A FAUNAL SURVEY OF COLEOPTERA, HEMIPTERA (HETEROPTERA), AND LEPIDOPTERA ASSOCIATED WITH *FRAXINUS PENNSYLVANICA* MARSHALL (OLEACEAE) IN THE RED RIVER VALLEY OF EASTERN NORTH DAKOTA

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ABSTRACT

The emerald ash borer (*Agrilus planipennis*; EAB) is an invasive wood-boring beetle causing mortality of ash trees in North America. This project was initiated because of the threat of EAB moving into North Dakota. The main objective was to establish a baseline of insects associated with ash (*Fraxinus*) in the Red River Valley of North Dakota before EAB arrives. Taxonomic groups focused on include: Coleoptera, Hemiptera (Heteroptera), and Lepidoptera. Ten sites were surveyed regularly. Sites were chosen due to their ash content: nine sites contained green ash (*Fraxinus pennsylvanica*), and one site contained black ash (*F. nigra*). Surveying was performed during the months of May through September in 2010 and 2011. Overall, 4,301 specimens from 53 families in three orders were identified in this study, totalling at least 276 distinct taxa. 23 of the species collected and identified in this study were found to be associated with *Fraxinus*.

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INTRODUCTION

Emerald ash borer (*Agrilus planipennis* Fairmaire; EAB) is an invasive metallic wood boring beetle (Coleoptera: Buprestidae) that is a major cause of ash tree mortality in northeastern North America. Emerald ash borer has been shown to attack and kill all North American species of ash (*Fraxinus* spp.) it has encountered (McCullough et al. 2004, Cappaert et al. 2005, Poland and McCullough 2006). The preferred host of EAB is green ash, *Fraxinus pennsylvanica* Marshall (Oleaceae), an important hardwood shade and riparian woodland tree in North Dakota (Burns and Honkala 1990). Two naturally-occurring species of ash in North Dakota, green ash and black ash (*F. nigra* Marshall) are of high economic, ecological, and aesthetic value (Kartesz 2011, USDA FS FIA, USDA–APHIS 2012).

Often, scientists are working 'behind' an infestation, essentially tracking an invasive pest after it has already gone through an area. In the case of EAB, there is an opportunity to work 'ahead' of the beetle and gather data prior to its establishment in North Dakota. The purpose of this study was to identify the insects associated with green ash, which could be potentially affected by significant ash mortality caused by EAB, with an emphasis on the taxonomic orders Coleoptera, Hemiptera (Heteroptera), and Lepidoptera in selected areas of the Red River Valley of eastern North Dakota. To the author's knowledge, this is the first insect survey of ash in North Dakota since the North American emerald ash borer invasion was identified in 2002. By surveying the insect fauna associated with ash, baseline data can be created. This is necessary in understanding the ecology, diversity, and potential impact that EAB will have on native insects when it arrives in North Dakota. The first step to any management plan is to take inventory of what is present and living on ash. This study intends to gain a better understanding of the insects associated with ash, which will provide basic data necessary to evaluate threatened *Fraxinus* communities, and could assist in making policy, regulation, and pest management decisions. Research was initiated in May of 2010 to survey for the arthropods associated with green ash (*F. pennsylvanica*) and to a lesser extent, black ash (*F. nigra*)

LITERATURE REVIEW

Emerald Ash Borer

General Overview

The order Coleoptera (beetles) is the most species-rich group of organisms on the planet, with an estimated 300,000–450,000 described species (Grove and Stork 2000). The Buprestidae (metallic wood-boring / jewel beetles) is one of the eight largest families within Coleoptera (Evans et al. 2000). *Agrilus* is the largest genus in the Buprestidae, and based on species estimates[1], may be the largest genus in the animal kingdom, with species found in Asia, Australia, Europe and North America (Browne 1968, Jendek 2000).

Agrilus planipennis Fairmaire, (Buprestidae, emerald ash borer; EAB) is an invasive wood-boring beetle that is a major cause of ash (*Fraxinus*, Oleaceae) tree mortality in northeastern North America. Emerald ash borer was first discovered in parts of southeastern Michigan near Detroit and in Windsor, Ontario in the summer of 2002 (Haack et al. 2002, Kovacs et al. 2010, US Forest Service 2010). The native range of *A. planipennis* includes portions of China, Korea, Mongolia, Japan, Russia, and Taiwan (Figure 1) (Chinese Academy of Science 1986, Yu 1992, Jendek 1994, Haack et al. 2002). How EAB arrived to North America is not known, but infested wood packaging materials, crating, dunnage, or pallets from Asia are suspected (Haack et al. 2002). Due to the range and extent of damage already done when EAB was identified, it's likely to have arrived to North America in the early 1990's (McCullough and Katovich, 2004, Cappaert et al. 2005, USDA Forest Service 2010). Since its introduction to North America, EAB is estimated to have killed over 53 million ash trees in Michigan, Ohio, and Indiana by 2007 (Smith et al. 2009, Kovacs et al. 2010). As of January 2014, EAB has been detected in 22 states (Colorado, Connecticut, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and Wisconsin) and two Canadian provinces (Ontario and Quebec) (Figure 2) (USDA–APHIS Jan, 2014).

1 USDA-APHIS (2011) states there are nearly 3,000 described species of *Agrilus* worldwide, and 171 known species in North America.

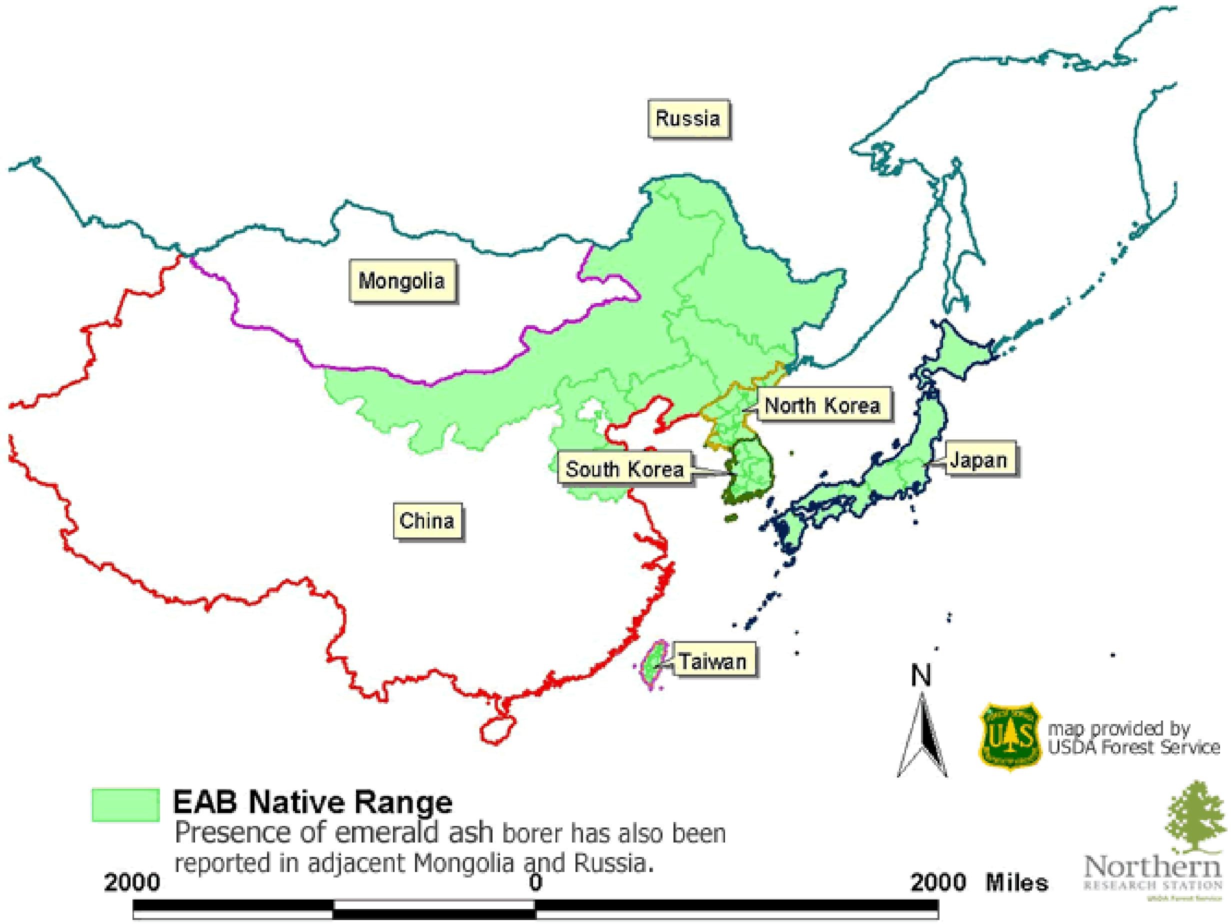

Figure 1. Native range of emerald ash borer in Asia. (Adapted image courtesy of USDA Forest Service).

Prior to 2002, little was known about EAB beyond taxonomic descriptions and a few short articles published in Chinese reference books (e.g. Chinese Academy of Science 1986, Yu 1992, Jendrek 1994). *Agrilus planipennis* has several synonyms, including *A. marcopoli* Obenberger, *A. marcopoli ulmi* Kurosawa, and *A. feretrius* Obenberger, which were synonymized under *A. planipennis* by Jendek in 1994. In parts of its native range, reports suggest *A. planipennis* is a rare insect, typically attacking only stressed ash trees at the edge of forests, and even though it can reportedly destroy forest stands when infestations are severe in its native range, it is not considered a major pest (Yu 1992, Schaefer 2004, Bauer et al. 2005, Gould et al. 2005, Rodriguez-Saona et al. 2007). This implies that ash species in EAB's native range have some natural resistance or biological control agents (predators, parasites and pathogens) which keep EAB in check. Prior to the emerald ash borer's discovery, ash trees in

North America had relatively few serious pest issues; the cause of the ash decline in Michigan was originally thought to be a combination of environmental stressors and ash yellows[2] (Haack et al. 2002).

Hosts

In its native range, EAB's hosts are species of *Fraxinus*, including Chinese ash (*F. chinensis* Roxburgh), Manchurian ash (*F. mandshurica* Ruprecht), and *F. rhynchophylla* Hance, as well as the introduced Nearctic species green ash (*F. pennsylvanica*), velvet ash (*F. velutina* Torrey), and white ash (*F. americana* L.) (Chinese Academy of Science 1986, Yu 1992, Haack et al. 2002, Liu et al. 2003). According to Chang et al. (1996), there are 22 species of ash in China. Zhao et al. (2005) maintains that despite these earlier reports of EAB infesting *F. chinensis* and *F. rhynchophylla*, EAB was rarely found infesting these native species. Zhao et al. (2005) also reported *Fraxinus* section *Meliodes* (which includes nearctic species such as *F. pennsylvanica* and *F. velutina*) to be infested more heavily than species in section *Fraxinus*, such as Asian native *F. mandshurica*. Some reports indicate emerald ash borer has hosts in addition to *Fraxinus* in its native range, including species of *Juglans* (Walnut, Juglandaceae), *Pterocarya* (Wingnut, Juglandaceae), and *Ulmus* (Elm, Ulmaceae) (Anulewicz et al. 2008). There has been no evidence of EAB successfully utilizing hosts other than *Fraxinus* spp. in North America (Haack et al. 2004, McCullough et al. 2004, Anulewicz et al. 2008).

Endemic EAB congeners in North America, such as the bronze birch borer (*A. anxius* Gory), and the two-lined chestnut borer (*A. bilineatus* (Weber)) typically only colonize stressed trees (Anderson 1944, Dunn et al. 1990). This is similar to EAB's behavior in its native range (Rebek et al. 2008).

2 Ash yellows is a North American disease caused by microbes (mycoplasma-like organisms) which generally slows ash growth and causes decline and dieback (Pokorny and Sinclair 1994).

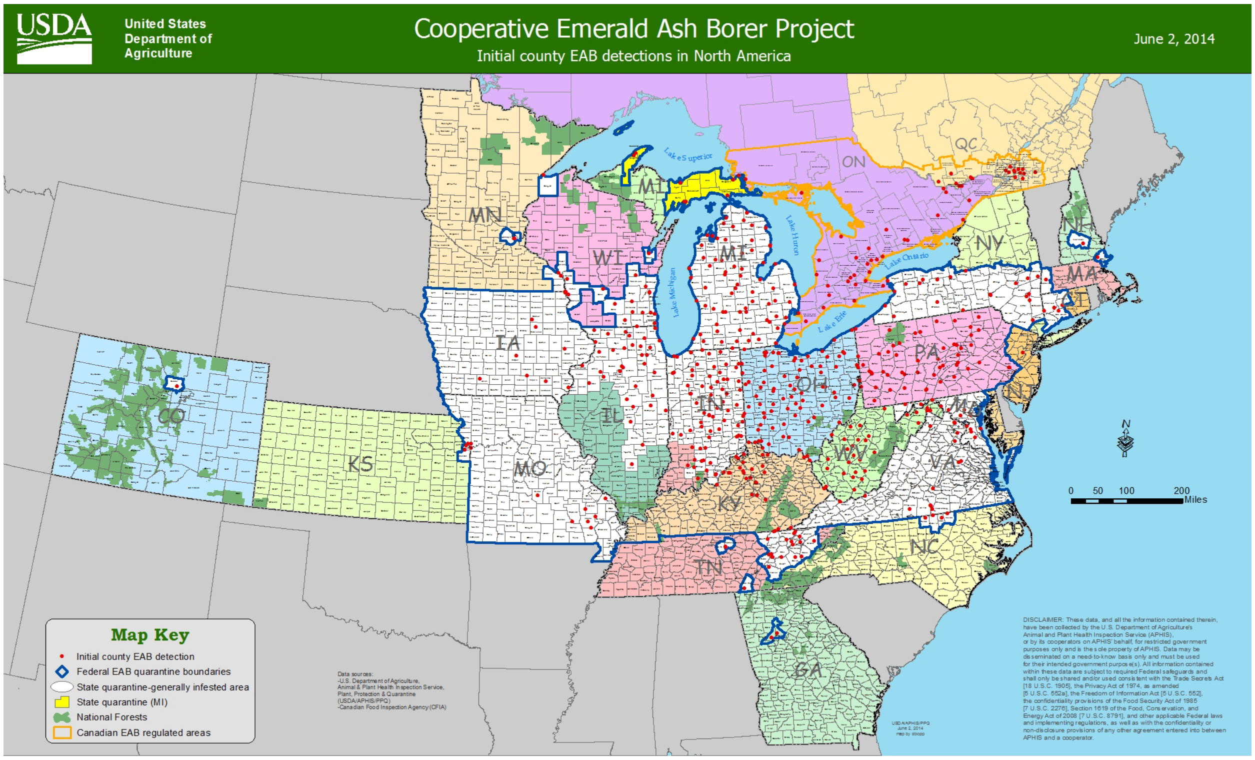

Figure 2. Initial county EAB detection map. June 2, 2014 (USDA–APHIS).

In eastern North America to date, EAB has successfully colonized all ash species it has encountered, including green ash (*F. pennsylvanica*), white ash (*F. americana*), black ash (*F. nigra*), blue ash (*F. quadrangulata* Michaux), pumpkin ash (*F. profunda* (Bush) Bush) and a number of hybrids (McCullough et al. 2004, Agius et al. 2005, Cappaert et al. 2005, Anulewicz et al. 2006, 2008, 2009, Poland and McCullough 2006, Rebek et al. 2008). In North America, there are at least 16 endemic species of ash, and all are likely to be susceptible to EAB (Poland and McCullough 2006). As of 2009, there were at least nine remaining native ash species and several European species occurring in the U.S. whose susceptibility to EAB was still unknown (Anulewicz et al. 2009). Emerald ash borer has been shown to have a clear preference for green ash, followed by white, black, and blue ash being least preferred (Anulewicz et al. 2007). In North America, EAB readily attacks and kills healthy ash, but has a preference for stressed trees (Haack et al. 2002, Agius et al. 2005, Cappaert et al. 2005, McCullough et al. 2006). Infestations can occur in nearly all sizes/ages of *Fraxinus*, ranging from trees >140 cm in diameter at breast height (d.b.h.) to 2.5 cm d.b.h. (McCullough et al. 2007, Kovacs et al. 2010, Knodel et al. 2013). In addition to *Fraxinus*, EAB has been observed to partially develop up to the second instar within Privet (*Ligustrum* sp., Oleaceae) (McCullough et al. 2004, Anulewicz et al. 2006).

In North Dakota, the two naturally-occurring species of *Fraxinus*, *F. nigra*, and *F. pennsylvanica* are of high economic, ecological, and aesthetic value (Great Plains Floral Association 1986). Manchurian ash (*F. mandshurica*) and white ash (*F. americana*) are occasionally planted as urban trees in North Dakota (Knodel et al. 2013). Manchurian ash, a native to northeastern Asia, and its hybrids such as northern treasure ash (*F.* x 'Northern Treasure'), have been shown to have some resistance to emerald ash borer, likely due to a coevolutionary history, but they are still vulnerable when EAB populations are high (Eyles et al. 2007, Rebek et al. 2008). The mountain-ash (*Sorbus* spp., Rosaceae) and the common prickly-ash (*Zanthoxylum americanum* Mill., Rutaceae) despite having "ash" in their common names, are not a true ash species and are not colonized by EAB.

Biology

Emerald ash borer, in common with all holometabolous insects, has four stages in its life cycle: egg, larva, pupa, and an adult stage. In North America, EAB's life cycle typically takes one-to-two years to complete, depending on a number of factors such as seasonal length and EAB's population density in relation to the species and health of ash (USDA–APHIS/ARS/FS 2012, Knodel et al. 2013). According to Cappaert et al. (2005), populations at low density on vigorous, healthy ash trees tend to have a two year life cycle, while populations of higher larval densities on stressed trees tend to have a one year life cycle; why this occurs is not yet clear (Cappaert et al. 2005).

Eggs are oblate, creamy white to amber in color, one millimeter long and 0.6-1.0 mm wide (USDA–APHIS 2011). They are often laid individually directly into crevices and cracks in the bark, and hatch within 7-10 days (Chinese Academy of Science 1986, Yu 1992, USDA–APHIS 2011). Egg placement tends to be correlated with direct sunlight (Chinese Academy of

Science 1986, USDA–APHIS 2011). Eggs hatch during the growing season, ranging from May to September (Cappaert et al. 2005).

Larvae are whitish in color, dorsoventrally flattened, with bell-shaped segments that flair out posterolaterally, have enlarged prothoracic segments and a pair of sclerotized terminal abdominal processes (urogomphi) (Chamorro et al. 2012). Larvae have four larval instars, the fourth instar larvae is 30-36 mm long (Chamorro et al. 2012). Larvae chew through the outer layers of the tree trunk down to the cambium, where they feed and develop from mid-June to mid-October, creating long, serpentine, frass-filled galleries that increase in size as the larvae feed and grow (Bauer et al. 2004, Cappaert et al. 2005). Galleries have been found in trunks and branches measuring as little as 2.5 cm in diameter (Kovacs et al. 2010). During the late summer and fall, fourth instar larvae will tunnel to the outer bark and outer layers of sapwood and create a pupation chamber where they overwinter in a 'J' position, with the head folded back onto the body (Bauer et al. 2004, USDA–APHIS 2011, USDA–APHIS/ARS/FS 2012). EAB is most destructive in the larval stage. In large densities, larval feeding will interrupt the tree's water and nutrient flow, causing death over a two-to-five year period depending on factors such as the tree's size, relative health, and the magnitude of the infestation (BenDora et al. 2006, USDA–APHIS 2011, Knodel et al. 2013).

Pupae are 13–17 mm in length, whitish in color, adecticous and exarate (Chamorro et al. 2012). Pupation begins when warmer weather arrives in the spring, usually in mid-April to mid-May, and adults emerge in about three weeks (Haack et al. 2002, USDA–APHIS 2011). Larvae that are too immature to pupate by autumn will overwinter *in situ* in the larval gallery, resume feeding in the spring, and complete development later in the summer (USDA–APHIS 2011, USDA–APHIS/ARS/FS 2012, Knodel et al. 2013).

Adults are 8.5 to 13.5 mm in length with an elongate, cuneiform body shape. Overall coloration is metallic emerald green; the pronotum has a brassy reflectance and the dorsal abdominal tergites (normally hidden by the elytra) are iridescent purple-red (USDA–APHIS 2011). Adults which are newly emerged from their pupal casing remain under the bark for approximately one-to-two weeks in North America until the accumulation of 400–500 growing degree days using a base of 10 C. Peak emergence of EAB is typically in early July and ranges from mid- to late May or early June. Adult emergence from the tree creates a characteristic D-shaped exit hole, which are about three to four mm in diameter (Haack et al. 2002, Cappaert et al. 2005, USDA–APHIS 2011, USDA–APHIS/ARS/FS 2012). Adults live from three to six weeks and are foliage feeders for one or two weeks prior to mating. Foliage feeding is regarded as a minor component of EAB damage (USDA–APHIS 2011). Adults are slow moving insects, traveling a total of only about two-to-three km from where they emerge, depending on availability of *Fraxinus* (Taylor et al. 2010). A mated female can lay between 60–90 eggs in her lifetime (USDA–APHIS 2011).

Transportation of infested ash materials (e.g. firewood, wood packaging, live nursery stock, untreated lumber) is likely the primary method EAB has been spreading in North America, making containment difficult (Haack et al. 2002, Anonymous 2005).

