MINNESOTA PEST RISK ASSESSMENT
Emerald Ash Borer, *Agrilus planipennis* (Fairmaire)
[Coleoptera: Buprestidae]
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I. Introduction

A. General

Agrilus is a large genus within a family of flat-headed, metallic colored woodborers, often called jewel beetles (CAB 2004). *Agrilus planipennis,* the emerald ash borer (Fig.1), is a significant new threat to all North American *Fraxinus* spp (Liu et al. 2003). It is native to Asia and known to occur in China, Korea, Japan, Mongolia, the Russian Far East and Taiwan (Haack et al. 2002). In some parts of the world, *A. planipennis* is also called the ash buprestid (Yu 1992). This pest can attack and kill healthy ash trees (McCullough and Roberts 2002) which are valued for ornamental purposes, as a timber resource, and as food sources for wildlife (Wei et al. 2004). This pest-initiated risk assessment evaluates the potential for establishment by *A. planipennis* in Minnesota. In this assessment we found *A. planipennis* is highly likely to establish in the state and damage ash trees. *A. planipennis* was probably introduced to North America in wood packaging material brought into Michigan in the late 1990's (McCullough and Roberts 2002).

Figure 1. Adult, larvae and pupae *A. planipennis* Deborah Miller
The Nature Conservancy

B. Risk Assessment Use

This risk assessment will be used by the Minnesota Department of Agriculture (MDA) to identify and prioritize the risk of bringing *A. planipennis* into Minnesota. In addition, identifying areas of the state considered high-risk for establishment by *A. planipennis* will provide accurate information for surveys and monitoring by field staff. The MDA has primary responsibility for excluding, eradicating and managing exotic or invasive plant pest species that threaten Minnesota's environment or agriculture (Minnesota Statutes 18G, 2003).

C. Previous Risk Assessments

A pest risk assessment completed for Canada in 2002 concluded that *A. planipennis* is a significant threat to all 16 species of ash found throughout North America (Dobesberger 2002).

The likelihood of introduction to Canada was rated high because larvae are very hardy and can survive northern temperatures. Establishment potential rated high because of Canada's suitable climate. The pest is already established in Ontario. The potential economic impact also rated high because the insect can cause severe damage and mortality to nursery stock, pole wood, and to various age classes of hardwoods in urban settings and natural forests. Dispersal potential rated high because of the insect's high fecundity, adaptable life cycle and cold hardiness and because adults may disperse through corridors of contiguous host material in urban and natural environments. To contain this pest a well planned and executed management program along with a harmonized quarantine program will be required (Dobesberger 2002).

A similar risk assessment concluded that *A. planipennis* posed a very high risk for all of North America (Ciesla 2003). Establishment potential, economic impact potential and environmental impact potential were all rated very high with a very high degree of confidence.

The European and Mediterranean Plant Protection Organization (EPPO) also consider *A. planipennis* an A2 quarantine pest, a pest that has a limited distribution among EPPO member countries and should be regulated to contain its movement (CAB 2004; EPPO 2006). It is likely that *A. planipennis* would survive and have economic impact in many parts of Europe and the Mediterranean, though the impact of the insect on European species of ash is uncertain (EPPO 2006). Control, including containment and suppression, would be very difficult to achieve.

II. SUMMARY OF FINDINGS

Element	**Rating (Score)**
Consequences of Invasion	
1. Potential geographic distribution	High (3)
a. Host range	High[a]
b. Climate suitability	High[a]
2. Dispersal potential	High (3)
3. Potential abundance	Low (1)
4. Economic impact	High (3)
5. Environmental impact	High (3)
6. Health impact	Negligible (0)
7. Social and political impact	Low (1)
8. Management	Low[b]
Sub-score	63
Likelihood of Invasion	
1. Pest history	High (108)
2. Quantity of commodity imported	Medium (2)
3. Estimated pest density per unit imported	Low (1)
4. Likelihood of surviving post harvest treatment	High (3)
5. Likelihood of surviving shipment	High (3)
6. Likelihood of moving to a suitable climate	High (3)
7. Likelihood of finding a host	High (3)
8. Potential for eradication	Low
Sub-score	270

Overall Risk Score	**170.10**

a, contributes to the assessment of potential geographic distribution
b, not included in the calculation of overall, unmitigated risk.

III. SUMMARY OF RISK ASSESSMENT METHODS

This document presents guidelines for conducting a pest-based, qualitative pest risk assessment. Risk is defined as the joint likelihood of the pest becoming established in the state and the severity of consequences after pest establishment. In a qualitative assessment, risk is estimated through a standard set of risk elements, factors that contribute to establishment success or impact potential. The criteria are based on 2000 USDA standards (USDA 2000) and a model for regional assessment of pest risk (Venette and Davis 2006).. Each risk element is given a high, medium, or low rating based on available information in previous pest risk assessments, peer reviewed journal articles, internet websites, electronic databases, and United States Geographical Survey (USGS) and World Wildlife Fund maps.

A numerical risk score was calculated by converting the rating of each element to a score (negligible=0; low=1; medium=2; high=3). Overall risk is the product of the consequences and likelihood of invasion. Unmitigated consequences of introduction follow the formula C=GxDxAx(Ec+En+H+S), where *C* is the total consequences; *G*, potential geographic distribution; *D*, dispersal potential; *A*, potential abundance; *Ec*, economic impact; *En*, environmental impact; *H*, health impacts to humans and vertebrates; *S*, social and political impacts. This regional assessment includes a rating of management potential, an indication of the availability and effectiveness of control options for the pest, but this rating is not included in the evaluation of consequences. The unmitigated probability of invading, *I*, is I = PH+(QxPxSpxSsxMxF), where *PH* is the pest history of the organism; *Q*, quantity of host material imported annually; *P*, estimated density of pest per unit imported; *Sp*, likelihood of surviving post harvest treatment; *Ss*, likelihood of surviving shipment; *M*, the likelihood of being moved to a suitable habitat; and *F*, the likelihood of finding a host. Pest history is nearly as important as the existence of known pathways because new, unforeseen pathways for the introduction of a pest may arise in the future. As a result, ratings for pest history are converted to scores using a slightly different system (negligible=0; low = 12; medium=36; high=108). The assessment also includes a rating of the potential for eradication, but this rating does not factor into the calculation of the likelihood of invasion. The overall risk score is (*C*x*I*)/100.

IV. PEST RISK POTENTIAL

A. Consequences of Introduction

1. Potential Geographic Distribution: High
Agrilus planipennis is likely to find suitable host plants and a suitable climate in more than 40% of Minnesota. The following two subsections describe the potential host range and climatic suitability within the state.

a. Host Range Rating: High
In China, *A. planipennis* occurs mainly in *Fraxinus chinensis* and *F. rhynchophylla* forests (Yu 1992). Other reported hosts in Asia include *F. mandshurica* var. *japonica, Ulmus davidiana* var. *japonica, Juglans mandshurica* var. *sieboldiana* and *Pterocarya rhoifolia* (Haack et al. 2002). *Agrilus planipennis* has only attacked and killed green ash (*F. pennsylvanica*), white ash (*F. americana*) and black ash (*F. nigra*), as well as several horticultural varieties of ash in North

America (Table 1). Blue ash (*F. quadrangulata*) was the least preferred ash species in a recent experiment by the USDA, but *A. planipennis* was also found to feed on other members of the ash family such as forsythia, fringe tree, lilac, privet, and swamp privet (Haack et al. 2002). This pest will attack weakened and stressed trees first but can kill healthy vigorous trees as well (McCullough and Roberts 2002). See Appendix B for maps showing host plant ranges.

