus*.

Agrilus biguttatus has the potential to adversely affect threatened and endangered plant species. However, because *A. biguttatus* is not known to be established in the US and threatened and endangered plant species do not occur outside the US, it is not possible to confirm the host status of these rare plants from the scientific literature. From available host records, *A. biguttatus* is known to feed primarily on species within the family Fagaceae. From these host records, we infer that threatened or endangered plant species which are closely related to known host plants might also be suitable hosts (Table D1). For our purposes closely related plant species belong to the same genus.

Table D1: Threatened and endangered plants in the conterminous U.S. that are potential hosts for *Agrilus biguttatus*.

Reported Hosts	Threatened and/or Endangered Plant		Protected Status[1]	
	Scientific Name	Common Name	Federal	State
Fagus sylvatica	none	beech		
Castanea sativa	*C. dentata*	American chestnut		KY (E) MI (E)
	C. pumilla	chinkapin		KY (T) MI (E)
Populus sp.[2]	*P. balsamifera*	balsam poplar		IL (E) OH (E) PA (E)
	P.heterophylla	swamp cottonwood		CT (E) MI (E) NY (T)
Quercus spp., *Q. cerris*, *Q. ilex*, *Q. petraea*, *Q. pubescens*, *Q. pyrenaica*, *Q. robur*, *Q. rubra*, *Q. suber*	*Q. acerifolia*	mapleleaf oak		AR (T)
	Q. bicolor	swamp white oak		ME (T)
	Q. coccinea	scarlet oak		ME (E)
	Q. falcata	southern red oak		OH (T) PA (E)
	Q. hinckleyi	Hinckley oak	T	TX (T)
	Q. ilicifolia	bear oak		VT (E)
	Q. imbricaria	shingle oak		NJ (E)

Table D1: Threatened and endangered plants in the conterminous U.S. that are potential hosts for *Agrilus biguttatus*.

Reported Hosts	Threatened and/or Endangered Plant		Protected Status[1]	
	Scientific Name	Common Name	Federal	State
	Q. lyrata	overcup oak		NJ (E)
	Q. macrocarpa	bur oak		CT (E)
	Q. muehlenbergii	chinkapin oak		IN (E)
	Q. nigra	water oak		NJ (E)
	Q. oglethorpensis	Oglethorpe oak		GA (T)
	Q. phellos	willow oak		IL (T) NY (E) PA (E)
	Q. prinus	chestnut oak		IL (T) ME (T)
	Q. shumardii	Shumard's oak		MD (T) PA (E)
	Q. sinuata var. *sinuata*	bastard oak		AR (T)
	Q. texana	Texas red oak		IL (E)

Source of threatened and endangered species: National Plants Database (USDA NRCS 2004)

1. E= Endangered; T=Threatened

2. Dubious host record, possibly a misidentification (*A. biguttatus* may have been confused with *Agrilus ater*) (Hellrigl 1978).

Appendix E. Biology of *Agrilus biguttatus*

Population phenology

A. biguttatus has 1 to 2 generations annually. Complete development typically occurs over a two-year period (Ciesla 2003, Vansteenkiste et al. 2004). The duration of development and the degree of survivorship during development may vary depending on several factors including host tree suitability and condition (wood moisture content; stressed or dying but not dead), warm temperatures, and sun exposure, particularly during spring and fall (Vansteenkiste et al. 2004). Successful colonization of a tree host may also depend on larval population density because numerous borers can work together to overcome tree defenses such as callus production (Vansteenkiste et al. 2004). *A. biguttatus* preferentially oviposits in fresh, moist wood with plenty of sun exposure, particularly within the thinning crown of a declining host. Older, larger diameter trees ranging from 30-40 cm (dbh) are also preferred. (Hackett 1995a, Moraal and Hilszczanski 2000a, Vansteenkiste et al. 2004).

Stage specific biology

Adult

Adults emerge from D-shaped holes (2.5-4 x 2-3 mm) between May and August. Peak emergence occurs in June and July. Adult flight occurs between May and July. Shortly after emergence adults feed on foliage in the tree crown. Females lay clusters of 5 or 6 eggs in bark crevasses from May to early August. (Key 1991, Hackett 1995a, Moraal and Hilszczanski 2000a, Vansteenkiste et al. 2004).

Egg

In the field, eggs typically hatch in 1-2 weeks (Vansteenkiste et al. 2004).

Larva

There are 5 larval instars. Upon hatch, larvae begin to bore longitudinally through the bark, then proceed toward the inner bark, cambial layer, and the outer sapwood, making a zig-zag patterned gallery. Once a tree is colonized, larvae form a network of galleries ranging from 0.5-5mm wide and 1.5 m long. Feeding occurs in the cambial layer of trees or in the stems of small woody plants (Ciesla 2003, Vansteenkiste et al. 2004). Larvae overwinter inside the bark for 1-2 winters, followed by pupation (Vansteenkiste et al. 2004). Mean length is 10 mm for first year larvae and 10 mm for 1 ½year-old larvae.

Pupa

Pupation occurs in the spring (April-May) of the second or third year in individual cells in the outer bark. Pupae develop in chambers 10.4-14.4 mm long and 3.0-4.5 mm wide. (Hackett 1995a, Moraal and Hilszczanski 2000a). Adults newly eclosed from pupae will remain in the bark for two weeks before emerging.