Symptoms of Emerald Ash Borer Attack

Dieback/thinning of the crown and epicormic sprouting[3] along the trunk are some of the visible symptoms of damage (Cappaert et al. 2005). But, these symptoms might not show up for up to three years (Haack et al. 2002, Knodel et al. 2013). Because of this lag-time between adult infestation and the appearance of symptoms, EAB populations can become established and spread beyond the main population before they're discovered. Methods of early detection are therefore very important. Woodpecker damage, including bark scaling (removal of bark flakes) and feeding holes through the bark, is perhaps the best early indicator of an EAB infestation, and is especially useful in winter, when the foliage does not interfere with viewing the trunk (USDA–APHIS/ARS/FS 2012). When EAB population densities are high, smaller, younger ash trees may die within two years of becoming infested; whereas larger, older trees may succumb in three to five years (USDA–APHIS 2011). High EAB densities may also cause splits in the bark (USDA–APHIS/ARS/FS 2012).

3 Epicormic sprouting is a compensatory measure trees will take to make up for loss of leafy surface area; it typically occurs when the tree is undergoing stress. Epicormic sprouts tend to be green in color and emerge directly from the trunk.

Pest Management Efforts

If not effectively controlled, EAB is expected to spread across the entire range of ash (Figure 3), potentially wiping out *Fraxinus* in North America (Kovacs et al. 2010). Shortly after EAB's discovery, federal and state regulatory agencies began placing quarantines on counties with infestations, and continue to do so (Figure 2) (APHIS/ARS/FS 2012). Eradication efforts were attempted initially after EAB's discovery, but due to a number of factors, such as high costs, limited detection and control methods at the time, and the potential for further accidental dispersal of EAB, the program has shifted focus instead to containment and management (USDA–APHIS/ARS/FS 2012). Removal of dead ash and treatment of living ash are two predominate economic expenses caused by EAB (Herms and McCullough 2014). Kovacs et al. (2010) projected treating or removing roughly half the affected urban trees will cost $10.7 billion (twice that amount if adjacent suburbs are also included) by modeling the spread and economic impact of EAB from 2009—2019.

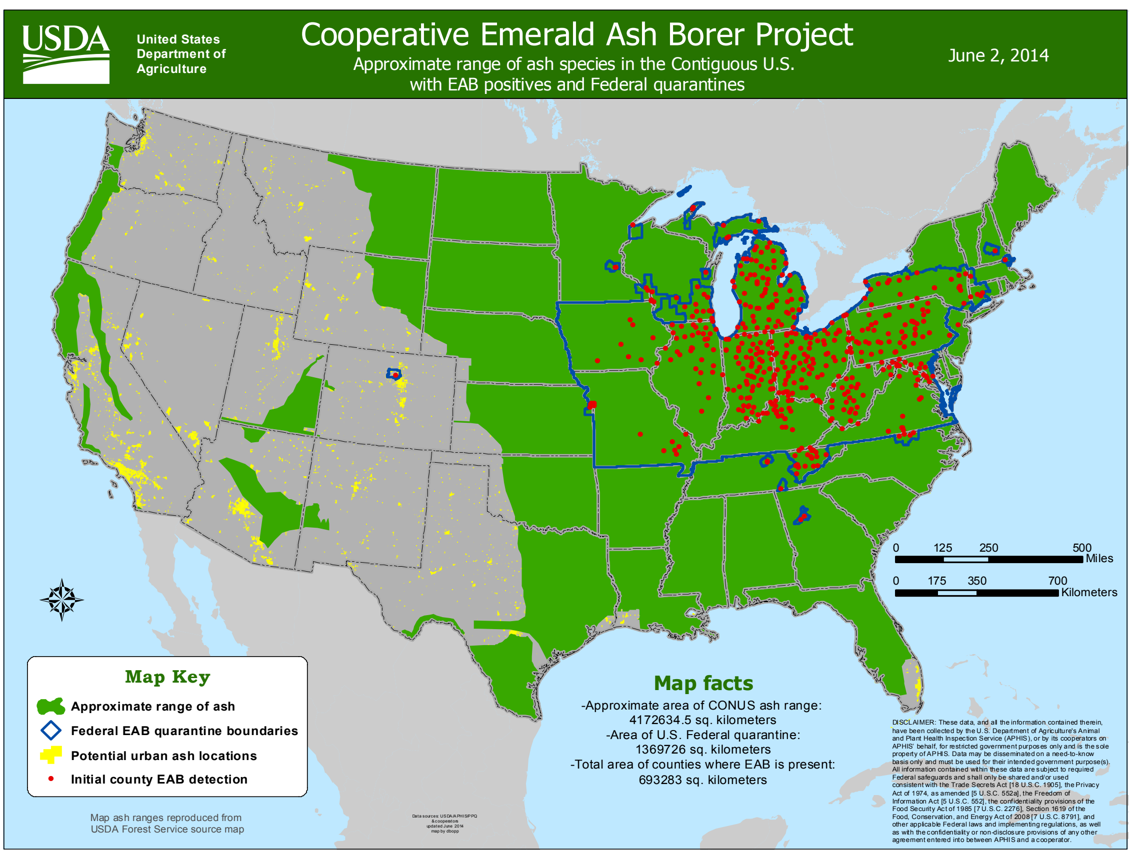

Figure 3. Approximate range of ash species in the contiguous U.S. with emerald ash borer positives and Federal quarantine. June 2, 2014 (USDA–APHIS).

Integrated pest management (IPM) is a multi-faceted approach to plant pest control and management, it is grounded in ecology and is environmentally conscious (Frisbie and Luna 1989). IPM combines many control strategies such as biological, chemical, and cultural controls, as well as host-plant resistance (Frisbie and Luna 1989). Biological control (biocontrol) is the use of natural enemies, such as predators, parasitoids, and pathogens as pest control agents, and can be an important component of IPM.

EAB biocontrol efforts were initiated by the U.S. Department of Agriculture's Animal and Plant Inspection Service (APHIS) and Forest Service (FS) shortly after EAB was detected in Michigan in 2002 (USDA Forest Service 2010). The search for natural enemies began in 2003, and several non-native Hymenoptera parasitoids from the EAB's native range have been found, three of which have been approved for release in the U.S.: a larval ectoparasitoid: *Spathius agrili* Yang (Braconidae), a larval endoparasitoid: *Tetrastichus planipennisi* Yang (Eulophidae), and an egg parasitoid: *Oobius agrili* Zhang and Huang (Encyrtidae) (USDA–APHIS/ARS/FS 2012). These parasitoids were initially released in Michigan in 2007, followed by Ohio and Indiana in 2008, and Maryland and Illinois in 2009 and 2010 (USDA APHIS 2007; Bauer et al. 2008, 2010, Duan et al. 2012). The parasitoids have apparently become established at several locations, with parasitism levels much lower (1.5%) than levels reported from China (12–73%) (Liu et al. 2003, 2007, Duan et al. 2010, 2012). In addition to these non-native species, two indigenous Hymenoptera parasitoids, *Atanycolus cappaerti* Marsh and Strazanac (Braconidae), and *Cerceris fumipennis* Say (Crabronidae) are being studied for their use in biocontrol (*A. cappaerti*) and biosurveillance (*C. fumipennis*) (USDA Forest Service et al. 2010, Knodel et al. 2013).

Pesticide/chemical research is ongoing, with studies focusing on cover sprays, systemic soil applications, bark-penetrating trunk sprays, and systemic trunk injections (Poland et al. 2010). Currently, treatments for large scale implementation are not cost effective, but depending on EAB population densities, there are treatments available for individual trees using pesticides, such as imidacloprid or emamectin benzoate (TREE-äge®) (Cappaert et al. 2005, USDA Forest Service et al. 2010, USDA–APHIS/ARS/FS 2012).

Fraxinus

North American Distribution of *Fraxinus pennsylvanica*

Ash (*Fraxinus* spp.) is an important hardwood shade tree with a wide distribution in North America, occurring in many different ecosystems (Giedriaitis and Kielbaso 1982). It is one of the more widely distributed tree genera in urban areas of the U.S., with more than 8.8 billion ash trees in the U.S. (Ottman and Kielbaso 1976, Michler and Ginzel 2010). Green ash (*F. pennsylvanica*) has a native range which extends from Nova Scotia to southeastern Alberta, south to eastern Texas to northern Florida and the Atlantic coast (Figure 4) (Burns and Honkala 1990, U.S. Geological Survey 1999).

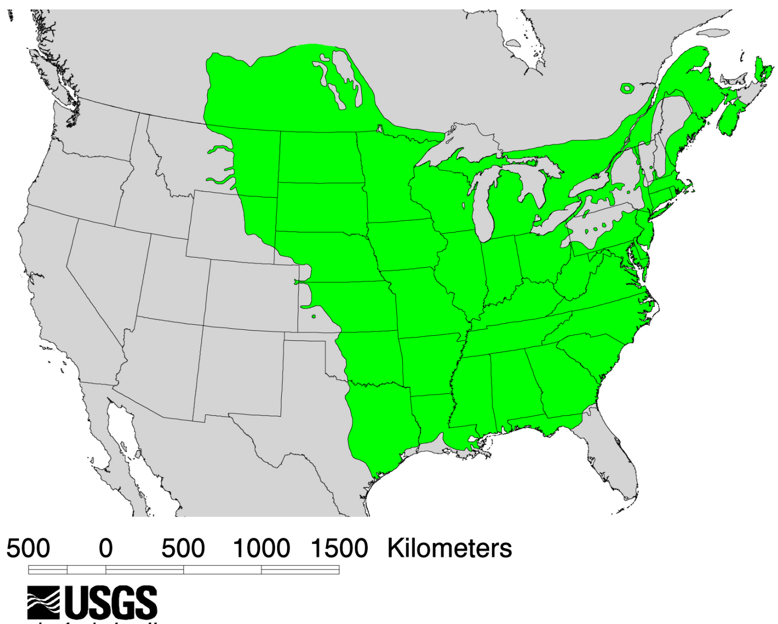

Figure 4. Distribution of *Fraxinus pennsylvanica* in North America. (Adapted image courtesy of the U.S. Geological Survey).

Fraxinus in North Dakota

Green ash is an important hardwood and riparian woodland tree in North Dakota (Burns and Honkala 1990). It is the second most abundant tree species (in terms of the number of individual trees) in North Dakota (quaking aspen, *Populus tremuloides* Michx., Salicaceae, is the most abundant), with more than 78 million trees, accounting for up to 60% of the trees in some urban communities (Haugen et al. 2009, Haugen and Harsel 2011). Nearly all of North Dakota's ash trees are green ash (96%), with black ash (*F. nigra* Marshall) filling out the remaining four percent in the state (Haugen et al. 2009). Black ash has a limited distribution in North Dakota, and is only found in the northeast corner of the state (Figure 5). Green ash is also ranked third in the state in biomass total volume, preceeded by bur oak, *Quercus macrocarpa* Michx. (Fagaceae), and cottonwood, *Populus deltoides* W. Bartram ex Humphry Marshall (Salicaceae) (Haugen et al. 2009). Green and black ash combined equal 18% of the total volume on forest land (more than 3.7 million cubic m) (Haugen et al. 2009, Haugen and Harsel 2011). In North Dakota, ash is very common, and comprises a large part of the woodland forests (North Dakota Forest Service 2012). Ash is often found in riparian areas and is widely planted in North Dakota communities and shelterbelts (Haugen et al. 2009).

Because green ash is so prevalent in North Dakota, widespread ash mortality caused by EAB may alter the composition and structure of North Dakota's woodlands, riparian zones, community forests, and urban areas (Haugen et al. 2009).

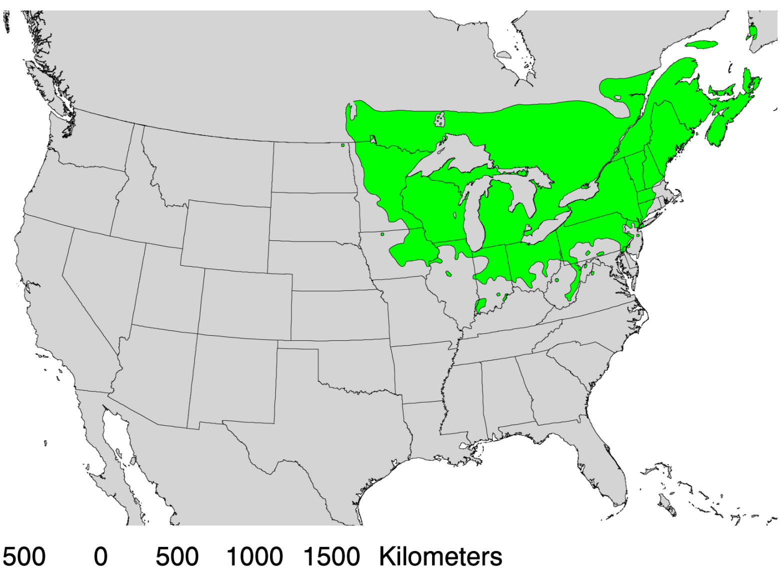

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Figure 5. Distribution of *Fraxinus nigra* in North America. (Adapted image courtesy of the U.S. Geological Survey).

Importance of *Fraxinus*

Green ash benefits North America in many ways. Baseball bats may be the best-known ash product, but ash wood is used for many things, such as general use lumber, cabinets, wall paneling, furniture, flooring, paper, and firewood (Burns and Honkala 1990). In the eastern U. S., ash accounts for approximately 7% of all saw timber, with ash timber (stumpage) grown in the eastern U.S. valued at an estimated $25.1 billion (Federal Register 2003).

In North Dakota, ash is widely planted as windbreaks/shelterbelts (comprising over 88 km), protecting livestock, fields, and farmsteads from desiccating winds in the summer, while slowing/stopping blowing snow in the winter (North Dakota Forest Service 2012, Knodel et al. 2013). Because of their pleasing shape and adaptability to a wide range of environments, green ash is a very popular shade tree, increasing real estate values and lowering heating and cooling costs by providing shelter and shade for numerous homes and businesses (Burns and Honkala 1990, Peper et al. 2004). Reducing impacts on air quality by sequestration and reduction of carbon dioxide and other greenhouse gases is also an important service provided by green ash (Peper et al. 2004). In some of North Dakota's woodlands, ash comprises up to 90% of the total canopy cover (North Dakota Forest Service 2012). The compensatory value of ash in North Dakota is estimated to be $3.55 billion (North Dakota Forest Service 2012). According to a Bismarck report by Peper et al. (2004), the most substantial benefit provided by municipal trees are their ability to reduce storm water runoff, and since green ash is such a heavily planted urban tree, it plays a large role in this service. Urban stormwater runoff is a substantial pathway for pollutants and contaminants to enter surface waterways, threatening fish and wildlife (Peper et al. 2004). Urban trees mitigate stormwater runoff by temporarily storing rainfall on the surfaces of their branches and leaves, helping reduce peak flow times (flood control); roots create space in the soil for overflow; and the tree canopies themselves intercept rainfall, which reduces soil erosion effects (Peper et al. 2004).

Ash may also provide benefits which are much harder to quantify, such as beauty to landscapes, sentimental value attributed by homeowners, or even human health benefits.

Donovan et al. (2013) shows a correlation between the loss of ash trees and higher human mortality rates related to cardiovascular and lower-respiratory diseases, suggesting the natural environment and human heath may be linked. Their results do not demonstrate how or why this correlation exists, however, plausible mechanisms might include: improved air quality, reduced stress, increased physical activity, moderated temperature, and buffered stressful life events (Donovan et al. 2013).

Potential Ecological Effects

Green ash plays an important foundational role in North Dakota's ecosystem, serving as a level one primary producer in the food web. Much of North Dakota's wildlife value ash as shelter and a food source, including waterfowl, song birds, small mammals, and deer (Herman and Chaput 2003). A number of insect species also depend on ash for food and shelter (Appendix A). According to combined North American host indices (Ives and Wong 1988, Johnson and Lyon 1991, Zeleznik et al. 2005, Gandhi and Herms 2010), 140 Lepidoptera, 74 Coleoptera, and 46 Hemiptera species depend on ash on some level. As noted in the literature, these numbers are likely underestimates, particularly for polyphagous species. As ash trees are killed by EAB, many of these animals may be at risk of coextinction as their food and shelter are eliminated. For example, two specialist insects, the American chestnut moth (*Ectoedemia castaneae* Busck, Nepticulidae, Lepidoptera) and the phleophagan chestnut moth (*Ectoedemia phleophaga* Busck, Nepticulidae, Lepidoptera) were driven to extinction when their host, American chestnut, was nearly killed off by chestnut blight, an Asian fungus (Opler 1978, IUCN 2009a, b, Gandhi and Herms 2010, Colwell et al. 2012).

Impacts on species threatened by mass *Fraxinus* mortality, and the subsequent ecological cascading effects may be difficult to predict. In forest environments heavily populated with ash, dramatic increases of ash death can alter many things, such as the amount of sunlight reaching the forest floor, or the soil's pH, moisture, and mineral levels, all of which directly affects living trees and understory flora and ecology (Rice and Klooster 2010). According to Rice et al. (2009), canopy gaps created by dying ash trees can have indirect effects on insects, such as the giant swallowtail (*Papilio cresphontes* Cramer; Papilionidae) - which feed exclusively on species of *Citrus* - by affecting the soil in which their host plant grows (Graves and Shapiro 2003).

Coleoptera Thought to be Ash-Obligates in North America

According to Gandhi and Herms (2010), 44 native arthropod species are thought to have an exclusive relationship with ash[4]. These arthropods depend primarily on ash for feeding (phytophages, general sap feeders, and xylem/phloem specialist feeders), and/or for reproduction (i.e. gall-producing). Of those 44, nine species of North American Coleoptera are listed as having an exclusive relationship with species of *Fraxinus* and are therefore at a high risk of mortality if *Fraxinus* is driven to extinction by EAB:

Apion porosicolle Gemm. (Brentidae) has been reported as emerging from *Fraxinus latifolia* (Oregon ash) seeds (Keen 1958). *Fraxinus latifolia* does not occur naturally in North Dakota (U.S. Geological Survey 1999). Adults are presumed to feed on *F. latifolia* stems and leaves (Keen 1958). According to Moore (1937), *A. porosicolle* have also been found on *Lotus* (Fabaceae), *Baccharis* (Asteraceae), *Rhus* (Anacardiaceae), and *Eriogonum* (Polygonaceae). Whether this beetle feeds on these additional plants is not mentioned, and little else is known about its host(s). *Apion porosicolle* is found in the western United States north to Washington, and is not recorded in North Dakota (Bright 1993).

Hylesinus aculeatus (Say) (Scolytidae) (eastern ash bark beetle) feed and develop within the cambium of *F. americana* (white ash), *F. pennsylvanica*, and presumably other *Fraxinus* species (Wood 1982, Solomon 1995, Cranshaw 2004). Its range is from the eastern U.S. west to the Rocky Mountains, and from eastern Canada to Manitoba (though *F.* range reaches further west to Alberta) (Craighead 1949, Keen 1952, Furniss and Carolin 1977, Ives and Wong 1988, Solomon et al. 1993, Hiratsuka et al. 1995, U.S. Geological Survey 1999).

4 Gandhi and Herms (2010) has some 'arthropods at risk' species listed twice, including *Olceclostera angelica* (Grote), *Prionoxystus robiniae* (Peck) (listed under both Coleoptera and Lepidoptera), *Lignyodes bischoffi* (Blatchley), and *L. helvolus* (LeConte), which were listed as both their current and old names (*Thysanocnemis biscoffi* Blatchley and *Thysanocnemis helvola* LeConte, respectively). *Thysanocnemis* is a junior subjective synonym of *Lignyodes*, and *Thysanocnemis helvola* has been synonymized to *Lignyodes helvolus* (Clark 1980).

Hylesinus criddlei (Swaine) (Scolytidae) (northern ash bark beetle/Criddle's bark beetle) feeds and develops within the cambium of *F. americana*, and *F. pennsylvanica*. *Hylesinus criddlei* is generally distributed east of the Great Plains, and has been reported specifically from Minnesota, North Dakota, Wyoming, Colorado, Manitoba, and Quebec (Furniss and Carolin 1977, Wood 1982, Ives and Wong 1988, Solomon et al. 1993, Hiratsuka et al. 1995, Solomon 1995, Cranshaw 2004).

Hylesinus fasciatus (LeConte) (Scolytidae) (white-banded ash bark beetle) feeds and develops within the cambium of *F. americana*, which is not naturally found in North Dakota. *Hylesinus fasciatus* has a distribution from Pennsylvania and New Jersey to Missouri, and North Dakota (Craighead 1949, Wood 1982, Solomon et al. 1993, U.S. Geological Survey 1999), and ND specimens have been examined in the North Dakota State Insect Reference collection (NDSIRC).

Hylesinus oregonus (Blackman) (Scolytidae) (Oregon ash bark beetle) feeds and develops within the cambium of *F. latifolia*, which is not naturally found in North Dakota. *Hylesinus oregonus's* range is from Washington to California (Furniss and Carolin 1977, Wood 1982, U.S. Geological Survey 1999).

Hylesinus pruinosus Eichhoff (Scolytidae) feeds and develops within *Fraxinus*, and has a range including North Dakota, Ontario, Vermont to Tennessee and Virginia (Wood 1982).