Table 1. Host plants of *Agrilus planipennis*

Host	Reference
Fraxinus spp.	(Yu 1992)
Fraxinus chinensis subsp. chinensis	(Yu 1992)
Fraxinus chinensis sbsp. ryhchophylla	(Yu 1992)
Fraxinus pennsylvanica	(Liu et al. 2003)
Fraxinus americana	(Liu et al. 2003)
Fraxinus nigra	(Liu et al. 2003)
Fraxinus quadrangulata	(Liu et al. 2003)
Fraxinus mandshurica	(Liu et al. 2003)
Fraxinus velutina	(Liu et al. 2003)
Fraxinus mandshurica var. japonica	(Liu et al. 2003)
Juglans mandshurica var. sieboldiana	(Haack et al. 2002; Liu et al. 2003)
Julglans mandshurica var. sachalinensis	(Haack et al. 2002; Liu et al. 2003)
Pterocarya rhoifolia	(Haack et al. 2002; Liu et al. 2003)
Ulmus davidianan var. japonica	(Haack et al. 2002; Liu et al. 2003)

Table 2. Genera of known hosts of *Agrilus planipennis* that occur in Minnesota

Host	Range in Minnesota
Fraxinus pennsylvanica	All of Minnesota
Fraxinus americana	Southeast Minnesota
Fraxinus nigra	Northern, Central, Southeastern Minnesota

b. Climate Suitability Rating: High

See Appendix A for a more complete description of this analysis. *A. planipennis* is native throughout the Palearctic and Indo Malayan regions of northeastern Asia (Table 3). More recently, this pest has invaded Ontario, Canada and the Midwestern United States specifically, Michigan, Indiana and Ohio (Fig. 2). Although *A. planipennis* has been detected on nursery stock in Maryland and Virginia, no evidence suggests the insect has established in these states. Our pest risk assessment for Minnesota found that the historical distribution of *A. planipennis* may be most closely associated with temperate broadleaf and mixed forests. Temperate broadleaf and mixed forest occur in the northeastern two thirds of Minnesota (Fig. 3) (Olson et al. 2001) and would be suitable for *A. planipennis*.

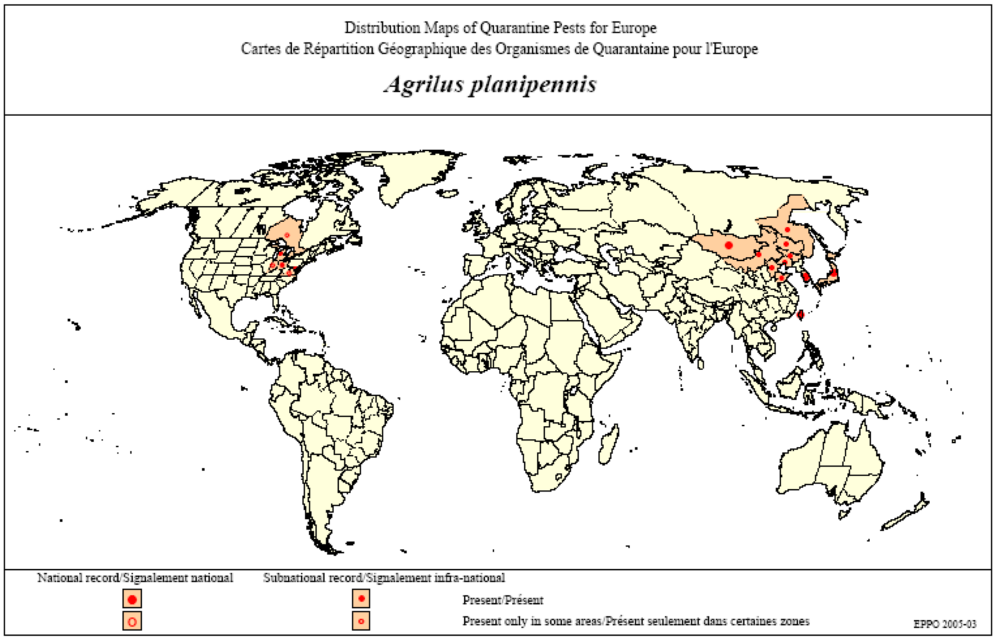

Figure 2. Worldwide distribution of *A. planipennis*. [Image reproduced from EPPO (2005).]

Table 3. Reported geographic distribution of *Agrilus planipennis*

Location	References
Canada – Ontario	(Liu et al. 2003)
Essex County	(CFIA 2005)
Chatham Kent	(CFIA 2005)
China	(Liu et al. 2003)
Beijing	(Gould et al. 2005)
Changzui	(Liu et al. 2003)
Hebei Province (EAB collected)	(Liu et al. 2003; Gould et al. 2005)
Heilongjiang Province (EAB collected)	(Liu et al. 2003; Gould et al. 2005)
Haerbin	(Yu 1992)
Harbin (EAB collected)	(Liu et al. 2003)
Shangzhi	(Liu et al. 2003)
Jilin Province (EAB collected)	(Liu et al. 2003; Gould et al. 2005)
Changchun (EAB collected)	(Liu et al. 2003)
Jiaohe	(Liu et al. 2003)

Location	References
Jilin (EAB collected)	(Liu et al. 2003; Gould et al. 2005)
Liaoning Province (EAB collected)	(Liu et al. 2003; Gould et al. 2005)
Benxi (EAB collected)	(Liu et al. 2003)
Shenyang	(Liu et al. 2003)
Shandong Province	(Liu et al. 2003)
Binzhou	(Liu et al. 2003)
Tangshan	(Liu et al. 2003)
Tianjin Province (EAB collected)	(Liu et al. 2003; Gould et al. 2005)
Dagong	(Smith 2005)
Guangang (EAB collected)	(Liu et al. 2003)
Hangu	(Smith 2005)
Jinnan	(Liu et al. 2003)
Zhangzhuang	(Liu et al. 2003)
Japan (EAB collected)	(Haack et al. 2003; Liu et al. 2003)
Shiroishi City	(Smith 2005)
Korea	(Haack et al. 2003; Liu et al. 2003)
South Korea	(Smith 2005)
Mongolia	(Haack et al. 2003; Liu et al. 2003)
Russia	(Haack et al. 2003; Liu et al. 2003)
Taiwan	(Haack et al. 2003; Liu et al. 2003)
U.S.- Indiana	(Liu et al. 2003)
Adams Cnty.	(USDA 2005)
Lagrange Cnty.	(USDA 2005)
Randolph Cnty.	(USDA 2005)
Steuben Cnty.	(USDA 2005)
Maryland	(Liu et al. 2003)
Prince George Cnty.	(Bean 2004)
Michigan	(Liu et al. 2003; Davis et al. 2005)
Ohio	(Liu et al. 2003)
Auglaize Cnty.	(USDA 2005)
Defiance Cnty.	(USDA 2005)
Delaware Cnty.	(USDA 2005)
Erie Cnty.	(USDA 2005)
Fulton Cnty.	(USDA 2005)
Hancock Cnty.	(USDA 2005)
Lucas Cnty.	(USDA 2005)
Ottawa Cnty.	(USDA 2005)
Sandusky Cnty.	(USDA 2005)
Williams Cnty.	(USDA 2005)
Wood Cnty.	(USDA 2005)

Location	References
Virginia	(Liu et al. 2003)
Fairfax Cnty.	(USDA 2005)

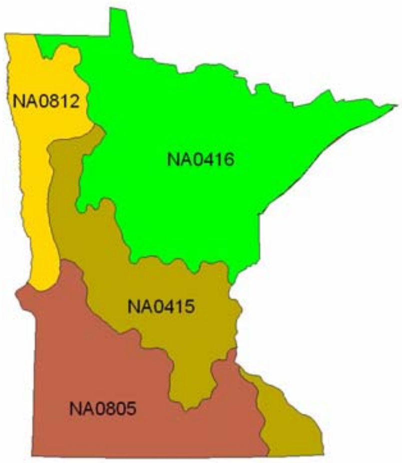

Figure 3. Biomes of Minnesota as described by Olson et al. (2001)
NA0416 - Western Great Lakes forests (Temperate Broadleaf and Mixed Forest Biome)
NA0415 – Upper Midwest forest-savanna transition (Temperate Broadleaf and Mixed Forest Biome)
NA0805 – Central tall grasslands (Temperate Grasslands, Savannas & Shrublands)
NA0812 – Northern tall grasslands (Temperate Grasslands, Savannas & Shrublands)

2. Dispersal Potential Rating: High

Agrilus planipennis has been transported unintentionally through infested nursery stock, firewood, logs and wood packing with bark (Liu et al. 2003; CAB 2004; Haack and Petrice 2004). *Agrilus planipennis* is highly likely to continue moving from infested to uninfested areas by one or more of these pathways (Haack et al., 2002; Ohio Department of Agriculture, 2003). The beetle also disperses through adult flight. *Agrilus planipennis* adults are strong fliers and typically fly in 8 to 12 meter bursts (Yu 1992). Flights of more than 1 kilometer have also been recorded (Haack et al. 2002). Due to their small size, adults can be moved by air currents. Dispersal and damage by *A. planipennis*s are affected by the spatial distribution and health of hosts (MacFarlane and Meyer 2005).

Firewood is a primary means by which *A. planipennis* is introduced to new areas (Haack and Petrice 2004) and is the most likely means by which the insect may arrive in Minnesota. A recent review of Minnesota state park camper data (MNDNR 2006) from six Minnesota State Parks (Split Rock Lighthouse, Gooseberry Falls, Itasca, Interstate, Sibley and Fort Snelling) indicated that 0.46 percent or 1 of every 217 campers that visited these parks came from an *A. planipennis* quarantined or regulated area. A survey completed by the Minnesota Department of Agriculture in 2005 indicated that 43 percent of campers bring their own firewood to recreational areas. Similarly, a 2005 survey by the Minnesota Department of Natural Resources showed that

60 percent of all campers in state parks brought their own firewood and 5.5 percent of campers were from out of state and brought firewood on at least one camping trip (Mike Albers, MNDNR, personal communication 2006).

The emerald ash borer's high fecundity, adaptable life cycle and cold hardiness contributes to its successful dispersal potential (Dobesberger 2002). This insect generally has a one-year life cycle in southern Michigan although two years may be necessary in colder areas. Females may mate several times and lay 60-90 eggs throughout their lifetime (McCullough and Katovich 2004). The rapid spread of *A. planipennis* in Canada and United States urban and natural areas indicates that this species is highly invasive and that this spread will likely continue (Haack et al. 2002; CAB 2004).

3. Potential Abundance – Reproductive Rating: Low

The biology of *A. planipennis* is summarized in Appendix D. Both males are females are required for reproduction in this species. If conditions are optimal, a female may produce 90 eggs, but 80 eggs is more common. In Minnesota, only a single generation is expected per year. Neither diapause nor cold exposure is known to be required for development. Assuming maximum reproduction, the standardized annual reproductive output would be 45 female offspring per mother. This reproductive rate is low relative to other pests.

4. Economic Impact Rating: High

The potential economic impact of *A. planipennis* is enormous (Liu et al. 2003). *A. planipennis* can destroy entire stands of ash trees during outbreaks (Yu 1992; Haack et al. 2002) and might destroy the entire ash population of North America (MacFarlane and Meyer 2005). In Ontario, it is estimated that 9,000 to 10,000 ash trees have died (CAB 2004). *Agrilus planipennis* can kill trees of various size and condition; from small trees of five centimeter trunk diameter to large mature trees. Significant infestations can kill trees within one to two years, although it may take three years following initial attack (Haack, 2002). Adults eat up to 0.45cm^2 of leaf tissues per day (Xiao 1991). The potential impact of *A. planipennis* nationwide to urban environments alone is 0.5 to 2 percent loss of total leaf area, or 30-90 million trees with a total loss of $20-60 billion dollars (McPartlan et al. 2004).

Millions of ash trees (*Fraxinus pennsylvanica*, *Fraxinus americana* and *Fraxinus nigra*, as well as several horticultural varieties of ash) have been killed recently in Michigan (Haack et al. 2002; Liu et al. 2003). Replacing these trees is difficult because replacement tree species tolerant to urban settings are limited. Loss of urban trees will likely contribute to urban heating costs (Haack et al. 2002). In addition, private campgrounds in Michigan have been negatively impacted because campers who cannot bring their own firewood from quarantined areas are no longer camping (McPartlan et al. 2004).

Ash occurs throughout the United States (MacFarlane and Meyer 2005), and spread of *A. planipennis* would permanently alter the Midwest's forest ecosystem, which is composed of up to 40 percent ash in some areas (McPartlan et al. 2004). Ash also accounts for as much as 20 percent of street trees throughout the Midwest (Haack et al. 2002). Intangible values associated with loss of ash could include energy conservation, storm-water attenuation, noise buffering, provision of wildlife habitat, enhanced aesthetics, protective shelter belts and psychological well-being (Kenney and Idziak 2000).

Potential Economic Impacts to Minnesota:
Minnesota's ash resource is mainly smaller diameter trees suitable for pulpwood mills (Table 4). Some logs are suitable for veneer and high quality sawlogs which would be negatively impacted by *A. planipennis* due to bore holes reducing the quality and market value (Dobesberger 2002). The 2005 estimate for ash harvested in Minnesota is approximately 71,000 cords. Of this, 15,000 cords will be used for fuelwood. The Minnesota Department of Natural Resources estimates $15 million annually in ash stumpage (MNDNR 2004).