Lignyodes bischoffi Blatchley (Curculionidae) (ash seed weevil) has been observed developing within seeds of *F. americana*, *F. nigra*, and *F. pennsylvanica* (Knull 1932, Ives and Wong 1988, Wanat and Mocarski 2008). According to Solomon et al. (1993), *L. bischoffi* feeds on seeds of *Syringa* (Oleaceae).

Lignyodes fraxini LeConte (Curculionidae) (ash seed weevil) develops within the seeds of *F. americana* (Clark 1980). Neither *L. fraxini* nor *F. americana* are naturally found in North Dakota (Clark 1980, U.S. Geological Survey 1999).

Lignyodes helvolus LeConte (Curculionidae) (ash seed weevil) probably develop within the seeds of *Fraxinus*, but this has not been confirmed (Ives and Wong 1988). According to Solomon et al. (1993), *L. helvolus* feeds on seeds of *Syringa* (Oleaceae).

Agrilus subcinctus Gory (native ash borer) is not listed as an ash obligate by Gandhi and Herms (2010), but it is the only other *Agrilus* species in the Midwest (besides *A. planipennis*) known to occur on *Fraxinus* spp. (Gandhi and Herms 2010, USDA-APHIS 2011). *Agrilus subcinctus* has also been recorded from Privet (*Ligustrum* spp.) (Bright 1987).

Hemiptera (Heteroptera) Thought to be Ash-Obligates in North America

There are 46 species (Appendix A) of Hemiptera thought to have a relationship with ash, of those, six are thought to have an exclusive relationship with ash (Gandhi and Herms 2010). All six species belong in the family Miridae, in the genus *Tropidosteptes* (ash plant bugs):

Tropidosteptes amoenus (Reuter) feeds on *F. pennsylvanica*, but is also listed as simply feeding on *Fraxinus*; whether *T. amoenus* feeds strictly on *F. pennsylvania* or other species of ash is not clear (Craighead 1949, Ives and Wong 1988, Johnson and Lyon 1991, Solomon et al. 1993, Hiratsuka et al. 1995, Cranshaw 2004). *Tropidosteptes amoenus* has a wide distribution in North America, which includes North Dakota (Henry and Froeschner 1988).

Tropidosteptes brooksi Kelton feeds on *F. pennsylvanica*, and is often listed as simply feeding on *Fraxinus* (Kelton 1980, Johnson and Lyon 1991, Cranshaw 2004). Accoring to Henry and Froeschner (1988), this species is found in Saskatchewan eastward to Quebec; it is not listed from North Dakota.

Tropidosteptes cardinalis Uhler is listed as feeding on the foliage of *Fraxinus* spp., and *F. americana* (Froeschner 1949, Solomon et al. 1993, Chordas et al. 2011). According to Henry and Froeschner (1988), this species is found in Manitoba eastward to Quebec, Minnesota south to Illinois, east to Massachusetts, as well as South Dakota, Texas, and Mississippi; it is not listed from North Dakota.

Tropidosteptes illitus (Van Duzee) feeds on *F. velutina* (velvet ash), which is not naturally found in North Dakota (Usinger 1945, Furniss and Carolin 1977, Solomon et al. 1993, U.S. Geological Survey 1999). Henry and Froeschner (1988) report this species from California only; it is not listed from North Dakota.

Tropidosteptes pacificus (Van Duzee) feeds on *F. latifolia*, and *F. velutina*, which are not naturally found in North Dakota (Usinger 1945, Furniss and Carolin 1977, Johnson and Lyon 1991, Solomon et al. 1993, U.S. Geological Survey 1999, Cranshaw 2004). According to Henry and Froeschner (1988), this species is found in Arizona, California, Oregon, Pennsylvania, Utah, and Washington; it is not listed from North Dakota.

Tropidosteptes tricolor Van Duzee is listed as feeding on *Fraxinus* spp., and had been recorded from Illinois, Indiana, Massachussettes, Mississippi, Missouri, and New Jersey; North Dakota is not listed (Knight 1941, Henry and Froeschner 1988, Solomon et al. 1993).

Tropidosteptes plagifer Reuter, 1909 is not listed on any of the 'host indices' (Appendix A). But, Kelton (1980) lists *Tropidosteptes plagifer* as collected from *F. nigra*. Its range includes Manitoba and Minnesota (Henry and Froeschner 1988, Maw et al. 2000). According to Henry and Froeschner (1988), this species is found in Illinois, Manitoba, Minnesota, New York, Ontario, Quebec, and Wisconsin; it is not listed from North Dakota.

Lepidoptera Thought to be Ash-Obligates in North America

There are 140 species of Lepidoptera (Appendix A) that are associated with ash, of these, nine appear to be obligate ash insects (Gandhi and Herms 2010):

Copivaleria grotei Morrison (Noctuidae) (Grote's sallow) is a foliage feeder of *Fraxinus*, and of *F. americana* specifically. (Rings and Downer 2001, Covell 2005, Wagner 2007, Robinson et al. 2010). As of April, 2014, the Moths Photographers Group website listed *C. grotei* has been collected throughout the eastern US, including North Dakota.

Marmara basidendroca Fitzgerald (Gracillariidae) is recorded as a bast (phloem) miner of *F. pennsylvanica*. (Wagner 2007, Robinson et al. 2010). As of April, 2014, the Moths Photographers Group website lists *M. basidendroca* has only been collected from New York state.

Marmara corticola Fitzgerald (Gracillariidae) is recorded as a bast (phloem) miner of *F. americana* and *F. pennsylvanica*. (Fitzgerald 1973, Wagner 2007, Robinson et al. 2010). As of April, 2014, the Moths Photographers Group website lists *M. basidendroca* has only been collected from New York state.

Marmara fraxinicola Braun (Gracillariidae) (Serpentine Miner) is recorded as a bast (phloem) miner of *F. americana* and *F. pennsylvanica*. (Fitzgerald and Simeone 1971, Wagner 2007, Robinson et al. 2010). As of April, 2014, the Moths Photographers Group website lists *M. fraxinicola* has been collected from Minnesota, New York, and Ohio.

Palpita magniferalis (Walker) (Crambidae) is recorded as feeding on *F. americana*, *F. nigra*, and *F. pennsylvanica* (Rings and Downer 2001, Covell 2005, Robinson et al. 2010). As of April, 2014, the Moths Photographers Group website lists *P. magniferalis* has been collected primarily in the eastern United States, from North Dakota south to eastern Texas and eastward to the eastern Atlantic seaboard.

Philtraea latifoliae Buckett (Geometridae) is recorded as feeding on *F. latifolia*, which is not naturally found in North Dakota (Wagner 2007, Robinson et al. 2010). As of April, 2014, the Moths Photographers Group website lists *P. latifoliae* has been collected only from California.

Philtraea surcaliforniae Buckett (Geometridae) is recorded as a foliage feeder on *Fraxinus* spp., but is also noted to be in need of further study (Wagner 2007). As of April, 2014, the Moths Photographers Group website lists *P. latifoliae* has been collected only from California.

Plagodis kuetzingi (Grote) (Geometridae) (purple plagodis moth) is recorded as a foliage feeder of *F. americana*, and *F. quadrangulata* (Rings and Downer 2001, Covell 2005, Wagner 2007). As of April, 2014, the Moths Photographers Group website lists *P. kuetzingi* has been collected in Iowa, southeast to South Carolina, northeast to Maine and Nova Scotia and west to Michigan, including southern Quebec and Ontario, it is not listed from North Dakota.

Zelleria hepariella Stainton (Yponomeutidae) (ermine moths) is an exotic species, recorded as feeding on *F. excelsior* (European ash), which is not naturally found in North Dakota, and on other *Fraxinus* spp. (Wagner 2007, Robinson et al. 2010, Kartesz 2011). The North American range of *Z. hepariella* is either unknown, or not readily available.

MATERIALS AND METHODS

Collection Methods

Surveying was conducted at ten sites in eastern North Dakota. Most surveying was conducted from the end of May through the end of September in 2010 and 2011 (approximately four-month sample periods). Three surveying methods were employed: Lindgren funnel traps, windowpane flight intercept traps, and beating sheet collecting. A total of ten Lindgren funnel traps and ten windowpane flight intercept traps were deployed by the survey's completion. During the 2010 season, only windowpane flight intercept traps were used, except for EK-CP and EK-WL (Figure 8), which also had one Lindgren trap in addition to the windowpane flight intercept traps. During the 2011 season, sites had one Lindgren funnel trap and one flight intercept trap hung from either the same ash tree or from two ash trees in close proximity. No attractants were used in this survey. Trap samples were collected approximately every two weeks throughout the season. Ash trees used for trapping, as well as surrounding ash, were visually inspected for symptomatic damage associated with EAB, such as D-shaped exit holes, extensive bark removal/scaling from woodpeckers, vertical splits in the bark, crown die-back, and excessive epicormic sprouting.

Beating Sheet Collecting

A beating sheet[5] was used sporadically during the survey. An aspirator[6] was also used with the beating sheet to gather smaller arthropods. The beating sheet itself consisted of a sheet of white canvas material (marine boat cover) stretched across a wooden frame, forming a square approximately 1.3 m in dimension. The beating sheet was held under the tree canopy while the branches were shaken and vigorously beaten with a 1.5 m long wooden dowel in order to dislodge arthropods clinging to the branches, twigs, and leaves. Branches were beaten for approximately one-to-two minutes. Cardinal directions were not taken into account. Arthropods that fell onto the sheet were collected, smaller individuals by using the aspirator. Specimens

5 BioQuip® beating sheet, catalogue number 2840C. www.bioquip.com
6 BioQuip® aspirator, catalogue number 1135A. www.bioquip.com

were then placed into a cooler with ice and brought to the lab, specimens were then transferred to a storage freezer at -26C until they could be processed.

Lindgren Funnel Traps

Lindgren funnel traps[7] (referred to as 'Lindgren traps' or simply 'Lindgren' in this study; 'L' on specimen locality labels) (Figure 6) are a specialized flight intercept trap designed for bark beetles (Lindgren 1983). They consist of twelve black, vertically-oriented, loose-fitting, plastic funnels, 20 cm in diameter, 112 cm tall when extended, and a collection cup containing approximately 150 ml of propylene glycol attached to the bottom funnel. Many insects (particularly beetles), while flying, will drop to the ground after striking a solid object; these types of traps are intended to take advantage of this behavior. The dark, vertical shape of the Lindgren trap is meant to mimic a tree trunk, therefore acting as a passive visual attractant to insects that are drawn to tree trunks (such as bark beetles and other wood-boring insects). Specimens that collided with any of the funnels arranged in the vertical array were deflected downward into the collection cup at the bottom where the propylene glycol immobilized, killed, and temporarily preserved the specimens.

Figure 6. Lindgren funnel trap. (Photograph by James Walker).

7 BioQuip® Lindgren funnel trap, catalogue number 2854. www.bioquip.com.

Windowpane Flight Intercept Traps

The windowpane flight intercept traps (referred to as 'flight intercept traps' or 'FITs' in this study and on specimen locality labels) (Figure 7) are another type of flight intercept trap. The traps used in this survey were designed and constructed using 6 millimeter thick sheets of clear polycarbonate[8]. The main 'window' portion of the trap consisted of two polycarbonate sheets 40.6 x 40.6 cm in dimension. A rain guard constructed from the same polycarbonate was attached to the top (30.5 x 30.5 cm), and a funnel fabricated from four triangulate polycarbonate sheets attached to the bottom. Several sections of the trap were held together with nylon cable ties[9] so that the traps could be easily assembled in the field and broken down for transport. Clear packaging tape[10] adhered the lateral edges of the funnel, and clear silicon caulk[11] attached the base of the funnel to the collection cup's cover, which had a circular hole cut out of the top. These traps appeared nearly invisible when placed in the tree, since all major parts were constructed with transparent materials. Traps were approximately 66 cm tall when fully assembled. These were intended to function in the same manner as other flight intercept traps: insects inadvertently collide with the window portion when in flight and tumble down toward the funnel, which directs them to the collection cup at the bottom. The collection cup contained approximately 100 ml of propylene glycol and would immobilize, kill, and temporarily preserve specimens.

8 Model Number: 1PC3648A | Menards® SKU: 4334630 Variation: Clear Polycarbonate.

9 500 Piece Assorted Cable Tie Canister-White Model Number: 50098N | Menards® SKU: 3642689

10 Scotch® Packaging Tape Model Number: 3850-1 | Menards® SKU: 5658161

11 Loctite® Clear Silicone Sealant Model Number: 908570 | Menards® SKU: 2515250 Variation: Clear

Figure 7. Free-hanging window pane flight intercept trap (FIT). (Photograph courtesy of Dr. Gerald Fauske).

Samples (specimens and propylene glycol) from the FITs and Lindgren traps were strained through a fine mesh cone strainer[12] while at the trap site. Each strainer was then placed in its own Ziploc® bag[13] and transported to the lab and placed in a storage freezer at -26C until ready for processing. Adult insects were pinned and processed using traditional preservation techniques. Voucher specimens have been deposited in the North Dakota State Insect Reference Collection, NDSU, Department of Entomology, Fargo.

Trap heights were measured from the branch the trap was hung from to the ground directly under the trap. Tree trunk diameter was determined by measuring the circumference at approximately 1.3 m above the ground, and dividing this by π, which gives the diameter at breast height (d.b.h.). All measurements were recorded using the same 15.24 m long tape measure[14].

Sites were delimited into two categories, manicured and non-manicured, according to management of the site. Sites where the surrounding vegetation was mostly trimmed

12 Trimaco SuperTuff™ medium mesh cone strainers. Item number: 11101 | Menards® SKU: 6313746

13 Ziploc® Storage Bags Quart Model Number: 00330_70985 | Menards® SKU: 6480873

14 127 m Stanley® steel long tape, model #: 34-103.

grass, and/or pesticides/herbicides were used regularly in the area during the survey season were considered manicured. Sites left relatively untouched by anthropogenic impact were considered non-manicured.

Study Sites

This study was conducted in the Red River Valley in eastern North Dakota (Figure 8). Ten sites were surveyed regularly using passive trapping methods (Lindgren and FITs). These sites included: Brewer Lake (BR in Figure 8), TreFoil Park (TR in Figure 8), Chrisan subdivision (CH

Table 1. Trapping[1] performed at each site, organized by year.

Site[2]	**2010**	**2011**
BR	FIT, BS	FIT, L, BS
CA	BS	-
CH	FIT, BS	FIT, L, BS
CP	BS	-
EK-CP	FIT, L, BS	FIT, L, BS
EK-WL	FIT, L	FIT, L, BS
HO	BS	-
JA	-	FIT, L, BS
LA	FIT	FIT, L
LO	FIT	FIT, L, BS
TE-CW	FIT, BS	FIT, L, BS
TE-PE	FIT, BS	FIT, L, BS
TR	FIT	FIT, L

[1]BS: beating sheet, FIT: flight intercept trap, L: Lindgren trap.

[2]BR: Brewer Lake Cass County Park and Campgrounds, CA: Casselton reservoir/Tinta Tawa Park, CH: Chrisan subdivision, CP: Chahinkapa Park, EK-CP: Albert K. Ekre Grassland Preserve - cow pasture, EK-WL: Albert K. Ekre Grassland Preserve - woodland area, HO: Horse Trailhead, JA: Jay V. Wessels SWMA, LA: Lake Elsie, LO: Lower Wild Rice and Red River Cemetery, TE-CW: Tewaukon NWR - Cutler's Woods, TE-PE: Tewaukon NWR - Lake Tewaukon peninsula, TR: TreFoil Park.

in Figure 8), Lower Wild Rice and Red River Cemetery (LO in Figure 8), Lake Elsie (LA in Figure 8), Albert K. Ekre Grassland Preserve (EK in Figure 8), and Tewaukon National Wildlife Refuge (TE in Figure 8), and Jay V. Wessels State Wildlife Management Area (JA in Figure 8). All traps were hung from the branches of *F. pennsylvanica* except for the Jay V. Wessels State Wildlife Mangement Area site, which was the only site containing black ash, and JA wasn't added until July, 2011. Occasionally utilized active collection methods were employed at all sites. Three additional sites were also very briefly sampled only using the active collection methods, these included: Casselton Reservoir/Tinta Tawa Park (2010: May 26, June 16, July 15) (CA in Figure 8), Horse Trailhead (May 28, 2010) (HO in Figure 8), and Chahinkapa Park (July 21, 2010) (CP in Figure 8). These tertiary sites contained *F. pennsylvanica*, and were not sampled regularly. Table 1 shows trapping performed at each site, organized by year.

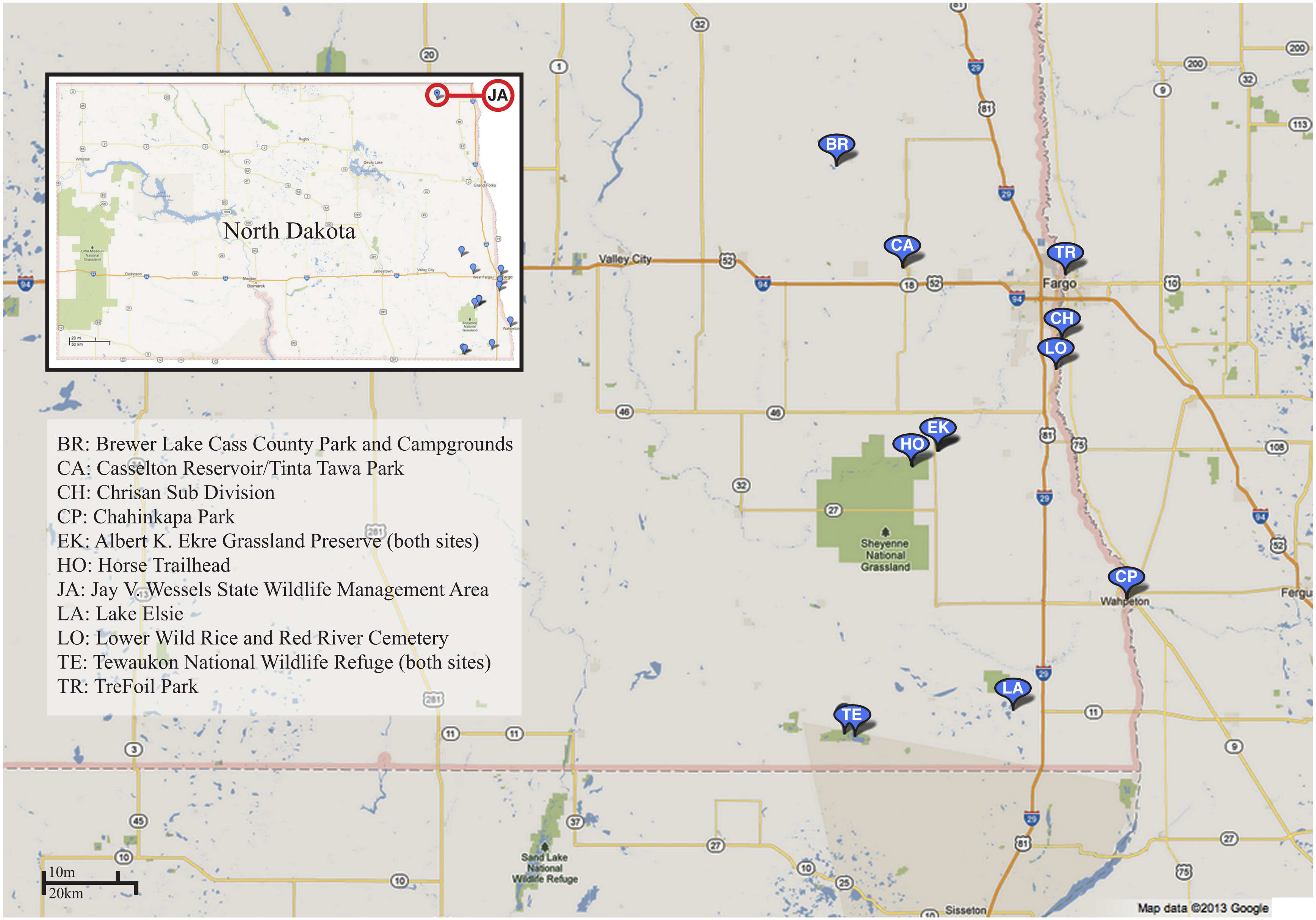

Figure 8. Study sites. (Adapted images courtesy of Google maps. Map data© 2013 Google).

Brewer Lake Cass County Park and Campgrounds

Brewer Lake Cass County Park and Campgrounds (Figure 9) is located near Erie, Cass County with GPS coordinates: N 47.099, W-97.415. Traps were hung in two separate *F. pennsylvanica* trees approximately six meters apart within the same shelter belt composed mostly of *F. pennsylvanica* and Caragana legumes, with a campsite on the southeast side just beyond a shelterbelt of conifers, and a wildlife management prairie area to the northwest. One Lindgren trap was added in late May, 2011. This site is categorized as non-manicured. In Table 2, the trap height and d.b.h are listed.

Figure 9. Brewer Lake Campground ash shelterbelt, Erie, Cass County, North Dakota. (Photograph by James Walker).

Albert K. Ekre Grassland Preserve

Albert K. Ekre Grassland Preserve (Happy Valley Ranch) (Figure 10) is located in Richland County. Lindgren and FIT were paired at two study sites, approximately 178 m apart. Site one (EK-CP, Figure 10) is a cow pasture ('park area [#1]' on locality labels) with GPS coordinates: N 46.552, W-97.132. This *F. pennsylvanica* was a lone tree in a frequently grazed cow pasture, with an alfalfa field approximately 60 m to the west. Traps were positioned on opposite sides of the same tree. Site two (EK-WL, Figure 10) is located to the northeast, and is a hydric, swampy woodland area ('forest area [#2]' on locality labels) with GPS coordinates: N 46.553, W-97.130. Traps were hung from two green ash trees in close proximity to one another. These trees were in a flooded, mixed woodland about fifteen meters adjacent to the cow pasture. Both sites are categorized as non-manicured. See Table 2 for trap height and d.b.h.