Ash makes up approximately 20 percent of Minnesota's tree production (worth $10-$40 million annually) and tree sales (worth $50-$70 million annually). There are also social and intangible costs of ash in Minnesota. If *A. planipennis* arrives in Minnesota it could be listed as a quarantine pest affecting trade and commerce throughout the state. The timber and nursery industries as well as urban shade trees could be significantly affected (Minnesota Statutes, 2003). In addition, Minnesota's black ash resource used for specialty products and baskets (Benedict 2001) could be impacted.

5. Environmental Impact Rating: High
Agrilus planipennis damage to trees depends on coverage and species composition of the ash stand, position within a tree, tree age and health, temperature and other environmental factors (Yiguo 1966; MacFarlane and Meyer 2005). In China, outbreaks occur in exposed forest stands of *F. chinensis subsp. chinensis* and *F. chinensis subsp. Rhychophylla* that are >7 yr old. Bark of infested trunks begins to peel off in patches within one to two years because the cambial layer dies underneath. At this time, dense feeding galleries become visible on the outer sapwood. Severe infestations ultimately lead to the destruction of the entire forest stand (Yu 1992). Trees most susceptible to attack were growing in open areas or forest edges (Chinese Academy of Science 1986). Damage to the trees in the first year of infestation is light when populations are low, however, attacks consecutively for two to three years with higher populations results in wilting or even tree death from destruction of vascular systems (Yu 1992). Invasive flora and fauna could also become established or enhanced in forested areas as a result of ash mortality due to *A. planipennis* (Puric-Mladenovic et al. 2000).

6. Vertebrate Health Impact Rating: Negligible
A. planipennis is not known to cause any adverse impacts to human or animal health. Larvae of the insect may serve as a supplemental food source for insectivorous birds such as woodpeckers.

7. Social Impacts to Minnesota. Rating: Low
Black ash is used for specialty products such as veneer and paneling and has been used by Native American Tribes for baskets for thousands of years (Benedict 2001). This tree is used for basket making because it is easy to separate the annual rings from the splints used to make a basket, the splint can be bent without splitting and the wood is very resilient. Only one out of ten black ash trees are good enough to make a basket. Trees must have a five or six inch diameter, have a straight trunk four to six feet in length with no defects and have 20 years of annual ring growth. Preferred trees are found at vernal ponds or in forest-wetland stands because seasonal flooding does not kill ash seeds but excludes herbs as well as other seedlings. A large population of black

ash is needed in order to supply trees with these characteristics (Benedict 2001). Basket weavers use black ash in Minnesota. The following is from Dennis Chilcote (personal communication, 2006) a black ash basket maker and instructor in Minnesota:

"Black ash basketry (or, more generally, the use of black ash splint) is, I think, pretty rare in MN in spite of our great supply of black ash. Well, not as great as it was a few years back, many of the black ash forests up north took a terrible blow two summers ago, makes me very sad. I work with black ash and birch bark, and I see the birch being logged in greater and greater numbers, but I have always thought that even if the birch effectively disappears, there will always be ash. Now I am not so sure. I personally know two other basket makers who work seriously with black ash in MN. Most basket makers that dabble in black ash buy splint from basketry supply stores, which is relatively expensive but simple.

Much of the commercially available black ash splint is provided by a fellow out of Michigan. It is so physically demanding and time consuming to start with a log and make the splint yourself (providing that you can get a log in the first place) that it really discourages most people from pursuing it, although there is a fair amount of interest in the process, and many folks have enjoyed trying it once.

I know that there is some black ash basketry pursued at Mille Lacs and White Earth, and probably at some of the other reservations as well. I do know a woman who is pretty well connected with the art community on the various reservations and may have a pretty good idea who is doing ash splint work there, I have not personally met any of these craftspeople. However, I have done many craft shows up north and met only a few people who have seriously pursued black ash basketry (all past tense). I have a friend who lives up near Aitkin who uses black ash splint to weave the seats on the rustic chairs that he makes. All his ash comes from his own 40.

My sense is that the current craft demand for black ash is very very limited. Now the problem is that the craft demand is also very selective. When selecting a black ash tree for splint, I want a straight, clean tree about 8" in dia. at the base with no branches or branch scars for seven to nine feet above the ground and no spiral twist to the bark pattern as you sight up the tree. I can walk through a good forest of black ash and not find many excellent candidates. So although the craft industry does not need many ash logs, it needs a large number of trees to cull through to provide a few high quality logs. It would be like cruising for veneer logs in a hardwood stand, typically few and far between. For the work that I do, one good log supplies my entire splint requirements for the year and then some. If I were to make larger baskets, like pack baskets, and work full time at it, I might require on the order of 5 logs a year. Not a big demand. Now multiply that by maybe ten folks in the state doing similar work, and you have a just a few cords of wood required per year for the whole craft community. In fact, I have gone by homes up north with 10 cords of black ash firewood piled in the yard, and thought that amount of ash would supply all my splint needs for the rest of my life."

Table 4 Minnesota Counties and volume of all standing live ash on forestland in cubic feet

County	White ash	Black ash	Green ash
Aitkin		102,100,600	21,123,422
Anoka	175,043	33,844	10,529,807
Becker		11,644,895	8,525,746
Beltrami		65,089,155	12,789,801
Benton		557,056	4,729,343

County	White ash	Black ash	Green ash
Big Stone			460,920
Blue Earth		88,571	1,472,635
Brown			1,569,706
Carlton		40,291,886	4,986,086
Carver			800,667
Cass		51,315,985	20,535,997
Chisago		4,514,886	1,088,322
Clay			1,822,509
Clearwater			7,449,884
Cook			1,421,777
Cottonwood			11,835,310
Crow Wing		26,406,415	3,496,291
Dakota		423,422	1,358,361
Dodge			302,052
Douglas		4,788,470	2,583,749
Fairbault			2,134,659
Fillmore	2,215,727	460,896	2,447,816
Goodhue	910,670	110,732	5,484,546
Hennepin	28,998	1,706,367	604,493
Houston	1,224,489		1,653,725
Hubbard		6,461,261	2,913,926
Isanti		8,892,283	3,022,101
Itasca		110,778,000	9,233,960
Kanabec		21,831,613	8,235,564
Kandiyohi		294,353	13,025,557
Kittson		330,720	3,640,308
Koochiching		111,154,650	7,564,187
Lac qui Parle			3,393,791
Lake		43,641,971	2,931,657
Lake of the Woods		15,567,993	1,248,039
Le Sueur			9,015,144
Lincoln	5,739,494		
Lyon			2,267,506
Mahnomen		4,148,866	4,863,205
Marshall		130,009	2,052,734
Martin			16,630,859
Meeker			6,381,491
Mille Lacs		29,572,457	12,560,917
Morrison	237,614	16,598,280	7,182,314
Mower			822,966
Murray			46,781
Nicollet			2,408,158
Norman		560,036	6,243,732
Olmsted	180,810		891,432
Ottertail		5,794,712	11,912,162

County	White ash	Black ash	Green ash
Pine		28,656,124	6,469,376
Polk		736,872	6,212,622
Pope		486,090	10,693,679
Red Lake			1,542,202
Redwood			797,582
Renville			970,958
Rice	346,673		1,942,116
Roseau		11,322,562	3,238,293
St. Louis		120,984,850	6,219,373
Scott			843,174
Sherburne			3,356,681
Sibley			350,824
Stearns		4,893,733	4,998,361
Stevens		869,941	
Swift			5,897,835
Todd		11,023,111	8,395,402
Traverse			644,608
Wabasha			2,177,871
Wadena		1,806,390	1,530,915
Waseca			214,923
Washington	388,914	906,693	2,722,039
Watonwan			7,138,769
Wilkin			2,673,144
Winona		212,596	1,354,392
Wright	35,569	850,453	5,911,369
Total	11,484,002	913,530,324	355,992,620

FIA Database, 2002 – Minnesota counties containing ash

8. Management Rating: Low

No effective control methods are currently available for *Agrilus planipennis*. However, research is under way on the evaluation of systemic insecticides, natural enemies, and survival rates in cut trees. Presently, infested trees containing larvae and pupae should be cut and chipped (CAB 2004). The control and management of *A. planipennis* will require an integrated pest management approach including biological control methods (Gould et al. 2005). *Spathius sp.* (Hymenoptera: Braconidae) and *Tetrastichus sp.* (Hymenoptera: Eulophidae) were found to parasitize *A. planipennis* in China at 6.3 and 6.6 percent respectively (Liu et al. 2003). In a Michigan study, parasitism rates were less than 1 percent and insufficient to contain *A. planipennis* populations for ash tree survival (Gould et al. 2005). Entomopathogenic fungi resulted in less than two percent life stage mortality beneath ash bark (Gould et al. 2005). Chemical control research has shown that imidacloprid injections at a dosage of 0.25g/cm early in the season resulted in exposure concentrations above toxicity thresholds for both adults and larvae within seven days of treatment (Helson et al. 2005). Other chemical control measures currently available include commercial application of Dursban or Tempo in June or July and Merit treatments to the soil beneath trees in the summer or fall to reduce larval populations (Dobesberger 2002). Planting a wide diversity of species and avoiding monocultures in urban areas will be very effective in reducing infestations of *A. planipennis* (Dobesberger 2002). In

Europe, use of trap logs to collect adults during flight periods has been successful to contain their populations and mass trapping could result in pest suppression (Vite 1952; Schwenke 1974) but these techniques have not been tested in North America for *A. planipennis*. These are the management options available at this time. As new alternatives are discovered MDA will adjust management tactics and develop management plans as needed.

B. Likelihood of Invasion

1. Pest history rating: High

A. planipennis has invaded countries outside its native range, specifically the United States and Canada. Although the precise pathway of introduction is not known, it seems likely that the insect was introduced in infested wood, possibly solid wood packing materials, from Asia. Additionally, within North America, the insect has been moved in infested nursery stock and firewood.

Within its native range, the insect has not been reported as a major pest, though it is noted to damage stressed trees. In North America, *A. planipennis* is a major pest. See 'Economic Impact Rating' for a full discussion of the extent of damage caused.

2. Quantity of Commodity Imported: Medium

It is possible to move all *A. planipennis* life stages (eggs, larvae, pupae and adults) on raw wood with bark attached used for processing, dunnage, crating and firewood (Dobesberger 2002; CAB 2004). Larvae may be found in host material at any time of the year, but pupae and adults are only found at specific times of the year. Since larvae require green wood to survive, dead timber products would reduce survival, whereas pupae and adults are more tolerant to dry conditions and could survive in solid wood packing material. Seasoned and cured firewood would reduce larval survival as would fall firewood shipments.

In most commercial trade, *A. planipennis* is most likely to be associated with wooden pallets, dunnage, and crating materials. In Minnesota, nearly 22 percent of the freight tonnage moving in our transportation system has neither an origin nor destination in the state, but rather serves the national economy. The vast majority of the freight traveling through Minnesota is generated by the Midwest, Plains and Mountain states, which are also major trading partners for Minnesota. In addition, Minnesota serves as a major gateway for freight shipped to and from Canada. Overall, the freight shipped through Minnesota is split almost equally between rail and truck. The commodities moving through Minnesota are primarily bulk freight such as farm and food products, coal, chemicals and lumber.

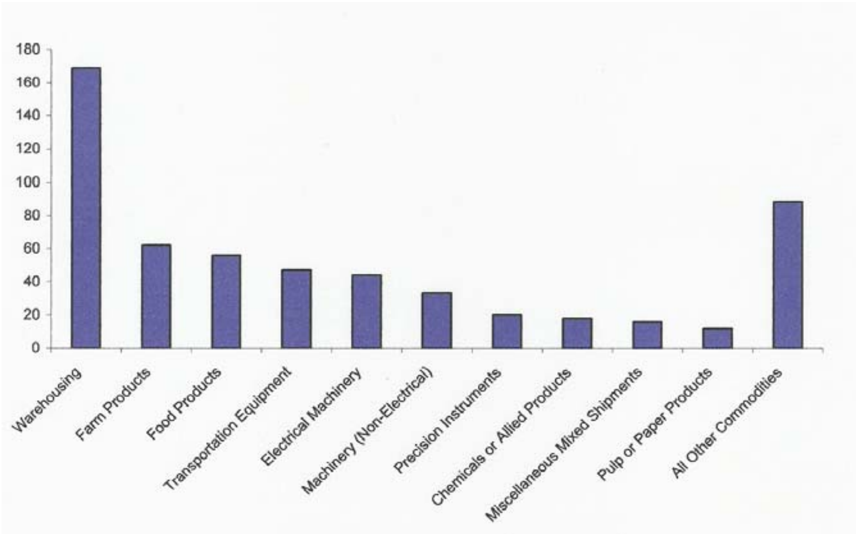

Figure 4. Minnesota Commodity Value in Annual Dollars (Billions) 2001 (MNDOT 2005)

As shown in Figure 4, the top five freight commodities overall moving in Minnesota by value are warehousing, farm products, food products, transportation equipment and electrical machinery. (MNDOT 2005).

The movement of infected nursery stock and infested firewood are also potential pathways for the introduction of this pest. See risk element #2, Dispersal Potential, for statistics about campers coming to Minnesota from areas quarantined for *A. planipennis*.

3. Estimated Pest Density per Unit Imported Rating: Low

There have been no attempts to quantify the number of insects that might be associated with a particular commodity. No *A. planipennis* interceptions have been made in Minnesota; however, *Agrilus* interceptions have been made by the United States Department of Agriculture 36 times at ports in 11 eastern states. Those shipments originated from at least 11 countries (Federal Register: October 14, 2003 (Volume 68, Number 198)). Presently, there are at least six exotic species of *Agrilus* established in the United States. Between 1985 and 2000, 38 confirmed detections of *Agrilus spp.* were made at United States points of entry, 28 from dunnage, four from crating, four from grapevine leaves, one from a cutting and one in a ship's hold (Haack et al. 2002).