Figure 10. Albert K. Ekre Grassland Preserve (Happy Valley Ranch), Richland County, North Dakota. EK-CP: cow pasture. EK-WL: woodland. (Photographs courtesy of Dr. Gerald Fauske).

Tewaukon National Wildlife Refuge

Tewaukon National Wildlife Refuge (NWR) (Figure 11) is located in Cayuga, in Sargent County. There were two study sites, site one is in Cutler's Woods (TE-LP, Figure 11) ('forest area' on locality labels), two traps, and two trees (*F. pennsylvanica*) with GPS coordinates: N 46.005, W-97.394. These *F. pennsylvanica* trees were separated by about 20 m, and were both located in a wooded area composed mostly of *F. pennsylvanica*. Site two was located at the Lake Tewaukon peninsula (also known as 'the point') (TE-CW, Figure 11), just east of the NWR office and visitor center ('lake point' on locality labels) with GPS coordinates: N 46.002, W-97.364. These traps were positioned within a small cluster of *F. pennsylvanica*, located on the edge of a wooded area. Sites one and two are both categorized as non-manicured. In Table 2, the trap height and d.b.h. are listed.

Figure 11. Tewaukon NWR, Cayuga and Sargent Counties, North Dakota. TE-LP: Lake Tewaukon peninsula. TE-CW: Cutler's Woods. (Photographs by James Walker).

The Chrisan Subdivision

The Chrisan subdivision site (Figure 12) is located in Cass County, south Fargo with GPS coordinates: N 46.768, W-96.783. It is a mixed grass, hydric, reclaimed floodplain. FIT and Lindgren traps were hung from a green ash on the edge of the Red River. This site is categorized as non-manicured. In Table 2, trap height and d.b.h. are listed.

TreFoil Park

TreFoil Park (Figure 12) is a highly manicured public park located in Cass County, in Fargo with GPS coordinates: N 46.892, W-96.772. The Lindgren and FIT were put in green ash trees about 30 m apart. The Red River was approximately 93 m from both trees. This site is categorized as manicured. In Table 2, the trap height and d.b.h. are listed.

Figure 12. Fargo, Cass County, North Dakota. CH: Chrisan Subdivision. TR: TreFoil Park. (Photographs by James Walker).

Lake Elsie

Lake Elsie (Figure 13) is located in Richland County, approximately two km southwest of Hankinson, North Dakota with GPS coordinates: N 46.052, W-96.920. It's approximately 415 meters northeast of Lake Elsie ('Lake Elsie National Wildlife Refuge' on locality labels, however, this site is not actually within the refuge area). Two traps (Lindgren and FIT) were hung on one *F. pennsylvanica* on a small hill surrounded immediately by (disturbed area and remnant prairie vegetation) prairie with mixed woodland. This site is categorized as non-manicured. In Table 2, the trap height and d.b.h. are listed.

Lower Wild Rice and Red River Cemetery

Lower Wild Rice and Red River Cemetery (Figure 13) is located in Cass County, in Horace (*Lower Wild Rice Cemetery* on locality labels) with GPS coordinates: N 46.711, W-96.798. Two traps were placed in a small cluster of *F. pennsylvanica*, which were adjacent to a field and a cemetery. The trap trees at this site were grouped together in close proximity to one another. This site is categorized as manicured. In Table 2, the trap height and d.b.h. are listed.

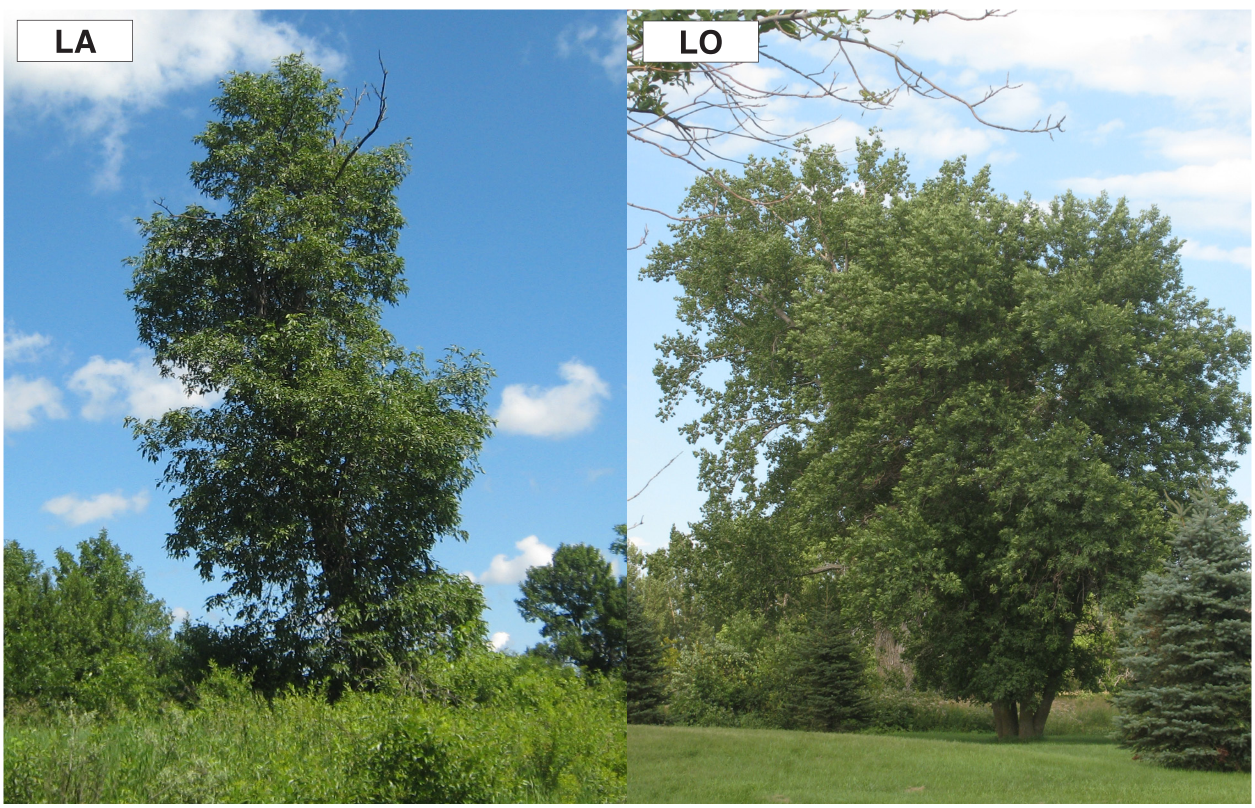

Figure 13. LA: Lake Elsie, Richland County, North Dakota. LO: Lower Wild Rice and Red River Cemetery, Horace, Cass County, North Dakota. (Photographs by James Walker).

Jay V. Wessels State Wildlife Management Area

Jay V. Wessels State Wildlife Management Area (SWMA) (Figure 14) is 11.3 km south, and 4.8 km east of Walhalla, in Pembina County with GPS coordinates: N 48.817, W-97.818. This site is a poorly drained riparian forest with swampy areas. Two traps (Lindgren and FIT) were hung from two *F. nigra* (black ash). This was the only *F. nigra* sampled. This site was added in July, 2011. Trees were six meters apart, both located about six meters from a swampy, flooded area to the north. This site is categorized as non-manicured. In Table 2, the trap height and d.b.h. are listed.

Figure 14. Jay V. Wessels SWMA, Pembina County, North Dakota. (Photograph by James Walker).

Additional Survey Sites

Results from three additional sites were also included in this study, and were surveyed using only a beating sheet and aspirator. Unlike the regularly-sampled sites, where the same small number of trees were repeatedly surveyed, a larger number of ash trees were irregularly sampled at each of these sites. GPS coordinates indicate the area, rather than a specific tree.

Casselton reservoir/Tinta Tawa Park is located in Casselton, Cass County (CA in Figure 8) with GPS coordinates: N 46.905, W-97.230. *Fraxinus pennsylvanica* adjacent to the reservoir were surveyed near highly manicured bike paths and softball fields on three occasions: May 26, June 16, and July 15 in 2010. This site is categorized as manicured.

Chahinkapa Park is located in Wahpeton, Richland County (CH in Figure 8) with GPS coordinates: N 46.272, W-96.601. This site is a highly manicured public park. *Fraxinus pennsylvanica* was surveyed using a beating sheet and aspirator on a single date (July 21, 2010). This site is categorized as manicured.

Horse Trailhead, is located in Sheyenne National Grassland, Ransom County (HO in Figure 8), approximately 80 km southwest of Fargo with GPS coordinates: N 46.522, W-97.200. Surveying was performed in northeastern area of the Sheyenne National Grassland, which consists primarily of Oak savanna with sandy dune-like areas. *Fraxinus pennsylvanica* was sampled using a beating sheet and aspirator on a single date (May 28, 2010). This site is categorized as non-manicured.

Table 2. Survey site trap heights[1] and tree diameters[2].

	Lindgren trap		**FIT**		**Both traps in one tree**
Sites[3]	**Height m**	**Tree d.b.h. m**	**Height m**	**Tree d.b.h. m**	**d.b.h. m**
BR	4.6	0.3	5.2	0.3	-
CH	4.4	-	4.2	-	0.7
EK-CP	3.6	-	3.4	-	0.3
EK-WL	2.8	0.3	4.6	0.3	-
JA	3.8	0.1	4.2	0.1	-
LA	3.7	-	3.7	-	0.6
LO	5.4	-	5.2	-	0.3
TE-CW	2.7	0.2	4.1	0.2	-
TE-PE	2.7	-	4.6	-	0.4
TR	5.2	0.6	5.3	0.6	-
mean	3.89	0.3	4.45	0.3	0.46
range	2.7	0.5	1.9	0.5	0.4
SD	0.99	0.19	0.65	0.19	0.18

[1] Measured from branch to ground.
[2] Tree diameter at breast height.
[3] BR: Brewer Lake Cass County Park and Campgrounds, CH: Chrisan subdivision, EK-CP: Albert K. Ekre Grassland Preserve - cow pasture, EK-WL: Albert K. Ekre Grassland Preserve - woodland area, JA: Jay V. Wessels SWMA, LA: Lake Elsie, LO: Lower Wild Rice and Red River Cemetery, TE-CW: Tewaukon NWR - Cutler's Woods, TE-PE: Tewaukon NWR - Lake Tewaukon peninsula, TR: TreFoil Park.

Insect Identification

All specimens were identified using morphology-based keys. Most Coleoptera, Hemiptera (Heteroptera), and Lepidoptera species identifications were checked for accuracy by Dr. David A. Rider and/or Dr. Gerald M. Fauske. Many were directly compared with specimens from The North Dakota State Insect Reference Collection (NDSIRC), which is housed in the Department of Entomology at North Dakota State University. Hemiptera (Heteroptera) specimens were determined using keys in: Slater and Baranowski 1978, Kelton 1980, Triplehorn and Johnson 2005, and Dr. David A. Rider (pers. comm.). Coleoptera specimens were determined using keys in: Blatchley and Leng 1916, Parsons 1943, Quate 1967, Aarhus 1970, Clark 1971, 1980, O'Brien and Wibmer 1982, Gordon 1985, Anderson 1989, Young and Stribling 1990, Goodrich and Skelley 1993, Anderson and Howden 1994, Kojima and Morimoto 1996, Arnett and Thomas 2000, Arnett et al. 2002, Fauske 2003, Triplehorn and Johnson 2005, Lingafelter 2007, Aguilera et al. 2008, and Dr. Gerald M. Fauske (pers. comm.). Lepidoptera specimens were determined using keys in: Triplehorn and Johnson 2005, Fauske 2009, Schmidt 2010, and Dr. Gerald M. Fauske (pers. comm.). Voucher specimens have been deposited in the NDSIRC, NDSU, Department of Entomology, Fargo.

Biodiversity Indices

This study's primarily goal was to create a baseline of species associated with ash trees in the Red River Valley. The secondary goal was to quantify the biodiversity at each site. The Simpson's index of diversity and the Shannon-Wiener diversity index were applied after the data was consolidated using Microsoft Excel® 2004 for Mac (version 11.6.6). The Shannon-Wiener diversity index calculates the average degree of uncertainty in predicting which species a randomly-picked specimen might be from a sampled community (Margalef 1958, Shannon 2001). The formula for this data was:

$$H' = -\sum(p_i)(\ln p_i)$$

Where H' is the Shannon-Wiener index, and p_i is the proportion of the total sample belonging to the 'i^th' species (Peet 1974, Magurran 1988, Skórka et al. 2007). This proportion (p_i) is calculated by dividing the number of individuals of a species by the total number of individuals in the community. The p_i is then multiplied by its natural log (ln), and the sum of those results are multiplied by (-1), and give the Shannon-Wiener index (H'). The larger H' is, the more diverse the community.

The Simpson's Index of Diversity is a measure of the probability that two individuals selected at random from a community will be different species. It is a scale ranging from 0 (no homogeneity or no diversity) to nearly 1 (high heterogeneity or a lot of diversity). Simpson's is a dominance Index, and in dominance indices, the most common species make the greatest contribution, and adding many rare species will not increase the index's value by much. The formula used for this data is:

$$D= 1-\sum(p_i)^2$$

Where D is the Simpson's index, "p_i" is the proportion of individuals of species 'i' in the community. A community dominated by one or two species is considered to be less diverse than one in which several different species have a similar abundance. As species richness and evenness increase, so diversity increases. Simpson's Diversity Index is a measure of diversity which takes into account both richness and evenness. The greater the index value, the greater the sample diversity.

RESULTS

Overall, this survey produced a total of 4,301 Coleoptera, Hemiptera (Heteroptera), and Lepidoptera specimens. A total of 276 unique taxa were identified from these groups. Symptoms of EAB, including crown die-back, D-shaped exit holes, vertical splits in the bark, extensive bark removal/scaling from woodpeckers, or epicormic sprouting were not found in this study. No specimens of emerald ash borer were found, and as of July 2014, EAB has not been discovered in North Dakota. These results are supported by the negative results from trapping led by the North Dakota Department of Agriculture and USDA-APHIS (A. Bergdahl communication via J. Knodel).

Not all specimens caught in this study were identified to species. All Coleoptera, Hemiptera (Heteroptera), and Lepidoptera species caught, which were thought to be associated with *Fraxinus* were identified to species, except for one small series of Scarabaeidae, which were identified to subgenus (Phyllophaga). Six species collected during this study may represent new state records.

Overall, 4,301 specimens from 53 families in three orders were identified in this study, totalling at least 276 distinct taxa. The great majority collected - both in terms of species richness and individual specimens - were Coleoptera, with 3,560 specimens from 35 families, totalling at least 202 species. Six hundred sixty-five Hemiptera (Heteroptera) specimens were collected from 13 families, totalling at least 45 species. Lepidoptera collected and identified in this study included 76 specimens from five families, totalling at least 30 species. A total of 221 samples were taken during this study. A ‘sample’ is defined as either a retrieval of a trap (FIT or Lindgren) from a site, or a beating sheet session at a site. Traps were retrieved approximately every two weeks, so each ‘sample’ represents approximately two weeks of trapping.

Coleoptera collected in this survey include two state records: *Chrysobothris sexsignata*, and *Eupogonius pauper*. Hemiptera (Heteroptera) collected in this survey include up to four state records: *Tropidosteptes brooksi*, *T. commissuralis*, *T. plagifer*, and *Peritropis saldaeformis*.

A literature review revealed a total of 23 of the species collected and identified in this study to be associated with *Fraxinus*. Because these insects make use of *Fraxinus* in a variety of ways, an all-encompassing term is useful. The term *fraxinicolus* is an adjective derived from Latin, which literally translates to "ash-inhabiting". It is used in this text to refer to insects which utilize *Fraxinus* for reproduction and/or as a food source. *Fraxinicolus* arthropods depend primarily on ash for feeding (phytophages, general sap feeders, and xylem/phloem specialist feeders), and for reproduction (e.g. gall-producing). The *fraxinicolus* insects found in this survey consist of 610 specimens from 10 families in three orders. Approximately 14% of the total specimens collected and identified (Coleoptera, Hemiptera: Heteroptera, and Lepidoptera) are *fraxinicolus*. However, some of the records suggesting a relationship to *Fraxinus* are questionable, and are considered further in the discussion section.

Table 3 shows the results of Coleoptera, Hemiptera (Heteroptera), and Lepidoptera organized by site. These sites were regularly surveyed. The Shannon-Wiener index shows the Tewaukon National Wildlife Refuge (NWR), lake peninsula (TE-PE) site had the highest diversity index of 3.465. Chahinkapa park (CA), which was only briefly sampled one time, had the lowest Shannon-Wiener diversity index of 0.313. Of the sites which were sampled regularly, the Tewaukon NWR, Cutler's woods (TE-CW) site had the lowest Shannon-Wiener index of 2.512. The Simpson's Index of Diversity has a range from 0.836-0.943.

Table 4 shows the results of Coleoptera, Hemiptera (Heteroptera), and Lepidoptera organized by site. These sites were not regularly surveyed. These sites were only surveyed during the 2010 season (Table 1), and with only the beating sheet. In addition, Table 5 shows the results of Coleoptera, Hemiptera (Heteroptera), and Lepidoptera of Jay V. Wessels State Wildlife Management Area (JA), the only site with *Fraxinus nigra* (black ash).

Table 3. Hemiptera (Heteroptera), Coleoptera, and Lepidoptera diversity organized by site. Sites regularly surveyed.

Site[1]	Total samples	Total specimens	Average specimens per sample	Species richness	Shannon-Wiener Index	Simpsons Index
BR	26	850	32.7	83	2.781	0.875
CH	18	189	10.5	61	3.335	0.924
EK-CP	28	543	19.4	103	3.422	0.930
EK-WL	25	700	28	107	3.090	0.893
LA	23	418	18.2	82	3.442	0.924
LO	19	599	31.5	83	2.883	0.874
TE-CW	22	314	14.3	50	2.512	0.836
TE-PE	20	269	13.5	70	3.465	0.943
TR	25	262	10.5	69	3.382	0.936
mean	22.889	460.444	19.844	78.667	3.146	0.904
range	10	661	22.2	57	0.953	0.107
SD	3.408	225.863	8.776	18.527	0.347	0.036

[1]BR: Brewer Lake Cass County Park and Campgrounds, CH: Chrisan subdivision, EK-CP: Albert K. Ekre Grassland Preserve - cow pasture, EK-WL: Albert K. Ekre Grassland Preserve - woodland area, LA: Lake Elsie, LO: Lower Wild Rice and Red River Cemetery, TE-CW: Tewaukon NWR - Cutler's Woods, TE-PE: Tewaukon NWR - Lake Tewaukon peninsula, TR: TreFoil Park.

Table 4. Hemiptera (Heteroptera), Coleoptera, and Lepidoptera diversity organized by site. Sites not regularly surveyed. Only beating sheet method used.

Site[1]	Total samples	Total specimens	Average specimens per sample	Species richness	Shannon-Wiener Index	Simpsons Index
CA	3	36	12	12	2.151	0.873
CP	1	41	(41)	6	0.722	0.313
HO	1	16	(16)	6	1.511	0.783
mean	1.667	31	23	8	1.461	0.656
range	2	25	29	6	1.429	0.56
SD	1.155	13.229	15.716	3.464	0.716	0.301

[1]CA: Casselton reservoir/Tinta Tawa Park, CP: Chahinkapa Park, HO: Horse Trailhead.

Table 5. Hemiptera (Heteroptera), Coleoptera, and Lepidoptera diversity of Jay V. Wessels SWMA (JA). The only site surveyed with black ash. Site sampled for a partial season.

Site	Total samples	Total specimens	Average specimens per sample	Species richness	Shannon-Wiener Index	Simpsons Index
JA	10	64	6.4	27	2.608	0.877

Figure 15 shows total number specimens (individuals) collected by months during 2010–2011 (combined Coleoptera, Hemiptera (Heteroptera), and Lepidoptera). The first half of July had the highest number of specimens caught, with a total of 1,125 Coleoptera, Hemiptera (Heteroptera), and Lepidoptera specimens. The lowest numbers of specimens were collected at the end of May (103) and the second half of September (55).

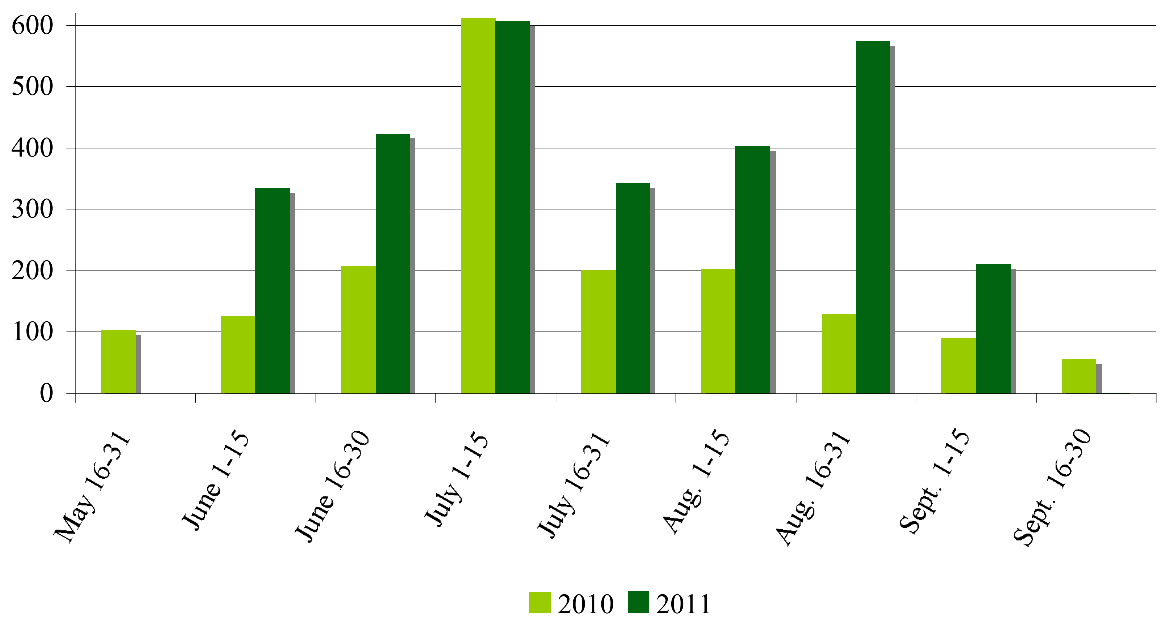

Figure 15. Total specimens collected.

Figure 16 shows total samples taken during this study. Differences in trapping between years are also shown in Table 1. Three sites were briefly surveyed by beating sheet in 2010 which were not surveyed in 2011. Jay V. Wessels State Wildlife Management Area was added in 2011.

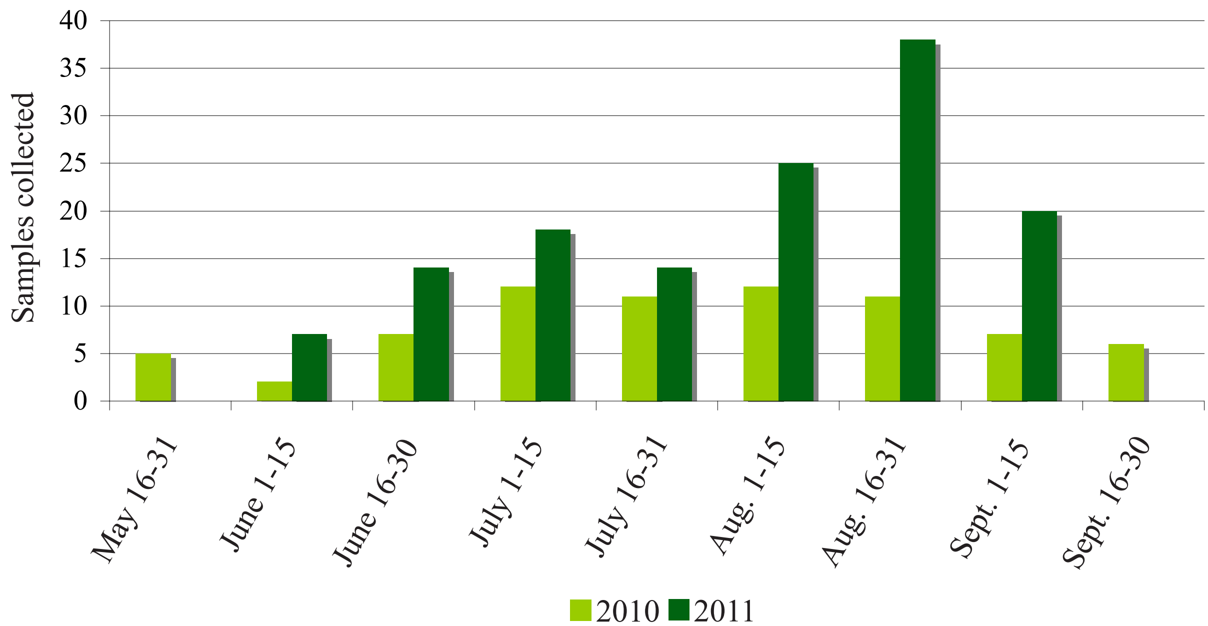

Figure 16. Total samples collected. All trapping methods are included.

Coleoptera Identifications

A total of 3,560 Coleoptera specimens were caught and identified. Two hundred and two species were estimated from 35 families. This is likely an underestimate of the total number of species found in this study. Sixty-six species and 52 genera were identified with 52 undetermined species. The other 84 species were identified to various taxonomic levels and categorized as distinct 'morpho species' based on apparent morphological differences in order to estimate biodiversity. One hundred and fifty eight species (78%) were represented by less than ten specimens each. Fifty eight species (28.7%) were represented by only a single specimen.

Thirteen species of Coleoptera which are associated with *Fraxinus* were collected in this survey. These include: three species of Cerambycidae (*Eupogonius pauper*, *Obrium rufulum*, and *Stenocorus schaumii*) (five specimens collected), eight species of Curculionidae (*Hylurgopinus rufipes*, *Hylesinus aculeatus*, *H. criddlei*, *H. fasciatus*, *H. pruinosus*, *Lignyodes horridulus*, *L. bischoffi*, *L. helvolus*) (129 specimens collected), one species of Buprestidae (*Chrysobothris sexsignata*) (one specimen collected), and one subgenus of Scarabaeidae (*Phyllophaga* sp.) (one specimen collected).

Looking at the biodiversity of just the Coleoptera, (Table 6, Table 7) the Shannon-Wiener index shows that Chrisan subdivision had the highest diversity index with a 3.404. Horse Trailhead had the lowest with 0.637, which was only surveyed once. Of the sites that were regularly surveyed, Jay V. Wessels SWMA had the lowest diversity index of Coleoptera, with a Shannon-Wiener index number of 2.3; this site was only surveyed during the second half of 2011. Tewaukon National Wildlife Refuge, Cutler's woods showed the lowest Shannon-Wiener index of the regularly-surveyed sites with green ash with a value of 2.35.

Table 6. Coleoptera diversity organized by site. Sites regularly surveyed.

Site[1]	**Total samples**	**Total specimens**	**Species richness**	**Shannon-Wiener index**	**Simpsons index**
BR	26	731	61	2.522	0.842
CH	16	114	42	3.404	0.965
EK-CP	27	424	67	3.032	0.899
EK-WL	24	617	76	2.849	0.868
LA	23	399	69	3.301	0.917
LO	19	527	60	2.560	0.840
TE-CW	21	259	42	2.350	0.793
TE-PE	20	248	60	3.314	0.934
TR	24	174	48	3.189	0.933
mean	22.222	388.111	58.333	2.947	0.888
range	11	617	34	1.054	0.172
SD	3.528	208.549	12.010	0.392	0.056

[1]BR: Brewer Lake Cass County Park and Campgrounds, CH: Chrisan subdivision, EK-CP: Albert K. Ekre Grassland Preserve - cow pasture, EK-WL: Albert K. Ekre Grassland Preserve - woodland area, LA: Lake Elsie, LO: Lower Wild Rice and Red River Cemetery, TE-CW: Tewaukon NWR - Cutler's Woods, TE-PE: Tewaukon NWR - Lake Tewaukon peninsula, TR: TreFoil Park.

Table 7. Coleoptera diversity organized by site. Sites not regularly surveyed. Only beating sheet method used.

Site[1]	**Total samples**	**Total specimens**	**Species richness**	**Shannon-Wiener index**	**Simpsons index**
CA	3	29	11	2.059	0.855
CP	1	4	3	1.040	0.875
HO	1	3	2	0.637	0.667
mean	1.667	12	5.333	1.245	0.799
range	2	26	9	1.422	0.208
SD	1.155	14.731	4.933	0.733	0.115

[1]CA: Casselton reservoir/Tinta Tawa Park, CP: Chahinkapa Park, HO: Horse Trailhead.

Table 8. Coleoptera diversity of Jay V. Wessels SWMA (JA) organized by site. The only site surveyed with black ash. Site sampled for a partial season.

Site	Total samples	Total specimens	Species richness	Shannon-Wiener index	Simpsons index
JA	8	31	14	2.300	0.882

Figure 17 shows total number of specimens of Coleoptera collected over time, with months partitioned into halves. The first half of July had the highest number of specimens collected, with a total of 1,044. The remaining months ranged between 231 and 544 (May 16-31 and September 16-30). Coleoptera collected during July 1-15 (both years) represent about 26% of all specimens collected. Moderate levels of Coleoptera specimens (231-544) were collected in June, late July, August, and early September. The lowest total Coleoptera specimens collected occurred during late May and late September, with totals of 25 and 39, respectively and only in 2010.

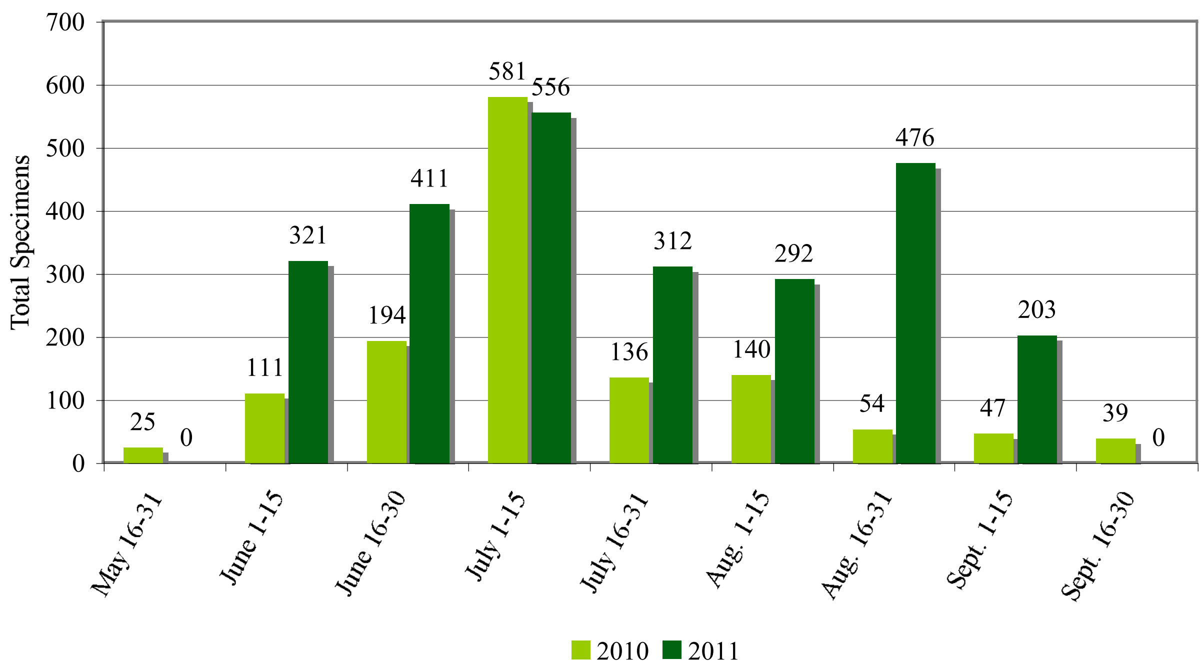

Figure 17. Total number of Coleoptera specimens collected monthly during 2010–2011.

Overview of Coleoptera With *Fraxinus* as a Host

Twelve species and one subgenus of Coleoptera were found in this study which are thought to be associated with *Fraxinus* (see Appendix A). The life histories, North American distributions, and risk assessment of co-extinction with *Fraxinus* according to Gandhi and Herms (2010) of these species follows. Risk assessments used are defined by Gandhi and Herms (2010) and are categorized as follows: high risk species are ash monophages (feed exclusively on ash), high-moderate risk species are biphagous (feed on ash and one other host), moderate species are triphagous (feed on ash and two other hosts), and low risk species are polyphagous (feed on ash and more than two other hosts).

A single *Chrysobothris sexsignata* (Say) (Buprestidae) specimen was caught at Lake Elsie (LA). This represents a new county record. This species is a native buprestid beetle with a wide range of hosts. Larval hosts include *Amelanchier arborea* (Rosaceae), *Carya ovata* (Juglandaceae), *Celtis laevigata* (Cannabaceae), *F. pennsylvanica* (Oleaceae), *Gleditsia triacanthos* (Fabaceae), and *Ulmus rubra* (Ulmaceae) (Nelson and MacRae 1990, MacRae 1991). *Chrysobothris sexsignata* has also been periodically reported in Minnesota stands of *Fraxinus nigra* (Palik et al. 2011). According to Gandhi and Herms (2010), *C. sexsignata* is considered a low risk species.

A single *Eupogonius pauper* LeConte (Cerambycidae) specimen was caught at Jay V. Wessels, the only site with *F. nigra* (black ash). This represents a new county record. *Eupogonius pauper* has a wide range of hosts, including *Acer* (Aceraceae), *Asimina* (Annonaceae), *Carpinus* (Betulaceae), *Carya*, *Castanea dentata* (Fagaceae), *Celastrus* (Celastraceae), *Cercis* (Fabaceae), *Cornus* (Cornaceae), *Fraxinus* (Oleaceae), *Gleditsia triacanthos*, *Hamamelis* (Hamamelidaceae), *Juglans* (Juglandaceae), *Morus* (Moraceae), *Prunus (Rosaceae)*, *Quercus* (Fagaceae), *Rhus* (Anacardiaceae), *Tilia americana* (Tiliaceae), *Ulmus*, and *Zanthoxylum* (Rutaceae) (Linsley and Chemsak 1984). According to Gandhi and Herms (2010), *E. pauper* is considered a low risk species.

Two *Obrium rufulum* Gahan (Cerambycidae) specimens were caught at Lake Elsie (LA). Hosts include *Quercus*, *Fraxinus*, and *Tilia* (Linsley 1963, Yanega 1996, Vlasak and Vlasakova 2002, Lingafelter 2007). According to Gandhi and Herms (2010), *O. rufulum* is considered a moderately at risk species.

Two *Stenocorus schaumii* (LeConte) (Cerambycidae) specimens were caught from the Albert K. Ekre Grassland Preserve. Hosts include *Acer*, *Amelanchier*, *Fagus grandifolia* (Fagaceae), *Fraxinus*, *Juglans nigra* (Linsley and Chemsak 1972, Yanega 1996, Lingafelter 2007). According to Gandhi and Herms (2010), *S. schaumii* is considered a low risk species.

Ten *Hylesinus aculeatus* (Scolytidae) (eastern ash bark beetle) specimens were caught (Appendix B). *Hylesinus aculeatus* feed and develop within the cambium of *F. americana* (white ash), *F. pennsylvanica*, and presumably other *Fraxinus* species (Wood 1982, Solomon 1995, Cranshaw 2004). Its recorded range is from the eastern U.S. west to the Rocky Mountains, and from eastern Canada to Manitoba (though *F. pennsyvanica's* range reaches further west to Alberta) (Craighead 1949, Keen 1952, Ives and Wong 1988, Solomon et al. 1993, Hiratsuka et al. 1995, U.S. Geological Survey 1999, Furniss and Carolin 1977). It is found in North Dakota (NDSIRC 2012). According to Gandhi and Herms (2010), *H. aculeatus* is considered a high risk species.

Eleven *Hylesinus criddlei* (Scolytidae) specimens were caught (Appendix B). *Hylesinus criddlei* feed and develop within the cambium of *Fraxinus americana*, and *F. pennsylvanica*. *Hylesinus criddlei* is generally distributed east of the Great Plains, and has been reported specifically from Minnesota, North Dakota, Wyoming, Colorado, Manitoba, and Quebec (Furniss and Carolin 1977, Wood 1982, Ives and Wong 1988, Solomon et al. 1993, Hiratsuka et al. 1995, Solomon 1995, Cranshaw 2004, NDSIRC 2012). *Hylesinus criddlei* is considered a high risk species (Gandhi and Herms 2010).

Seven *Hylesinus fasciatus* (Scolytidae) specimens were caught (Appendix B). *Hylesinus fasciatus* feed and develop within the cambium of *Fraxinus americana*, which is not a naturally found tree in North Dakota. This implies that *H. fasciatus* may have more hosts apart from *F.*

americana. *Hylesinus fasciatus* has a distribution from Pennsylvania and New Jersey to Missouri, and as of 2007, is recorded from North Dakota (Craighead 1949, Wood 1982, Solomon et al. 1993, U.S. Geological Survey 1999, NDSIRC 2012). *Hylesinus fasciatus* is considered a high risk species (Gandhi and Herms 2010).

Two *Hylesinus pruinosus* (Scolytidae) specimens were caught (Appendix B). *Hylesinus pruinosus'* host is recorded as *Fraxinus*, and has a range including North Dakota, Ontario, Vermont to Tennessee and Virginia (Wood 1982). *Hylesinus pruinosus* is considered a high risk species (Gandhi and Herms 2010).

Thirty five *Hylurgopinus rufipes* (Eichhoff) (Scolytidae) (native elm bark beetle) specimens were caught (see Appendix B). Hosts include *Fraxinus*, *Prunus avium*, *Tilia americana*, and *Ulmus* (Solomon 1995). This species' range includes North Dakota (NDSIRC 2012). According to Gandhi and Herms (2010), *H. rufipes* is considered a low risk species.

Eighteen *Lignyodes bischoffi* (Curculionidae) specimens were caught (Appendix B). *Lignyodes bischoffi* has been observed developing within seeds of *Fraxinus americana*, *F. nigra*, and *F. pennsylvanica* (Knull 1932, Ives and Wong 1988, Wanat and Mocarski 2008). According to Solomon et al. (1993), *L. bischoffi* also feeds on seeds of *Syringa* (Oleaceae). *Lignyodes bischoffi* is considered a high-moderate risk species (Gandhi and Herms 2010).

Seventeen *Lignyodes helvolus* (Curculionidae) specimens were caught (Appendix B). *Lignyodes helvolus* probably develop within the seeds of *Fraxinus*, but Ives and Wong (1988) say it's not confirmed. Solomon et al. (1993) also lists *L. helvolus* as feeding on seeds of *Syringa* - which is in the Oleaceae family with *Fraxinus*. *Lignyodes helvolus* is considered a high-moderate risk species (Gandhi and Herms 2010).

Twenty nine *Lignyodes horridulus* (Casey) (Curculionidae) (ash seed weevil) specimens were caught (Appendix B). Hosts listed are *Fraxinus* and *Syringa* (Oleaceae) (Solomon et al. 1993). According to Gandhi and Herms (2010), *L. horridulus* is considered a high-moderate risk species.

Six *Phyllophaga* (subgenus) spp. (Scarabaeidae) specimens were caught (Appendix B). Species were not determined. Both *Phyllophaga* species (*P. ilicis* and *P. vehemens*) are listed by Gandhi and Herms (2010) as low risk species. The abundances of these Coleoptera species are compared in Figure 18.

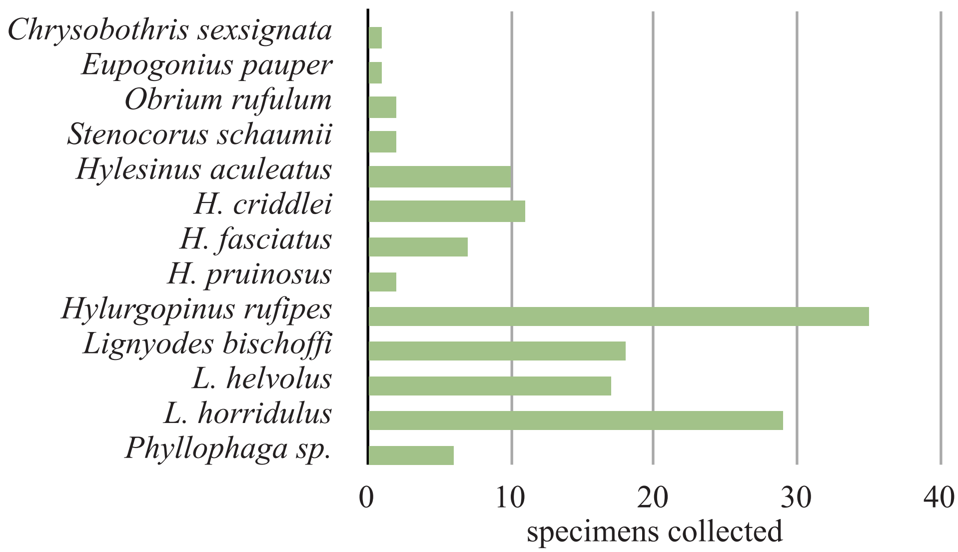

Figure 18. Total number of *fraxinicolus* Coleoptera specimens collected.

The following Coleoptera were found in large numbers, but are not necessarily dependent on *Fraxinus*:

Forty seven *Oligomerus* sp. and 21 *Hemicoelus* sp. (both Anobiidae) specimens were caught in this study (Appendix B). These are xylophagous insects, whose larvae bore into, and feed on the fungi within dry, decaying wood (many types of wood, including *Fraxinus*) (White 1998, Arnett et al. 2002). It is not considered an at-risk group (Gandhi and Herms 2010).