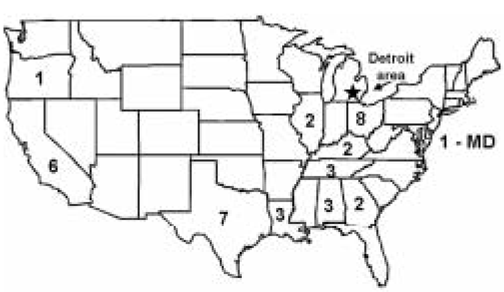

Figure 5. Interceptions of *Agrilus* in the United States 1985-2000
(Haack et al. 2002)

4. Likelihood of Surviving Post Harvest Treatment Rating: High

International regulations for the treatment of wood used for crating, pallets, or dunnage should be adequate to kill these insects in infested wood. Consequently, introduction of *A. planipennis* from overseas seems relatively unlikely. This insect is most likely to be moved into the state in firewood or nursery stock from an infested state. Currently, no post harvest treatments are consistently or reliably applied to these goods. Domestic quarantines may limit opportunities for the beetle to move from state to state. But, quarantines are only applied when beetle infestations can be confirmed. Unfortunately, such confirmation may come several years after the beetle has established in an area.

5. Likelihood of Surviving Shipment: High

We believe more than 10% of *A. planipennis* individuals could survive standard shipping conditions, especially in firewood or nursery stock. However, we could find no studies to support this speculation.

6. Likelihood of Moving to Suitable Climate Rating: High

Agrilus planipennis was discovered in southeastern Michigan in 2002 around the Detroit area and was probably introduced in solid wood crating material. It is probable the insect was in the Detroit area for several years before detection and has probably been in this country for the past eight or nine years (McCullough and Roberts 2002). The insect has spread rapidly throughout Michigan and has also been found in several surrounding states and Ontario, Canada. The climate of its native range is similar to that found in the Midwest and there are suitable host species available for establishment. In Minnesota, 75 counties contain green, white and/or black ash (Table 3). The majority of our ash resources are in the eastern two thirds of the state (FIA 2002). A preliminary analysis by Kluza and Jendek indicates a potential distribution overlap with greater than 50% of the geographic range of nine North American ash species (Kluza and Jendek 2004) including species in Minnesota. Furthermore, the Twin Cities Metropolitan area, the port city of Duluth, and several state and national parks occur in the areas predicted to be climatically suitable for *A. planipennis*. These areas are likely to receive significant volumes of material that may harbor the insect.

7. Likelihood of Finding a Host Rating: High

Agrilus planipennis is only a periodic pest of ash in China due to natural enemies and host plant resistance (Liu et al. 2004; Gould et al. 2005). This insect is able to survive for long periods of time underneath host tree bark and may stay dormant for several years (Xiao 1991). Its ability to fly for distances up to a few kilometers means it could easily disperse throughout urban and natural area corridors searching for host species (Dobesberger 2002). In addition, susceptible species are found throughout Minnesota in natural and urban environments (MNDNR 2004). Nursery stock plantations growing susceptible ash species with enough bark surface area could also be suitable for *A. planipennis* survival (Dobesberger 2002). Minnesota's ash resource is dominated by smaller diameter material, high quality sawlogs and veneer ash (Table 5, Figure 6). Of the ash species found in Minnesota (black, green and white) black ash has by far the largest volume in Minnesota (Fig. 7) (MNDNR 2004). Minnesota's northern hardwood resource by cover type includes 10 percent ash (FIA 2002).

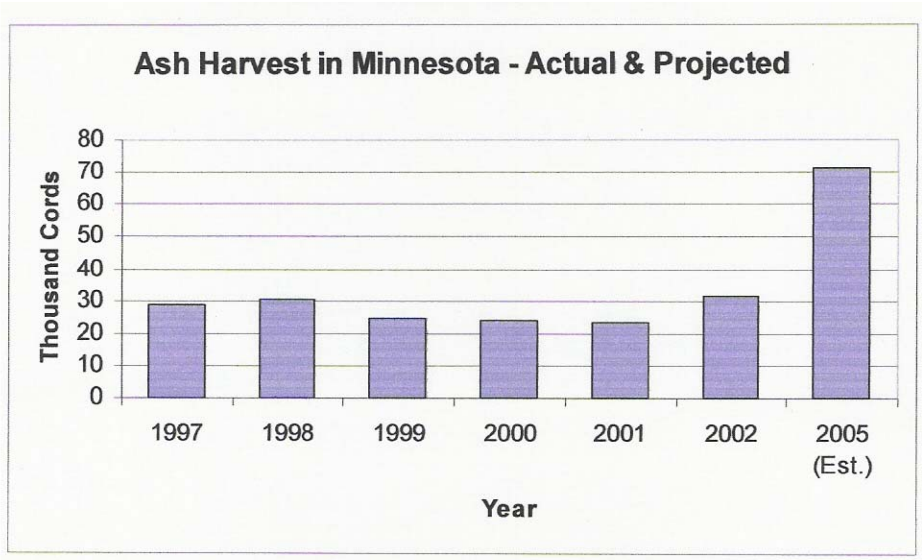

Figure 6. Minnesota Ash Harvest (MNDNR 2004)

Table 5. Current Demand for Ash from Minnesota Timberlands

Ash Product	2002 Harvest in cords	2005 Harvest in cords
MN pulpwood industries	3,700	44,000
Pulpwood export	0	1,000
Sawlogs and other	10,900	11,000
Fuelwood	15,300	15,000
Total	29,900	71,000

(MNDNR 2004)

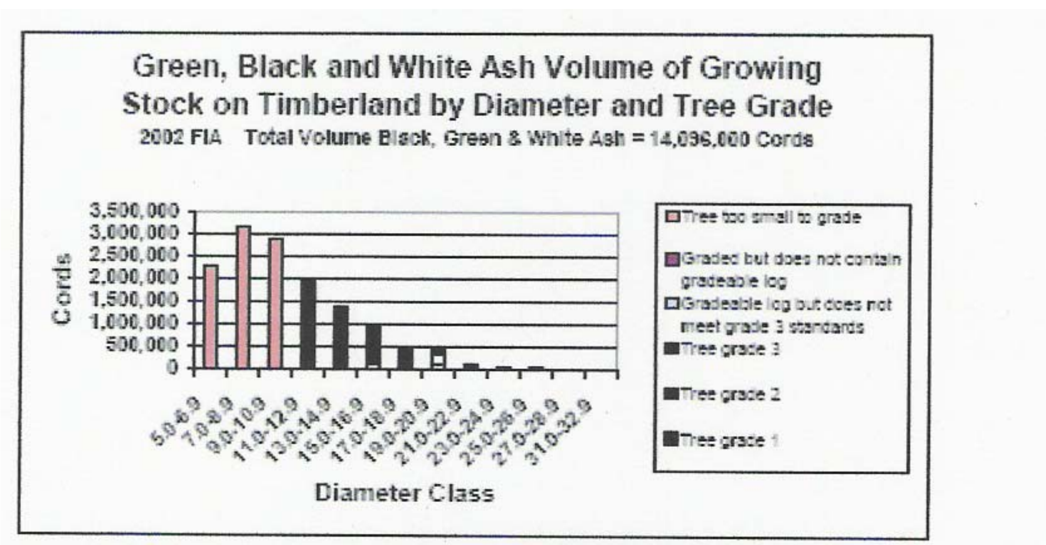

Figure 7. Ash Volume in Minnesota (MNDNR 2004)

8. Potential for Eradication Rating: Low

Currently, tools for the early detection of *A. planipennis* are rudimentary. Although research is underway, no pheromone lures are available. The sensitivity of trap tress has yet to be determined. Few chemical treatments are available, and those that are (e.g., imidacloprid) are only practical for valued landscape trees, not broad areas. In the early years following detection of *A. planipennis* in the US, all ash trees within a ½ mile radius of an infested tree were removed and destroyed (either chipped or burned). The success of these initial eradication efforts has yet to be fully evaluated. However, the apparently long period between the initial arrival of the insect and the time at which populations can be detected severely impairs efforts to delimit the geographic extent of the infestation.