One hundred eleven *Stenoscelis brevis* (Boheman) (Curculionidae) specimens were caught in this study (Appendix B). *Stenoscelis brevis* larvae bore into a wide range of hardwood hosts, and have been found with *Acer*, *Carpinus*, *Carya*, *Cornus*, *Fraxinus*, *Galanthus* (Amaryllidaceae), *Ilex* (Aquifoliaceae), *Magnolia* (Magnoliaceae), *Malus* (Rosaceae), *Myrica* (Myricaceae), *Liquidambar* (Altingiaceae), *Populus* (Salicaceae), *Quercus*, *Sambucus* (Adoxaceae), *Ulmus*, and others (Majka et al. 2007). *Stenoscelis brevis* also has a wide distribution, found in Ontario and Quebec, from

New England to Florida, west to North Dakota, Iowa, and Kansas (Majka et al. 2007, NDSIRC 2012). It is not considered an at-risk group (Gandhi and Herms 2010).

A total of 102 *Carpophilus brachypterus* (Say) (Nitidulidae) specimens were caught in this study (Appendix B). *Carpophilus brachypterus* feeds on sap in flowers, and fermenting fruit, and has a wide distribution. *Carpophilus brachypterus* is found in Manitoba, Nova Scotia, Quebec, south to North Carolina and west to Texas, Nebraska, Kansas, Iowa, and South Dakota (Majka et al. 2007). It is not considered an at-risk group (Gandhi and Herms 2010).

Coleoptera With Questionable Associations With *Fraxinus*

Seventeen *Lignyodes ocularis* (Curculionidae) specimens were collected. There doesn't seem to be host relationships reported in the literature, but there are indications of *Fraxinus* on the labels of specimens collected in Westerville, Ohio. However, these may only indicate incidental occurrences of adults on these plants (Clark 1980).

Hemiptera (Heteroptera) Identifications

A total of 665 Hemiptera (Heteroptera) specimens were caught and identified. Forty-six species/morpho species from 13 families were identified in samples collected (Anthocoridae, Corixidae, Lygaeidae, Miridae, Nabidae. Pachygronthidae, Pentatomidae, Piesmatidae, Reduviidae, Rhyparochromidae, Saldidae, Tingidae, and Veliidae). Seventeen of these were represented by only a single specimen.

Six species of Hemiptera (Heteroptera) which are associated with *Fraxinus* were collected in this survey. These include: four species of Miridae (*Tropidosteptes amoenus*, *T. brooksi*, *T. plagifer*, *T. commissuralis*) (238 specimens collected), one species of Pentatomidae (*Banasa dimidiata*) (four specimens collected), and one species of Tingidae (*Leptoypha mutica*) (186 specimens collected).

Looking at the biodiversity of all collected Hemiptera (Heteroptera), (Table 9, Table 10) the Shannon-Wiener index shows that Lake Elsie (LA) had the highest species diversity index with a 2.15. Beating sheet collecting at Casselton Reservoir (CA), which was surveyed only once revealed only one species of Hemiptera (Heteroptera), and therefore had a Shannon-Wiener index of zero. Of the sites we surveyed regularly, Tewaukon National Wildlife Refuge, Cutler's woods (TE-CW) had the lowest values for Hemiptera (Heteroptera) with a 0.548 for the Shannon-Wiener index and 0.212 for the Simpson's index of diversity.

Table 9. Hemiptera (Heteroptera) diversity organized by site. Sites regularly surveyed.

Site[1]	**Total samples**	**Total specimens**	**Species richness**	**Shannon-Wiener Index**	**Simpsons Index**
BR	18	99	16	1.035	0.442
CH	13	74	18	1.485	0.587
EK-CP	16	88	17	1.564	0.669
EK-WL	14	72	20	1.332	0.586
LA	6	17	11	2.150	0.919
LO	13	66	17	1.917	0.805
TE-CW	7	54	7	0.548	0.212
TE-PE	8	21	10	1.737	0.810
TR	20	88	21	1.863	0.691
mean	12.778	64.333	15.222	2	0.636
range	14	82	14	2	0.707
SD	4.919	28.944	4.790	0.492	0.214

[1]BR: Brewer Lake Cass County Park and Campgrounds, CH: Chrisan subdivision, EK-CP: Albert K. Ekre Grassland Preserve - cow pasture, EK-WL: Albert K. Ekre Grassland Preserve - woodland area, LA: Lake Elsie, LO: Lower Wild Rice and Red River Cemetery, TE-CW: Tewaukon NWR - Cutler's Woods, TE-PE: Tewaukon NWR - Lake Tewaukon peninsula, TR: TreFoil Park.

Table 10. Hemiptera (Heteroptera) diversity organized by site. Sites not regularly surveyed. Only beating sheet method used.

Site[1]	**Total samples**	**Total specimens**	**Species richness**	**Shannon-Wiener Index**	**Simpsons Index**
CA	1	7	1	0	0
CP	1	37	17	0.333	0.156
HO	1	13	4	1.119	0.679
mean	1	19	7.333	0.484	0.278
range	0	30	16	1.119	0.679
SD	0	15.875	8.505	0.575	0.356

[1]CA: Casselton reservoir/Tinta Tawa Park, CP: Chahinkapa Park, HO: Horse Trailhead.

Table 11. Hemiptera (Heteroptera) diversity of Jay V. Wessels SWMA (JA) organized by site. The only site surveyed with black ash. Site sampled for a partial season.

Site[1]	Total samples	Total specimens	Total species	Shannon-Wiener Index	Simpsons Index
JA	7	29	10	1.206	0.527

Figure 19 shows total number specimens of Hemiptera (Heteroptera) collected over time, with months partitioned into halves, and years separated (2010, 2011). Overall, August had the highest number of specimens collected (313), and June had the lowest total number of specimens collected (46).

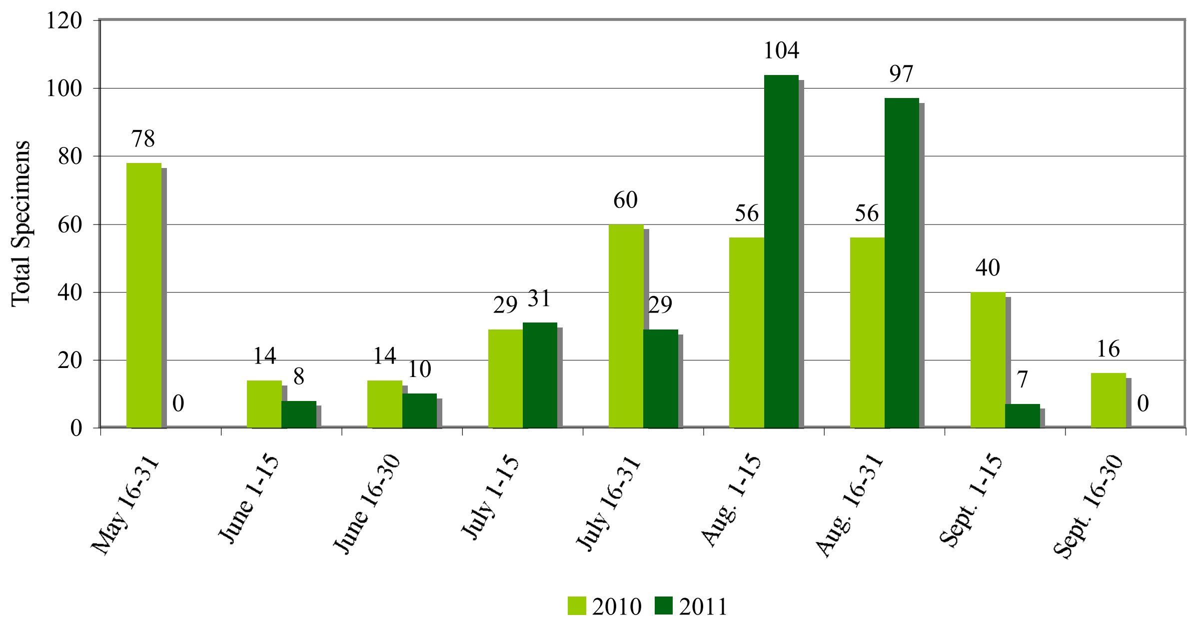

Figure 19. Total number of Hemiptera (Heteroptera) specimens collected monthly during 2010–2011.

Overview of Hemiptera (Heteroptera) With *Fraxinus* as a Host

The following are Hemiptera (Heteroptera) collected and identified in this survey that are known to be associated with ash (*Fraxinus*).

Four *Banasa dimidiata* (Say) (Pentatomidae) specimens were found in this study (Appendix B). All were caught in August and were found at Albert K. Ekre Grassland Preserve, cow pasture site (EK-CP). Hosts include *Betula* (Birch), *Fraxinus* (Ash), and *Quercus* (Oak) (Ives and Wong 1988). This species has a wide distribution throughout North America, extending to both coasts, it has been reported from North Dakota (Henry and Froeschner 1988). According to Gandhi and Herms (2010), *B. dimidiata* is considered a low risk species.

A total of 186 *Leptoypha mutica* (Say) (Tingidae) specimens were found in this study (Appendix B). This species was the second-most abundant Hemiptera (Heteroptera) found in this survey. The majority (73) were found at Brewer Lake Cass County Park and Campgrounds (BR). Forty five specimens were caught at Albert K. Ekre Grassland Preserve, woodland area (EK-WL). Fifty six were caught at Tewaukon National Wildlife Refuge, 48 of which were at the Cutler's woods site (TE-CW), and eight specimens were at the Lake Tewaukon peninsula (TE-PE). The majority of these specimens 88% (162/186) were found by beating sheet collecting - 66 in BR, 30 in EK-WL, 48 in TE-CW, 8 in TE-PE, 2 in JA, 2 in CP, and 2 in HO. Hosts include *Chionanthus* and *F. americana* (both Oleaceae) (Froeschner 1944, Usinger 1946). This species has a distribution reported in the east/northeast of North America, Ontario and Quebec, Maine south to Florida west to Mexico north to North Dakota (Henry and Froeschner 1988). According to Gandhi and Herms (2010), *L. mutica* is considered a high-moderate risk species.

A total of 216 *Tropidosteptes amoenus* Reuter (Miridae) (ash plant bug) total specimens were caught. This was the most abundant Hemiptera (Heteroptera) species found in the survey. We found specimens from nearly all sites (Appendix B). No specimens were found at Jay V. Wessels State Wildlife Management Area (JA), or either site at the Tewaukon National Wildlife Refuge (TE-CW, TE-PE) (also none were found at Horse Trailhead (HO), but sampling there was extremely limited). *Tropidosteptes amoenus* has *Fraxinus* and *F. pennsylvanica* listed as hosts, and has a widespread distribution in eastern species in the United States (Craighead 1949, Ives and Wong 1988, Johnson and Lyon 1991, Solomon et al. 1993, Hiratsuka et al. 1995, Cranshaw 2004). According to Henry and Froeschner (1988), *T. amoenus* is found transcontinental in Canada, from British Columbia east to Quebec, and from North Dakota south to Texas, and many states eastward, including Maine south to Florida. Gandhi and Herms (2010) list *T. amoenus* a high risk species.

Three *Tropidosteptes brooksi* Kelton (Miridae) specimens were caught in this study. One specimen was caught from Chrisan (CH), and one at each site at Albert K. Ekre Grassland Preserve (EK-WL, EK-CP). *Tropidosteptes brooksi* is listed as a *F. pennsylvanica* feeder, but is often listed as feeding on *Fraxinus*; whether *T. brooksi* strictly feeds on *F. pennsylvanica* or other species of ash is not clear (Kelton 1980, Johnson and Lyon 1991, Cranshaw 2004). According to Henry and Froeschner (1988), this species is found in Saskatchewan eastward to Quebec; it is not listed from North Dakota. This may represent a new state record. *Tropidosteptes brooksi* is listed as a high risk species.

Twenty *Tropidosteptes commissuralis* (Reuter) (Miridae) specimens were caught in this study. This species is not listed in any of the *Fraxinus* lists in Appendix A, but Kelton (1980) reports this species being collected from *F. pennsylvanica*. However, we found no specimens on green ash, all of the specimens collected in this survey were found on black ash (3 in FIT, 5 in Lindgren, 12 beating sheet collecting). This species' listed range is from Manitoba east to Nova Scotia, British Columbia, Minnesota, Iowa, Illinois, and New York, it is not listed from North Dakota (Kelton 1980, Henry and Froeschner 1988). This may represent a new state record.

Nineteen *Tropidosteptes plagifer* Reuter (Miridae) specimens were caught in this study. Specimens were found at five sites (Appendix B). This species is not listed in any of the *Fraxinus* lists in Appendix A, but Kelton (1980) reports *T. plagifer* being collected from *F. nigra*. We found only a single specimen on *F. nigra*. This species' range is listed from Manitoba east to Quebec, Minnesota, Wisconsin, Illinois, and New York, it is not listed from North Dakota (Kelton 1980, Henry and Froeschner 1988, Maw et al. 2000). This may represent a new state record. Gandhi and Herms (2010) do not list *T. plagifer* at all. The abundances of these Hemiptera (Heteroptera) species are compared in Figure 20.

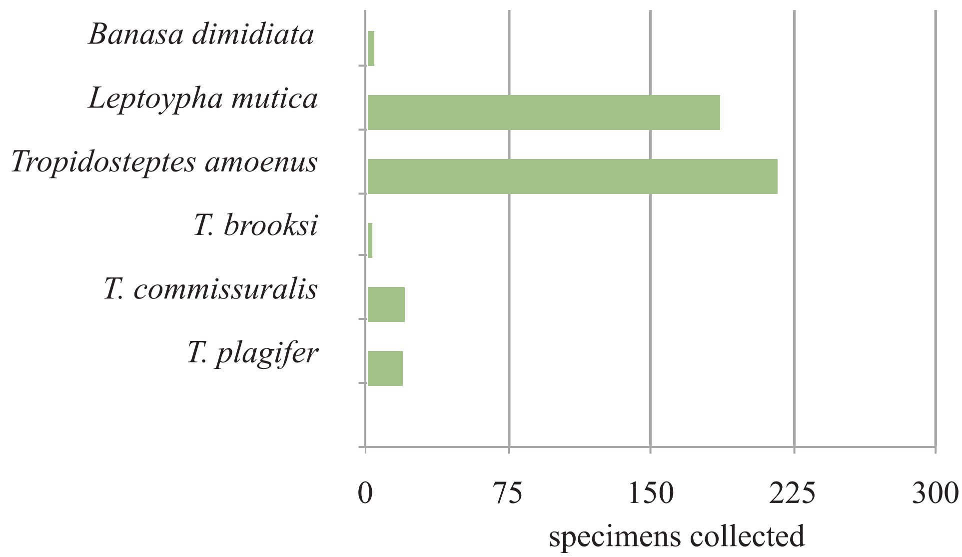

Figure 20. Total number of Hemiptera (Heteroptera) specimens collected and associated with *Fraxinus*.

The following Hemiptera (Heteroptera) were found in relatively large numbers, but are not necessarily dependent on *Fraxinus*:

Thirty-two *Peritropis saldaeformis* Uhler (Miridae) specimens were found in this survey. All were caught in August, with 29 specimens caught in the first half of the month, and three in the second half. The majority of specimens (25) were found at Lower Wild Rice and Red River Cemetery (LO); all of these were caught with the Lindgren trap. This species has a Nearctic and Neotropical distribution (Gorczyca and Eyles 1997), and has been collected from *Carya* (Juglandaceae) (Henry and Smith 1979). This species is not listed in North Dakota, the closest states are Iowa and Illinois (Henry and Froeschner 1988). It's also listed from Oklahoma, Texas, Florida, Pennsylvania, Washington, D.C., Maryland, as well as Brazil and Paraguay (Henry and Froeschner 1988). This may represent a new state record.

Lepidoptera Identifications

Twenty-four species of Lepidoptera from five families (Erebidae, Lycaenidae, Noctuidae, Nymphalidae, and Sphingidae) were identified in the samples collected. Fifteen of these were represented by only a single specimen.

Looking at the biodiversity of only the Lepidoptera (Table 12), the Shannon-Wiener index shows that Lake Elsie, cow pasture (EK-CP) had the highest species diversity index of Lepidoptera with a 2.62. Five sites (CA, CP, HO, TE-PE, TR) had no specimens of Lepidoptera to evaluate.

The Simpson's index (Table 5) revealed EK-CP to have the highest species diversity index of Lepidoptera with a 0.935, this site also had the highest total samples (10) and specimens evaluated (31). The second-most sampled sites includes BR and LO (five each), BR had a Simpson's Index of 0.447, with six species, and 20 specimens evaluated; while LO had a Simpson's Index of 1.000 from six species and six specimens evaluated.

Table 12. Lepidoptera diversity organized by site. Sites regularly surveyed.

Site[1]	**Total samples**	**Total specimens**	**Species richness**	**Shannon-Wiener Index**	**Simpsons Index**
BR	5	20	6	0.965	0.447
CH	1	1	1	0	0
EK-CP	10	31	19	2.620	0.935
EK-WL	4	11	9	1.972	0.927
LA	1	2	2	0.693	1
LO	5	6	6	1.792	1
TE-CW	1	1	1	0	0
mean	3.9	10.3	6.3	1.1	0.6
range	9	30	18	2.62	1
SD	3.288	11.427	6.370	1.011	0.462

[1]BR: Brewer Lake Cass County Park and Campgrounds, CH: Chrisan subdivision, EK-CP: Albert K. Ekre Grassland Preserve - cow pasture, EK-WL: Albert K. Ekre Grassland Preserve - woodland area, LA: Lake Elsie, LO: Lower Wild Rice and Red River Cemetery, TE-CW: Tewaukon NWR - Cutler's Woods.

Table 13. Lepidoptera diversity of Jay V. Wessels SWMA (JA) organized by site. The only site surveyed with black ash. Site sampled for a partial season.

Site[1]	**Total samples**	**Total specimens**	**Species richness**	**Shannon-Wiener Index**	**Simpsons Index**
JA	2	4	3	1.040	0.833

Figure 21 shows total number specimens (individuals) of Lepidoptera collected and identified over time, with months partitioned into halves, and years separated. The first half of July (2010) and the second half of August (2011) had the highest numbers of specimens caught. May had no specimens, and September had only four.

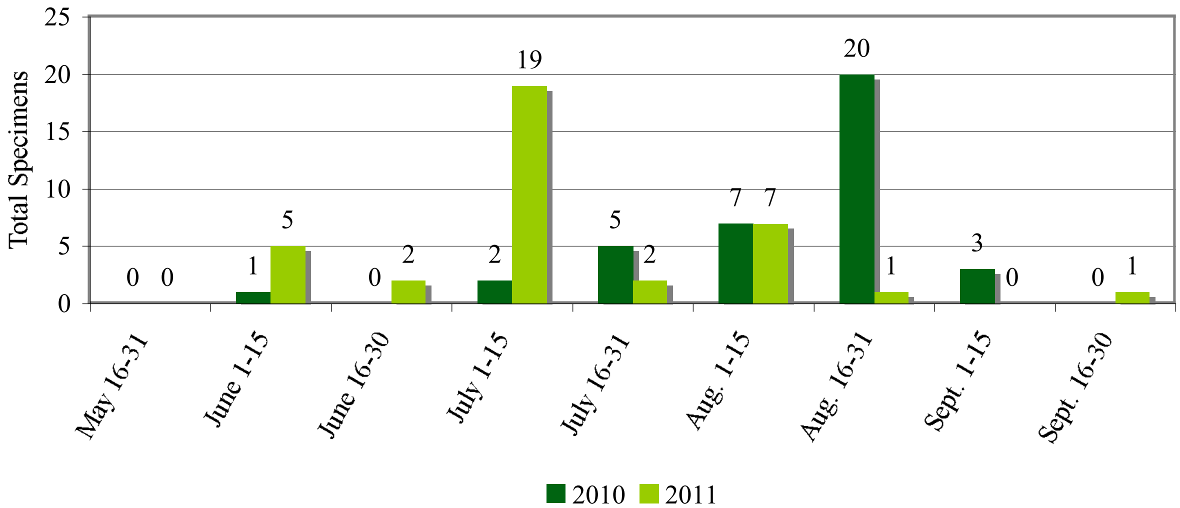

Figure 21. Total number of Lepidoptera specimens collected monthly during 2010–2011.

Overview of Lepidoptera With *Fraxinus* as a Host

Sixteen *Amphipyra pyramidoides* Guenée (Noctuidae) were collected in this survey. The majority of which (15) were found at Brewer Lake Cass County Park and Campgrounds (BR) in August (Appendix B). It is listed as feeding on *Acer* (Sapindaceae), *Betula* (Betulaceae), *Fraxinus pennsylvanica* (Oleaceae), and others (Robinson et al. 2010). According to Gandhi and Herms (2010), this species is considered a low risk species.

A single *Catocala ultronia* (Hübner) (Noctuidae) specimen was collected in this survey at Albert K. Ekre Grassland Preserve, cow pasture site (EK-CP). This species is found on many plants, including *F. pennsylvanica*, *Malus* (Rosaceae), *Prunus serotina* (Rosaceae), and *Quercus* (Fagaceae) (Robinson et al. 2010). According to Gandhi and Herms (2010), this species is considered a low risk species.

A single *Ceratomia undulosa* (Walker) (Sphingidae) specimen was collected in this survey at Albert K. Ekre Grassland Preserve, woodland site (EK-WL). It is listed as being found on a number of plants, including *F. americana*, *F. caroliniana*, *F. excelsior*, *F. nigra*, *F. pennsylvanica*, *Ligustrum* (Oleaceae), *Quercus* (Fagaceae), *Syringa* (Oleaceae) and others (Gandhi and Herms 2010). *Ceratomia undulosa* is listed as a low risk species.

Three *Nymphalis antiopa* (Linnaeus) (Nymphalidae) were collected in this survey. Two specimens at Albert K. Ekre Grassland Preserve, cow pasture site (EK-CP), the other specimen at Lower Wild Rice and Red River Cemetery (EK-CP). It is listed as being found on a number of plants, including *Acer*, *Betula*, *Fraxinus americana*, *Populus* (Salicaceae), *Salix* (Salicaceae) and others (Gandhi and Herms 2010). *Nymphalis antiopa* is listed as low risk species. The abundances of these species are compared in Figure 22.

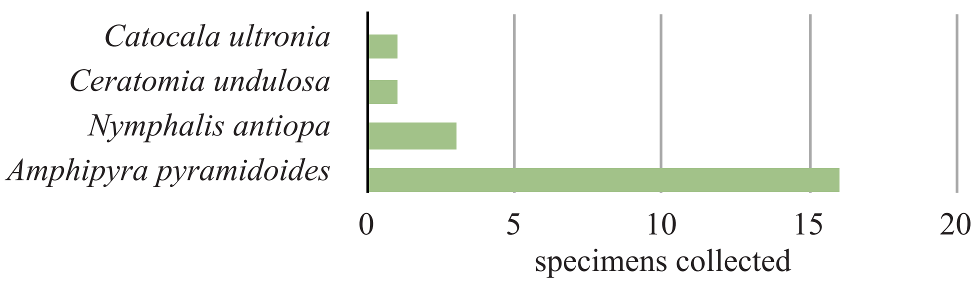

Figure 22. Total number of Lepidoptera specimens collected and associated with *Fraxinus*.

Lepidoptera With Questionable Associations With *Fraxinus*

There are four species listed as associated with Fraxinus in this paper. The relationship these species have to ash is suspect.

Groups Not Included in this Study

Acari

Less than ten Acari specimens were found in this survey, and were not included in this report. There are at least seven species thought to be associated with ash according to Gandhi and Herms (2010), these are: *Aceria chrondriphora* Keifer (Eriophyidae), *Aceria fraxiniflora* (Felt) (Eriophyidae), *Eriophyes fraxini* Garm. (Eriophyidae), *Oligonychus newcomeri* (McGregor) (Tetranychidae), *Platytetranychus thujae* (McGregor) (Tetranychidae), *Tetranychus homorus* Pritchard & Baker (Tetranychidae), and *Tetranychus urticae* Koch (Tetranychidae). The

Acari specimens obtained in this survey were not identified and were not evaluated.

At least four of these Acari are ash-obligates or have only one other known host plant in addition to *Fraxinus*, these include: *Aceria chrondriphora* Keifer, *Aceria fraxiniflora* (Felt), *Eriophyes fraxini* Garm., and *Tetranychus homorus* Pritchard & Baker (*Carya* is also listed as a host) (Johnson and Lyon 1991, Gandhi and Herms 2010).

Hemiptera: Sternorrhyncha and Auchenorrhyncha

Less than twenty specimens of Sternorrhyncha and Auchenorrhyncha were found in this survey and were not included in this report. There are at least 22 species associated with *Fraxinus*. According to Gandhi and Herms (2010), the following Sternorrhyncha are associated with ash: *Aspidiotus ancylus* (Putn.) (Coccidae), *Asterolecanium arabidis* (Signoret) (Asterolecaniidae), *Chionaspis furfura* (Fitch) (Diaspididae), *Lecanium corni* (Bouché) (Coccidae), *Lecanodiaspis prosopidis* Maskell (Coccidae), *Lepidosaphes ulmi* (L.) (Diaspididae), *Prociphilus americana* (Walker) (Aphididae), *Prociphilus fraxinifolii* (Riley) (Aphididae), *Pseudaulacaspis pentagona* (Targioni-Tozzetti) (Diaspididae), *Pseudococcus maritimus* (Ehrhorn) (Pseudococcidae), *Pulvinaria vitis* L. (Coccidae), *Psyllopsis fraxinicola* Forst. (Psyllidae), *Quadraspidiotus juglansregiae* (Comstock) (Diaspididae), *Saissetia oleae* (Olivier) (Coccidae), *Siphonius phillyreae* (Haliday) (Aleyrodidae), *Tetraleurodes mori* (Quaint.) (Aleyrodidae), and *Trialeurodes vaporariorum* (Westwood) (Aleyrodidae). The following Auchenorrhyncha are associated with ash: *Acanalonia conica* (Say) (Acanaloniidae), *Anormenis septentrionalis* (Spinola) (Flatinae), *Megicicada septendecim* (Linnaeus) (Cicadidae), *Metcalfa pruinosa* (Say) (Flatidae), and *Stictocephala bisonia* Kopp & Yonke (Membracidae) (Gandhi and Herms 2010). The Sternorrhyncha and Auchenorrhyncha specimens obtained in this survey were not identified and were not evaluated.

At least four of these Hemiptera are ash-obligates or have only one other known host plant in addition to *Fraxinus*, these include: *Psyllopsis fraxinicola* Forst., *Prociphilus fraxinifolii* (Riley), *Anormenis septentrionalis* (Spinola), *Prociphilus americana* (Walker) (*Abies* is also listed as a host) (Johnson and Lyon 1991, Gandhi and Herms 2010).

Hymenoptera

At least 300 specimens of Hymenoptera were found in this survey, but were not included in this report. There are at least nine species associated with *Fraxinus*, these include: *Eupareophora parca* (Cresson) (Tenthredinidae), *Eurytoma* spp. (Eurytomidae), *Macrophya punctumalbum* (Linnaeus) (Tenthredinidae), *Megachile* spp. (Megachilidae), *Tethida barda* (Say) (Tenthredinidae), *Tethida cordigera* (Beauvois) (Tenthredinidae), *Tomostethus multicinctus* (Rohwer) (Tenthredinidae), *Tremex columba* (Linnaeus) (Siricidae), and *Trichiosoma triangulum* Kirby (Cimbicidae) (Gandhi and Herms 2010). The Hymenoptera specimens obtained in this survey were not identified and were not evaluated.

At least five of these Hymenoptera are ash-obligates or have only one other known host plant in addition to *Fraxinus*, these include: *Tomostethus multicinctus* (Rohwer), *Tethida cordigera* (Beauvois), *Tethida barda* (Say), *Eurytoma* spp. (which species specifically are not listed), *Eupareophora parca* (Cresson) (*Carya illinoinensis* is also listed as a host) (Gandhi and Herms 2010).

Diptera

At least 300 specimens Diptera were also found in this survey, but were not included in this report. There are at least twelve species thought to be associated with ash, at least eleven of which are ash-obligates: *Cecidomyia pellex* (Osten Sacken), *Continaria canadensis* Felt, *Dasineura* spp., (which species specifically are not listed), *Dasineura apicata* Felt, *Dasineura fraxinifolia* Felt, *Colpodia temeritatis* Felt, *Lasioptera fraxiniflora* Felt, *Lestodiplosis fraxinifolia* Felt, *Phytobia* spp. (which species specifically are not listed), *Phytophaga fraxini* Felt, *Rhizomyia fraxinifolia* Felt (Gandhi and Herms 2010). The Diptera specimens obtained in this survey were not identified and were not evaluated.

DISCUSSION

To the author's knowledge, this is the first insect survey of ash in North Dakota since the North American emerald ash borer invasion was identified in 2002. Assessment of ash-associated insects' host specificity is a crucial step when determining the potential effects of large-scale ash death on ash-associated insects. But in many instances, insect host specificity is either not fully understood or it is unknown. Twenty-two species were collected in this study that have a relationship with *Fraxinus*, in that they use *Fraxinus* as a host at some point in their development. There are many species identified in this survey which have host plants that are either poorly known, or unknown.

Symptoms of EAB, including crown die-back, bark-splitting, woodpecks, or epicormic sprouting were not found in this study. No specimens of emerald ash borer were found, and as of July 2014, EAB has not been discovered in North Dakota. However, this does not mean it is not here. An insect's population density must typically reach a certain level before it's detectable. Negative results may simply be an indication of low population densities.

Tropidosteptes plagifer was not expected to be found. It is not known from North Dakota, and host records indicate it only inhabits black ash. We found a single specimen at our black ash site (Jay V. Wessels SWMA), and 19 specimens at green ash sites. This may represent an unrecorded host plant (*Fraxinus pennsylvanica*).

Lepidoptera specimen numbers were low relative to the Hemiptera and Coleoptera collected in this survey. This could be due to many factors, two possibilities include: the funnel/collection cup opening in the FITs being too small for larger specimens, and/or for many Lepidoptera, targeting the larval stage may be a more effective surveying strategy, due to many larval Lepidopteran's foliage-feeding behavior (versus many adult lepidopteran's nectar-feeding or non-feeding behavior).

Four species of Lepidoptera collected are listed as associated with *Fraxinus* by Gandhi and Herms (2010). These species include: *Amphipyra pyramidoides* (Noctuidae) (16 specimens collected), *Catocala ultronia* (Noctuidae) (one specimen collected), *Ceratomia* *undulosa* (Sphingidae) (one specimen collected), and *Nymphalis antiopa* (Nymphalidae) (3 specimens collected). Robinson et al. (2007) (via Gandhi and Herms 2010) is the only source referenced for three of these species, and is one of nine sources listed for *Ceratomia undulosa*. Many of the host plants listed by Robinson et al. (2007) are questionable in that they may not actually utilize *Fraxinus* as a host (Dr. Fauske, pers. comm.). None of these four species have an association with ash other than as a resting substrate (as any tree trunk could provide) (Dr. Fauske, pers. comm.). Host plants of this species are Rosaceae, especially Prunus. *Catocala ultronia* host plants listed by Wagner (2011): cherry and plum (*Prunus*) species are the principle hosts, but are also reported from apple and hawthorn. In the Northeast, black cherry and beach plum are favorites. However, Wagner's (2011) larvae "refused domestic apple and crabapple". *Catocala ultronia* host plants listed by Tietz (1972): *Cornus florida* Linn., *Malus pumila* Mill. (Apple), *Prunus domestica* Linn. (Plum), *Prunus ilicifolia* (Nutt. ex. H. & A.), *Prunus serotina* Ehrh., *Quercus* sp. (Oaks), *Quercus virginiana* Mill. The other two *Catocala* species collected (which are not listed as associated with *Fraxinus*), are Juglandaceae feeders (Dr. Fauske, pers. comm.).

Hylesinus fasciatus (LeConte) is reported from North Dakota, but is only reported to feed and develop within *F. americana*, which is not naturally found in ND. It is likely utilizing another *Fraxinus* species. There was no *F. americana* at our sites.

Nearly all specimens collected in this study were adults. All specimens that were positively identified were adults. However, Dr. Joseph Zeleznik collected a series of beetle larvae from ash seeds - these are likely *Lignyodes* larvae (Coleoptera: Curculionidae), and were not included in the findings of this survey. These are important, however, because ash-seed feeders were not specifically addressed in this study, but may represent an important feeding guild.

Lepidoptera are included because they are referenced as being ash-feeders in other studies, but they are not necessarily associated with *Fraxinus*, because their host records are likely erroneous (Dr. Fauske, pers. comm.).

Future Research

This study should be repeated if and when EAB comes to North Dakota. Future studies should compare their biodiversity indices with the indices found in this survey. Future research may also include work to find causal relationships between differences in manicured and non-manicured biodiversity. Those differences may be due to a number of factors, such as plant species diversity, insecticide spraying, habitat loss, or simply urban development. Follow-up studies should also focus on groups that were not examined, such as Acari, Hymenoptera, and Diptera. It is important to document the known ash-inhabiting species currently housed in the NDSIRC for future surveys. Targeting families which contain known ash-inhabiting species for identification at the outset is also recommended. Doing this will help prioritize both the specimen identifications and the trapping methods used in fieldwork.

In addition, future studies should also focus on: plant succession, insects indirectly affected (such as parasitoids of ash-obligates), and arthropods that may depend on any lichens utilizing ash. More work to understand the life histories of many of the species covered in this paper are also needed. Also, a number of the species identified have either unknown or poorly understood geographical ranges - continued survey work is needed to further understand their biogeography.

Strategies to increase the sampled biodiversity in the future include running traps longer (specifically, starting earlier in the season to ensure traps are running during EAB emergence times), trapping much higher in the trees themselves, and positioning some traps farther out on the branch, as well as against the trunk. Surveying *Fraxinus nigra* (black ash) more thoroughly is recommended. Additional collecting by rearing immature stages (eggs, nymphs, larvae, pupae) found on ash branches, seeds, leaves, buds and galls would likely yield additional records.

Traps themselves could also be improved. The window pane flight intercept trap designs could could have wider openings at the base of the funnel and the top of the collection cup to ensure easier acquisition of larger specimens. Finally the inclusion of ‘purple traps,’ currently in use by APHIS to survey for emerald ash borer, although not a focus of this study, would have made an interesting addition. The use of lures and volatiles would make an interesting addition.

CONCLUSIONS

This survey revealed 23 *fraxinicolus* species found in eastern North Dakota, where *Fraxinus* is the third most abundant tree species. Of these species, 13 are Coleoptera, six are Hemiptera (Heteroptera), and four are Lepidpotera. Table 14 shows the *fraxinicolus* insects collected and identified in this survey. Refer to Figure 8 for collection site locations. Risk levels used are defined by Gandhi and Herms (2010) and are categorized as follows: high risk species are ash monophages (feed exclusively on ash), high-moderate risk species are biphagous (feed on ash and one other host), moderate species are triphagous (feed on ash and two other hosts), and low risk species are polyphagous (feed on ash and more than two other hosts).

Table 14. Insects associated with ash found in survey.

Order	Family	Species	Site[1] collected	Specimens collected	Risk level
Coleoptera	Buprestidae	*Chrysobothris sexsignata*	LA	1	low
Coleoptera	Cerambycidae	*Eupogonius pauper*	JA	1	low
Coleoptera	Cerambycidae	*Obrium rufulum*	LA	2	moderate
Coleoptera	Cerambycidae	*Stenocorus schaumii*	EK-CP, EK-WL	2	low
Coleoptera	Scolytidae	*Hylesinus aculeatus*	BR, TR, LO, TE-PE, LA	10	high
Coleoptera	Scolytidae	*Hylesinus criddlei*	BR, TR, CH, LO, TE-PE	11	high
Coleoptera	Scolytidae	*Hylesinus fasciatus*	BR, TE-CW, TE-PE	7	high
Coleoptera	Scolytidae	*Hylesinus pruinosus*	CH, TE-PE	2	high

[1]BR: Brewer Lake Cass County Park and Campgrounds, CA: Casselton reservoir/Tinta Tawa Park, CH: Chrisan subdivision, CP: Chahinkapa Park, EK-CP: Albert K. Ekre Grassland Preserve - cow pasture, EK-WL: Albert K. Ekre Grassland Preserve - woodland area, HO: Horse Trailhead, JA: Jay V. Wessels SWMA, LA: Lake Elsie, LO: Lower Wild Rice and Red River Cemetery, TE-CW: Tewaukon NWR - Cutler's Woods, TE-PE: Tewaukon NWR - Lake Tewaukon peninsula, TR: TreFoil Park.

[2]Not listed by Gandhi and Herms (2010).

Table 13. Insects associated with ash found in survey (continued).

Order	Family	Species	Site[1] collected	Specimens collected	Risk level
Coleoptera	Scolytidae	*Hylurgopinus rufipes*	BR, EK-CP, EK-WL, CH, TE-CW, LO, TE-PE	35	low
Coleoptera	Curculionidae	*Lignyodes bischoffi*	TR, TE-CW, LO, CA, LA	18	high-moderate
Coleoptera	Curculionidae	*Lignyodes helvolus*	TR, EK-CP, LO, CA, LA	17	high-moderate
Coleoptera	Curculionidae	*Lignyodes horridulus*	BR, TR, EK-CP, LO, CA, LA	29	high-moderate
Coleoptera	Scarabaeidae	Phyllophaga sp.	BR, TE-CW, TE-PE	6	low
Hemiptera (Heteroptera)	Pentatomidae	*Banasa dimidiata*	EK-CP	4	low
Hemiptera (Heteroptera)	Tingidae	*Leptoypha mutica*	BR, EK-WL, TE-CW, LO, CP, HO, JA, TE-PE, LA	186	high-moderate
Hemiptera (Heteroptera)	Miridae	*Tropidosteptes amoenus*	BR, TR, EK-CP, EK-WL, CH, LO, CP, CA, LA	216	high
Hemiptera (Heteroptera)	Miridae	*Tropidosteptes brooksi*	EK-CP, EK-WL, CH	3	high
Hemiptera (Heteroptera)	Miridae	*Tropidosteptes commissuralis*	JA	20	high[2]
Hemiptera (Heteroptera)	Miridae	*Tropidosteptes plagifer*	TR, EK-CP, EK-WL, CH, LO, JA	19	high[2]
Lepidoptera	Noctuidae	*Amphipyra pyramidoides*	BR, EK-CP	16	low
Lepidoptera	Noctuidae	*Catocala ultronia*	EK-CP	1	low
Lepidoptera	Sphingidae	*Ceratomia undulosa*	EK-WL	1	low
Lepidoptera	Nymphalidae	*Nymphalis antiopa*	EK-CP, LO	3	low

[1]BR: Brewer Lake Cass County Park and Campgrounds, CA: Casselton reservoir/Tinta Tawa Park, CH: Chrisan subdivision, CP: Chahinkapa Park, EK-CP: Albert K. Ekre Grassland Preserve - cow pasture, EK-WL: Albert K. Ekre Grassland Preserve - woodland area, HO: Horse Trailhead, JA: Jay V. Wessels SWMA, LA: Lake Elsie, LO: Lower Wild Rice and Red River Cemetery, TE-CW: Tewaukon NWR - Cutler's Woods, TE-PE: Tewaukon NWR - Lake Tewaukon peninsula, TR: TreFoil Park.

[2]Not listed by Gandhi and Herms (2010).

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APPENDIX A. SPECIES ASSOCIATED WITH *FRAXINUS*

The following Coleoptera, Hemiptera, and Lepidoptera species are found in North America and are associated with *Fraxinus* (261 species listed) (Ives and Wong 1988, Johnson and Lyon 1991, Zeleznik et al. 2005, and Gandhi and Herms 2010). Bold and red font indicate species collected from the ash faunal survey during 2010–2011. *Tropidosteptes commissuralis* and *T. plagifer* have been included by the author.

Coleoptera
- Anthicidae
  - *Anthicus nitidulus* LeConte
- Apionidae
  - *Apion porosicolle* (Gemminger)
  - *Notoxus constrictus* Casey
- Bostrichidae
  - *Amphicerus bicaudatus* (Say)
  - *Lyctus brunneus* (Stephens)
  - *Lyctus cavicollis* LeConte
  - *Lyctus linearis* (Goeze)
  - *Lyctus parallelopipedus* (Melsheimer)
  - *Lyctus planicollis* LeConte
  - *Rhyzopertha dominica* (Fabricius)
  - *Xylobiops basilaris* (Say)
- Buprestidae
  - *Agrilus subcinctus* Gory
  - *Chrysobothris femorata* (Olivier)
  - *Chrysobothris mali* Horn
  - ***Chrysobothris sexsignata* Say**
  - *Dicerca divaricata* (Say)
- Cerambycidae
  - *Aegomorphus modestus* (Gyllenhall)
  - *Brothylus conspersus* LeConte
  - *Calloides nobalis nobalis* (Harris)
  - *Centrodera decolorata* (Harris)
  - *Eburia quadrigeminata* (Say)
  - *Encyclops caerulea* (Say)
  - *Eupogonius pauper* LeConte
  - *Hyperplatys aspersa* (Say)
  - *Megacyllene caryae* (Gahan)
  - *Molorchus bimaculatus bimaculatus* Say
  - *Neoclytus acuminatus* (Fabricius)
  - *Neoclytus caprea* (Say)
  - *Neoclytus conjunctus* (LeConte)
  - ***Obrium rufulum* Gahan**
  - *Parandra brunnea* (Fabricius)
  - *Phymatodes vulneratus* (LeConte)
  - *Pidonia ruficollis* (Say)
  - *Rosalia funebris* Motschulsky
  - *Saperda candida* Fabricius

Saperda lateralis Fabricius
***Stenocorus schaumii* (LeConte)**
Tylonotus bimaculatus Haldeman
Urographis fasciatus (DeGeer)
Xylotrechus colonus (Fabricius)
Chrysomelidae
Diabrotica undecimpunctata undecimpunctata Mannerheim
Epitrix subcrinita (LeConte)
Octotoma plicatula (Fabricius)
Curculionidae
Callirhopalus bifasciatus (Roelofs)
***Lignyodes bischoffi* (Blatchley)**
Lignyodes fraxini (LeConte)
***Lignyodes helvolus* (LeConte)**
***Lignyodes horridulus* (Casey)**
Pseudocneorhinus bifasciatus Roelofs
Xyleborus dispar (Fabricius)
Xyleborus ferrugineus (Fabricius)
Xyleborus sayi (Hopkins)
Corthylus punctatissimus (Zimmermann)
***Hylesinus aculeatus* Say**
Hylesinus californicus (Swaine)
***Hylesinus criddlei* (Swaine)**
***Hylesinus fasciatus* LeConte**
Hylesinus oregonus (Blackman)
***Hylesinus pruinosus* Eichhoff**
***Hylurgopinus rufipes* (Eichhoff)**
Xylosandrus germanus (Blandford)
Xyloterinus politus (Say)
Meloidae
Lytta sphaericollis Say
Scarabaeidae
Phyllophaga ilicis (Knoch)
Phyllophaga vehemens (Horn)
Tenebrionidae
Alobates pennsylvanica (DeGeer)
Haplandrus femoratus Fabricius
Lobopoda punctulata (Melsheimer)
Meracantha contracta Beauvois
Merinus laevis (Olivier)
Scotobates calcaratus Fabricius
Uloma imberbis LeConte
Xylopinus aenescens LeConte
Xylopinus saperdioides Olivier

Hemiptera
Auchenorrhyncha
Acanaloniidae
Acanalonia conica (Say)
Cicadidae
Magicicada septendecim (Linnaeus)
Flatidae
Anormenis septentrionalis (Spinola)
Metcalfa pruinosa (Say)

Membracidae

Stictocephala bisonia (Kopp and Yonke)

Heteroptera

Anthocoridae

Triphelps tristicolor White

Miridae

***Tropidosteptes amoenus* Reuter**

***Tropidosteptes brooksi* Kelton**

Tropidosteptes cardinalis Uhler

Tropidosteptes commissuralis (Reuter)

Tropidosteptes illitus (Van Duzee)

Tropidosteptes pacificus (Van Duzee)

***Tropidosteptes plagifer* Reuter**

Tropidosteptes tricolor Van Duzee

Pentatomidae

***Banasa dimidiata* (Say)**

Rhopalidae

Leptocoris trivittatus (Say)

Tingidae

Corythucha ciliata (Say)

Leptoypha costata Parshley

Leptoypha elliptica McAtee

Leptoypha ilicis Drake

Leptoypha nubilis Drake

Leptoypha mcateei Drake

Leptoypha minor McAtee

***Leptoypha mutica* (Say)**

Sternorrhyncha

Aleyrodidae

Siphonius phillyreae (Haliday)

Tetraleurodes mori (Quaint.)