IV. CONCLUSION – PEST RISK POTENTIAL/PHYTOSANITARY MEASURES

Currently, no infestations of *A. planipennis* have been reported in Minnesota. However, our risk assessment shows that the entire eastern two thirds of Minnesota are climatically suitable for *A. planipennis* establishment. In addition, *A. planipennis* rated high for consequences of introduction, dispersal potential, economic impact and environmental impact. Unfortunately, this insect pest is difficult to detect. *A. planipennis* is now established in several Midwestern states (Haack et al. 2002). Phytosanitary measures should cover the import of *A. planipennis* host plants and any untreated wood such as wood packing material, wood chips and firewood from the infested areas. Restrictions on the movement of these commodities are also important in the containment of established infestations. The Minnesota Department of Agriculture is responsible for intrastate movement of products and the United States Department of Agriculture is responsible for interstate movement of these commodities.

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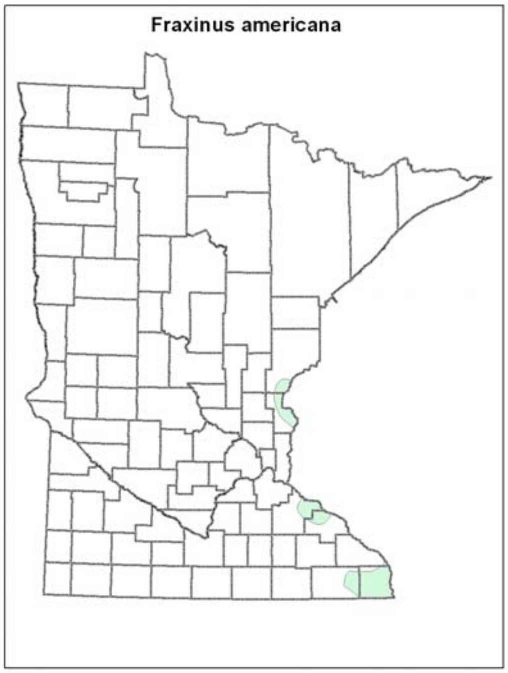
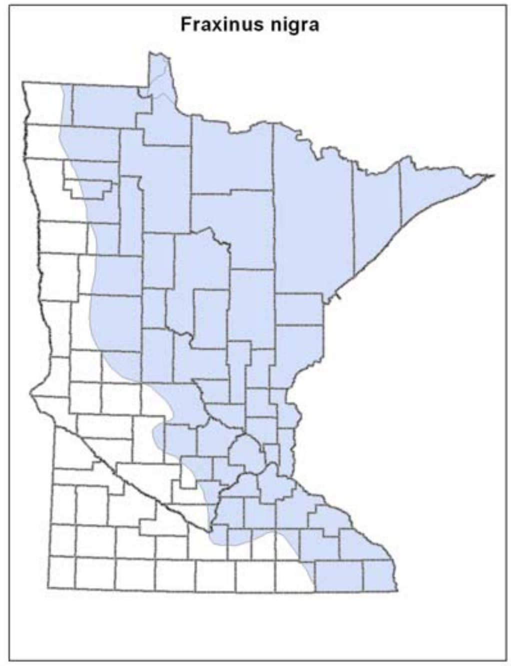
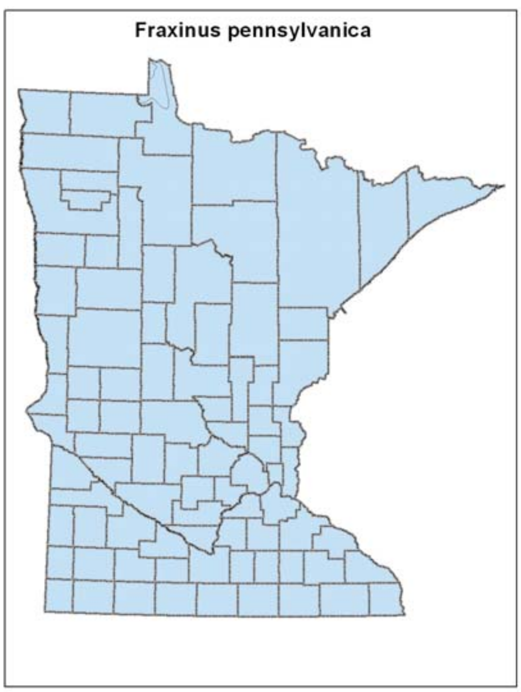
APPENDIX A: Comparison of Climate Zones and Geographic Distribution Table

To determine the potential distribution of this pest in Minnesota, we first collected information about the worldwide geographic distribution of the species (CAB 2004). We then identified which biomes as defined by the World Wildlife Fund (Olson et al. 2001), occurred within each country or municipality reported for distribution of the species. An Excel spreadsheet summarizing 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 or municipality. The list was then analyzed to determine the minimum number of biomes that could account for the reported worldwide distribution of the species. Biomes that occurred in countries or municipalities with only one biome were first selected. We then examined each country or 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 most frequently from the entire species' distribution was selected. The process of selecting additional biomes continued until at least one biome was selected for each county. The set of selected biomes was compared to biomes found for Minnesota.

APPENDIX B: Natural Distribution of Minnesota Hosts







APPENDIX C: Taxonomy and Morphology of *Agrilus planipennis*

Synonyms
Agrilus marcopoli Obenberger
Agrilus marcopoli ulmi Korosawa
Agrilus feretrius Obenberger

Description quoted from (Yu 1992)

Adults

The body is long and narrow, wedge-shaped; 8.5-13.5 mm long; metallic, coppery-green in color; head is flat with a shield-like vertex; compound eyes are kidney-shaped, obscure-aeneous (dark coppery) colored; prothorax rectangular, slightly wider than the head, but as wide as the front edge of the elytra; the front edge of the elytra has a horizontal, punctuated ridge; the back edge of the elytra rounded with small denticles (teeth). Adult flight covers 8-12 m at or below the height of 1-2 m above the ground.

Eggs

Eggs are cream-colored, becoming yellowish brown before hatching; oblate, 1.0 × 0.6 mm (length × width), slightly protruding in the center, with reductus (fold) extending radially toward the edges.

Larvae

Larvae are milk-white in color, flat and band-like, 26-32 mm long when fully mature. Head is small, brown in color, retracted inside the prothorax so that only the mouthparts appear visible. Prothorax is swollen whereas the meso- and metathorax are narrow. A pair of spiracles is found on the mesothorax and each of the first 8 abdominal segments. There are 10 segments in the abdomen with the last segment contains a pair of brown pincer-like appendages (urogomphi).

Pupae

Pupae are milk-white in color, 10-14 mm long; antennae extend backwards to the base of the wing buds; the last several abdominal segments slightly curved ventrally.

APPENDIX D: Biology

Population Phenology

In Haerbin, Heilongjiang province, after two winters, larvae start to feed in early to mid-April in the third year. Pupation occurs in late April, peaks in mid-May and ends in mid-June. Adults begin to emerge in mid-May, peaking in late June, whereas eggs appear in mid-June to mid-July. Adults are phototactic and thermotactic and most active between 9:00 to 13:00 hours on clear and windless days; they often fly to the sunlit side around tree crowns. Adults begin to emerge in mid-May and can be seen until early July, and eggs are found from early June to mid- and late July. Adults are relatively good fliers, often active between 6:00 to 17:00 hours on branches and leaf surfaces during the day, and perch motionlessly on crown leaf surfaces at night. Flight starts 3-4 hours after initial feeding. Adults start to mate between 9:00-15:00 hours, 7-10 days after emergence and mate up to 3 times maximum in their life. Mating lasts 20-90 minutes (average 60 min.). Oviposition begins 7–9 days after the initial mating. On cloudy or rainy days or days with strong wind, adults remain motionless on leaf petioles or inside bark crevices. Adults start to mate between 9:00-15:00 hours, 7-10 days after emergence and are able to mate as many as 3 times maximum in their life. Oviposition begins 7–9 days after the initial mating. Most eggs are laid between 14:00 to 17:00 hours on the southwest side of the exposed trunks and branches. Larvae bore into phloem and sapwood in succession and feed inside after they hatch in late June, and overwinter inside the galleries by mid-October when temperature drops (Yu 1992). In Michigan, *A. planipennis* has a one year life cycle (McCullough and Roberts 2002).

Specific Biology

In Shenyang, Liaoning province, *A. marcopoli* has one generation a year and overwinter as larvae, whereas in Haerbin, Heilongjiang province, it takes two years to complete a generation; larvae overwinter between phloem and sapwood or in galleries at the outer layer of sapwood.

Adults

Newly enclosed adults remain in their pupal chambers for 8-15 d before boring 3.5×4.1 mm oval exit holes for emergence. The newly emerged adults climb to the upper crown and feed on tender leaves. Adults consume the biggest portion of leaves within 5 d after emergence. When disturbed, adults will fall onto the ground and "play dead" (thanatosis). Adults prefer leaves of *F. chinensis subsp. chinensis, F. chinensis subsp. rhychophylla, and F. mandshurica* for maturation feeding, leaving irregular leaf patches with jagged edges. An adult can consume an average of 0.45-cm leaf tissue per day. Most eggs are laid in sunny bark crevices and on the base of the trunk. Only one egg is laid at each site. A female can produce 68-90 (average 76.6) eggs in her lifetime. The average longevity for females and males is 21.6 and 13 d, respectively.

Eggs and Larvae

The egg stage lasts 7 to 9 days. The newly hatched larvae feed on the phellem (cork) layer of the bark first and then bore into the cambium. Larvae etch deeper into the outer sapwood as their development progresses. Galleries are flat, meandering, 9-16 cm long, and packed with frass, reaching deep to the sapwood. Most galleries are found on tree trunks below 1.8 m.

Pupae

Pupation occurs in late April and pupal stage ends in mid-June at the end of a tunnel near the surface. Individual larvae that are not full grown by autumn, overwinter in the cambium, resume feeding in April and complete development in late summer.

Developmental Thresholds

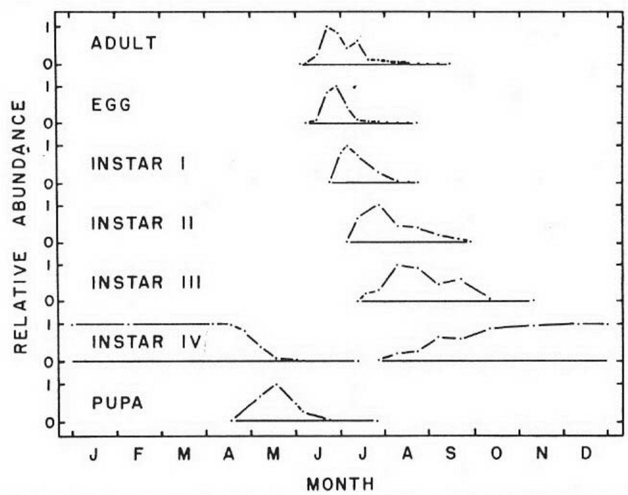
Little is known about the population dynamics of Buprestidae in North America. Among the 161 species of *Agrilus,* the best known are the twolined chestnut borer and bronze birch borer (Muzika et al. 2000) close relatives to *A. planipennis*. Due to its recent arrival in North America, research on developmental thresholds for *A. planipennis* is incomplete. In Ontario, Canada, Lyons and Jones 2005 showed adult emergence the first week of June, peaking in late June with median emergence on June 25 for males and June 26 for females in 2003 (Table 6). In 2004, emergence dates were June 11 and June 12 for males and females, respectively. There are four larval instars with the majority of the population in the prepupal stage late in the growing season although a small number of larvae were found in earlier instars at this time indicating some insects over wintering in the larval stage. Female longevity at 21ºC was 38 days and 5 days at 33ºC (Lyons and Jones 2005).

Table 6. Emerald ash borer development

Life Stage	**Basal Temperature (ºC)**	**Degree Days**
Adult – Male	13.5	303.0
Adult – Female	13.5	344.8
Prepupal	12.0	118.3
Prepupal	11.5	121.0
Pupal	13.6	139.2
Pupal	14.7	114.6
Teneral Adults	10.1	64.4
Teneral Adults	13.6	43.1
Egg Development	13.9	155.2

(Lyons and Jones 2005)

To determine approximately when developmental stages for *A. planipennis* might occur in Minnesota we looked at developmental rates for the twolined chestnut borer, *Agrilus bilineatus* in Wisconsin. Adult longevity for adults was 28 days at 20ºC and 8 days at 30ºC and for pupal stages was 11.7 days at 24ºC and 8.5 days at 30ºC (Haack and Benjamin 1982). Based on Figure 8, adult peak flight period is June 18-21, oviposition from June 14-August 16, first instars from June 30-August 23, second instars from July 12-September 21, third instars from July 18-November 10 and fourth instars from July 26 –December 10. Pupal cell construction lasted from August 9-December 10.



Relative abundance of *Agrilus bilineatus* life stages based on field experiments conducted from June 1979 through May 1980: Kettle Moraine State Forest, Jefferson County, Wisconsin.

Figure 8. *Agrilus bilineatus* life stages in Wisconsin