Trialeurodes vaporariorum (Westwood)

Aphididae

Prociphilus americanus (Walker)

Prociphilus fraxinifolii (Riley)

Asterolecaniidae

Asterolecanium arabidis (Signoret)

Coccidae

Aspidiotus ancylus (Putn.)

Parthenolecanium corni Bouche

Lecanodiaspis prosopidis Maskell

Pulvinaria vitis (Linnaeus)

Saissetia oleae (Olivier)

Diaspididae

Chionaspis acericola Hollinger

Chionaspis furfura (Fitch)

Chionaspis floridensis Takagi

Chionaspis gleditsia Sanders

Chionaspis salicisnigae Walsh

Chionaspis lintneri Comstock

Chionaspis kosztarabi Takagi and Kawai

Lepidosaphes ulmi (Linnaeus) (Oystershell Scale)

Pseudaulacaspis pentagona (Targioni-Tozzetti)

Quadraspidiotus perniciosus (Comstock)

Quadraspidiotus juglansregiae (Comstock)
Pseudococcidae
Pseudococcus maritimus (Ehrhorn)
Psyllidae
Psyllopsis fraxinicola Foerster

Lepidoptera
Amphisbatidae
Machimia tentoriferella Clemens
Bombycidae
Apatelodes torrefacta (J.E. Smith)
Olceclostera angelica (Grote)
Olceclostera seraphica (Dyar)
Cossidae
Prionoxystus macmurtrei (Guérin-Méneville)
Prionoxystus robiniae (Peck) (Carpenter worm)
Zeuzera pyrina (Linnaeus)
Crambidae
Palpita magniferalis (Walker)
Elachistidae
Antaeotricha leucillana (Zeller)
Erebidae
Catocala habilis Grote
Catocala piatrix Grote
***Catocala ultronia* (Hübner)**
Euproctis chrysorrhoea (Linnaeus)
Haploa colona (Hübner)
Haploa confusa (Lyman)
Halysidota tessellaris (J.E. Smith)
Hyphantria cunea (Drury)
Lophocampa caryae Harris
Lophocampa maculata Harris
Lymantria dispar (Linnaeus)
Orgyia antiqua (Linnaeus)
Orgyia leucostigma (J.E. Smith)
Palthis angulalis (Hübner)
Spilosoma latipennis Stretch
Spilosoma virginica (Fabricius)
Geometridae
Alsophila pometaria (Harris)
Anacamptodes ephyraria (Walker)
Anavitrinella pampinaria (Guenée)
Ectropis crepuscularia (Denis and Schiffermüller)
Ennomos magnaria Guenée
Ennomos subsignaria (Hübner)
Erannis tiliaria (Harris)
Euchlaena effecta (Walker)
Euchlaena johnsonaria (Fitch)
Euchlaena marginaria (Minot)
Eutrapela clemataria (J.E. Smith)
Hypagyrtis unipunctata (Haworth)
Lycia ursaria (Walker)
Melanolophia canadaria (Guenée)
Metanema determinata Walker

Nematocampa filamentaria (Guenée)
Nematocampa resistaria (Herrich-Schäffer)
Nemoria mimosaria (Guenée)
Operophtera brumata (Linneaus)
Paleacrita vernata (Peck)
Phigalia titea (Cramer)
Philtraea latifoliae Buckett
Philtraea surcaliforniae Buckett
Plagodis fervidaria (Herrich-Schäffer)
Plagodis kuetzingi (Grote)
Sicya macularia (Harris)
Tetracis cachexiata Guenée

Gracillariidae
Caloptilia fraxinella (Ely)
Gracillaria syringella (Fabricius)
Marmara basidendroca Fitzgerald
Marmara corticola Fitzgerald
Marmara fraxinicola Braun

Lasiocampidae
Malacosoma americanum (Fabricius)
Malacosoma californicum pluviale (Dyar)
Malacosoma californicum (Packard)
Malacosoma disstria Hübner
Tolype velleda (Stoll)
Phyllodesma americana (Harris)

Limacodidae
Euclea delphinii (Boisduval)
Phobetron pithecium (J.E. Smith)

Lycaenidae
Satyrium caryaevorum (McDunnough)

Noctuidae
Abagrotis alternata (Grote)
Achatia distincta Hübner
Acronicta americana (Harris)
Acronicta impleta Walker
Acronicta radcliffei (Harvey)
***Amphipyra pyramidoides* Guenée**
Copivaleria grotei (Morrison)
Crocigrapha normani (Grote)
Harrisimemna trisignata (Walker)
Lithophane antennata (Walker)
Lithophane bethunei (Grote and Robinson)
Lithophane laticinerea Grote
Lithophane petulca Grote
Lithophane querquera Grote
Melanchra assimilis (Morrison)
Morrisonia confusa (Hübner)
Orthosia hibisci (Guenée)
Orthosia revicta (Morrison)
Papaipema furcata (Smith)
Papaipema nebris (Guenée)
Sympistis chionanthi (J.E. Smith)
Sympistis fortis (Grote)

Nolidae

Baileya dormitans (Guenée)
Notodontidae
Datana ministra (Drury)
Heterocampa guttivitta (Walker)
Nadata gibbosa (J. E. Smith)
Schizura concinna (J.E. Smith)
Schizura ipomoeae Doubleday
Nymphalidae
Euphydryas phaeton (Drury)
***Nymphalis antiopa* (Linnaeus)**
Papilionidae
Papilio glaucus Linnaeus
Papilio multicaudatus Kirby
Papilio canadensis Rothschild and Jordan
Psychidae
Oiketicus townsendi Townsend
Thyridopteryx ephemeraeformis (Haworth)
Pyralidae
Acrobasis caryivorella Ragonot
Saturniidae
Antheraea polyphemus (Cramer)
Automeris io (Fabricius)
Callosamia promethea (Drury)
Citheronia regalis (Fabricius)
Eupackardia calleta (Westwood)
Hyalophora cecropia (Linnaeus)
Rothschildia lebeau forbesi Benjamin
Rothschildia orizaba (Westwood)
Samia cynthia (Drury)
Sesiidae
Albuna fraxini (Edwards)
Paranthrene asilipennis (Boisduval)
Podosesia aureocincta Purrington and Nielson
Podosesia fraxini (Lugger)
Podosesia syringae (Harris) (Ash Borer/Lilac Borer)
Sphingidae
***Ceratomia undulosa* (Walker)**
Manduca brontes (Drury)
Manduca jasminearum (Guérin)
Smerinthus jamaicensis (Drury)
Sphinx canadensis Boisduval
Sphinx chersis (Hübner)
Sphinx franckii Neumoegen
Sphinx gordius Cramer
Sphinx kalmiae J.E. Smith
Sphinx luscitiosa Clemens
Tortricidae
Archips argyrospila (Walker)
Archips cerasivorana (Fitch)
Archips purpurana (Clemens)
Choristoneura rosaceana (Harris)
Cydia ingrata (Heinrich)
Orthotaenia undulana (Denis and Schiffermüller)
Pandemis canadana Kearfott

Pandemis lamprosana (Robinson)
Pandemis limitata (Robinson)
Platynota idaeusalis (Walker)
Pseudosciaphila duplex (Walsingham)
Cenopis diluticostana (Walsingham)
Cenopis reticulatana (Clemens)

Yponomeutidae

Zelleria hepariella Stainton

APPENDIX B. COLEOPTERA IDENTIFIED IN THIS SURVEY

Coleoptera identified in this survey, organized by number of species found at each site.

	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	TE-PE	TR	JA	CA	CP	HO	Total
Anobiidae														
Actenobius sp.		1							1					2
Euceratocerus sp.						1								1
Euvrilletta sp.		1	2	1	6	1		1						12
Hemicoelus sp.			4	1	8	1		6	1					21
Lasioderma sp.						1								1
Oligomerus sp.		8	1		4	26		5	3					47
Priobium sp.			1		1	1								3
Ptilinus sp.							2							2
Sculptotheca sp.						2		1						3
Buprestidae														
Agrilus celti Knull								4						4
Chrysobothris sexsignata Say					1									1
Cantharidae														
morpho spp. 1–3	6	2	10	10	2	6	8							44
Carabidae														
morpho spp. 1–15	18	7	4	6	6	16	7	19	7	2				92
Cerambycidae														
Anelaphus parallelus (Newman)					1									1
Anelaphus villosus (Fabricius)								1						1
Clytus ruricola (Olivier)				1										1
Cyrtophorus verrucosus (Olivier)					3									3
Eupogonius pauper LeConte										1				1
Obrium rufulum Gahan					2									2

Codon key:
BR: Brewer Lake Cass County Park and Campgrounds
CA: Casselton reservoir/Tinta Tawa Park
CH: Chrisan subdivision
CP: Chahinkapa Park
EK-CP: Albert K. Ekre Grassland Preserve - cow pasture
EK-WL: Albert K. Ekre Grassland Preserve - woodland area
HO: Horse Trailhead
JA: Jay V. Wessels SWMA
LA: Lake Elsie
LO: Lower Wild Rice and Red River Cemetery
TE-CW: Tewaukon NWR - Cutler's Woods
TE-PE: Tewaukon NWR - Lake Tewaukon peninsula
TR: TreFoil Park

	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	TE-PE	TR	JA	CA	CP	HO	Total
Phymatodes amoenus (Say)			1											1
Psenocerus supernotatus (Say)				1										1
Saperda tridentata Olivier								1						1
Stenocorus schaumii (LeConte)			1	1										2
Sternidius alpha Say									1					1
Trigonarthris minnesotana (Casey)				1										1
Chrysomelidae														
Alticini (tribe) sp.				1										1
Crepidodera nana (Say)								1						1
Diabrotica sp.(vergifera group)	1								2					3
Diabrotica undecimpunctata howardi Barber		1												1
Galerucinae sp.						1								1
Pachybrachis sp.					3									3
Phyllotreta cruciferae (Goeze)			1								1			2
Phyllotreta robusta LeConte				1										1
Phyllotreta striolata (Fabricius)						1								1
Rhabdopterus deceptor Barber								1						1
Cleridae														
Cymatodera sp.				1			1	1						3
Enoclerus sp.				1				1						2
Madoniella sp.								2	1					3
Phyllobaenus sp.			1		1	2								4
Zenodosus sanguineus (Say)	1			3	1			1						6

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TR: TreFoil Park

	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	TE-PE	TR	JA	CA	CP	HO	Total
Coccinellidae														
Chilocorus sp.												2		2
Harmonia axyridis (Pallas)		1				1		1	1					4
Hippodamia convergens Guérin-Méneville								1						1
Hippodamia tredecimpunctata (Linnaeus)								1						1
Hyperaspis sp.					1							1		2
Psyllobora vigintimaculata (Say)				2	10			2						14
Cryptophagidae														
morpho spp. 1–5	197		48	19	37	25	7	2	6					341
Cucujidae														
Cucujus clavipes Fabricius				1										1
Cupedidae														
Tenomerga cinerea (Say)		1												1
Curculionidae														
Conotrachelus anaglypticus (Say)			1	1	1									3
Conotrachelus posticatus Boheman						1								1
Dryophthorus americanus Bedel					1									1
Hylesinus aculeatus Say	3				2	1		2	2					10
Hylesinus criddlei (Swaine)	3	4				1		2	1					11
Hylesinus fasciatus LeConte	5						1	1						7
Hylesinus pruinosus Eichhoff		1						1						2

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TR: TreFoil Park

	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	TE-PE	TR	JA	CA	CP	HO	Total
Hylurgopinus rufipes (Eichhoff)	13	4	2	2		2	6	6						35
Isochnus rufipes (LeConte)			2	56										58
Lignyodes bischoffi (Blatchley)					2	10	1		2		3			18
Lignyodes helvolus (LeConte)			2		8	2			3		2			17
Lignyodes horridulus (Casey)	4		3		2	2			8		10			29
Lignyodes ocularis (Casey)	2		2		2				8		3			17
Orchestes pallicornis Say					2	4		1						7
Parenthis sp.	1													1
Phloeophagus sp.	1		3	3				2						9
Phloeotribus dentifrons (Blackman)		1						1						2
Pityophthorus sp.	1								1					2
Rhinoncus sp.							1							1
Rhyncolus sp.			3											3
Scolytini (tribe) sp.	2													2
Scolytus schevyrewi Semenov	4													4
Stenoscelis brevis (Boheman)		7	30	45	5	3	18		3					111
Tychius meliloti Stephens	1				3						1			5
Dermestidae														
Dermestes morpho spp. 1–2					2	1								3
morpho spp. 1–7	3	1	5	12	18	3		1	4	2	3		2	54
Dytiscidae														
Celina sp.	1					1								2
Dytiscus sp.				1										1
Hydaticus sp.				1										1

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TE-PE: Tewaukon NWR - Lake Tewaukon peninsula
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	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	TE-PE	TR	JA	CA	CP	HO	Total
Elateridae														
Ampedus morpho spp. 1–5	2	10	13	10	56		4	14	2					111
Ctenicera sp.			2	3						1				6
Dalopius morpho spp. 1–2				3									1	4
Danosoma obtectum (Say)		1												1
Dolerosomus sp.				5										5
Hemicrepidius morpho spp. 1–2	3			1		2	3	13						22
Melanactes sp.		3	2		3		1							9
Melanotus sp.	3	3	104	3	2	11		23	22					171
Micrathous sp.				1			1							2
Sericus sp.	2			1										3
Erotylidae														
Triplax sp.				1										1
Triplax thoracica Say					1									1
Eucnemidae														
Eucnemidae sp.			1					5						6
Haliplidae														
Haliplus sp.						1								1
Heteroceridae														
Augyles sp.	1							1						2
Histeridae														
Anapleus sp.								1						1
Dendrophilus sp.								2						2
Geomysaprinus sp.					1									1
Margarinotus sp.				1										1
Platylomalus sp.	1													1
Platysoma sp.			1					1						2
Teretrius sp.	1													1
Hydrochidae														
Hydrochus sp.	4					8	1		2					15

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Hydrophilidae														
Ametor scabrosus (Horn)										1				1
Sphaeridium scarabaeoides (Linnaeus)				1										1
Tropisternus lateralis nimbatus (Say)						1			2					3
Lampyridae														
Ellychnia morpho spp. 1–2				11	1					2	1			15
morpho spp. 1–3			1		3		2	2						8
Photuris sp.		1	6		2		1							10
Pyractomena morpho spp. 1–2				3			1							4
Latridiidae														
morpho spp. 1–3	52	6	65	109	25	52	108	46	33	10	1	1		508
Lucanidae														
Ceruchus striatus LeConte					1									1
Meloidae														
Pseudozonitis sp.			1											1
Mordellidae														
Mordellamorpho morpho spp. 1–2			1	3										4
Mordellariamorpho morpho spp. 1–2				2		1								3
Mordellistena morpho spp. 1–4		7	9	5	17	2	3	9	1					53
Nitidulidae														
Carpophilus brachypterus (Say)	57		3	19	2	5	9	1	6					102
Glischrochilus fasciatus (Olivier)	229	1	21	183	7	148	20	6	8					623
Glischrochilus lecontei Brown								4						4

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Phenolia grossa (Fabricius)			1		9									10
Passandridae														
Catogenus rufus (Fabricius)			3		1									4
Catogenus sp.		2	1	1				2						6
Passandridae sp.				1		1								2
Taphroscelidia linearis (LeConte)								1						1
Ptiliidae														
Ptiliidae sp.	1	1	4	3		2	1	1						13
Scarabaeidae														
Ataenius sp.	1			1		4			1					7
Euphoria sp.	1							1						2
Gronocarus sp.								1						1
Osmoderma subplanta Casey		5	1	1	1	1			2					11
Phyllophaga (subgenus) sp.	3						2	1						6
Scirtidae														
Cyphon sp.	21	2	17	16	99	9	38	29	2	2	4			239
Scirtes orbiculatus Fabricius		1												1
Scirtidae sp.		3					2	4	1	3				13
Silphidae														
Necrophila americana (Linnaeus)					3									3
Nicrophorus orbicollis Say				2	4									6
Nicrophorus pustulatus Herschel			2	1										3
Nicrophorus tomentosus Weber				14	2									16
Oiceoptoma noveboracense (Forster)				4										4

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	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	TE-PE	TR	JA	CA	CP	HO	Total
Staphylinidae														
morpho spp. 1–21	80	27	38	30	24	161	7	9	35	6				417
Trogossitidae														
Tenebroides sp.	2	1		6		2	3	2	2	1				19
Totals:	731	114	424	617	399	527	259	248	174	31	29	4	3	3560

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APPENDIX C. HEMIPTERA (HETEROPTERA) IDENTIFIED IN THIS SURVEY

Hemiptera (Heteroptera) identified in this survey, organized by number of species found at each site.

	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	TE-PE	TR	JA	CA	CP	HO	Total
Anthocoridae														
Orius sp.									1					1
morpho sp.	5	5	5	1	2	9		5	6					38
Corixidae														
morpho sp.		1												1
Lygaeidae														
Nysius sp.	1													1
Miridae														
Capsus sp.	1			1										2
Ceratocapsus sp.								1	1					2
Corticoris pulchellus (Heidemann)		1					1	1	1					4
Corticoris signatus (Heidemann)						9	1		2					12
Deraeocoris morpho spp. 1–2					1	1	1		1	2				6
Eurychilopterella luridula Reuter						3			1					4
Eurychilopterella sp.						1								1
Hyaliodes harti Knight										1				1
Hyaliodes vitripennis (Say)		4							1			1		6
Lygidea sp.													1	1
Lygocoris sp.		3	4	1	4								5	17
Lygus morpho spp. 1–2	2	1	2						2					7
Metriorhynchomiris dislocatus (Say)					2									2
Metriorrhynchomiris sp.										1				1
Neoborella sp.			1							1				2
Peritropis saldaeformis Uhler		1				25	1	2	3					32
Phytocoris sp.	1		5		1	4			5					16

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Plagiognathus morpho spp. 1–2		1			1	2			10					14
Trigonotylus antennatus Kelton					1									1
Tropidosteptes amoenus Reuter	12	47	48	10	1	9			48		7	34		216
Tropidosteptes brooksi Kelton		1	1	1										3
Tropidosteptes canadensis Van Duzee		1							1					2
Tropidosteptes commissuralis (Reuter)										20				20
Tropidosteptes glaber (Knight)									1					1
Tropidosteptes plagifer Reuter		6	2	6		1			3	1				19
Nabidae														
Lasiomerus annulatus (Reuter)								1						1
Pachygronthidae														
Oedancala dorsalis (Say)													1	1
Pentatomidae														
Banasa dimidiata (Say)			4											4
Brochymena quadripustulata (Fabricius)							1						1	
Euschistus tristigmus (Say)				2	3									5
Euschistus variolarius (Palisot)							1							1
Piesmatidae														
Piesma sp.	1	1	15	4			1							22
Reduviidae														
Acholla multispinosa (De Geer)						1								1
Rhyparochromidae														
morpho sp.	2													2
Saldidae														
Saldula sp.	1													1

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	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	TE-PE	TR	JA	CA	CP	HO	Total
Tingidae														
Corythucha arcuata (Say)			1	1				2	1					5
Leptoypha mutica (Say)	73			45	1	1	48	8		2		2	6	186
Physatocheila variegata Parshley										1				1
Veliidae														
Microvelia sp.		1												1
Totals:	99	74	88	72	17	66	54	21	88	29	7	37	13	665

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APPENDIX D. LEPIDOPTERA IDENTIFIED IN THIS SURVEY

Lepidoptera identified in this survey, organized by species found and identified at each site. No specimens were identified from TE-PE, TR, CA, CP, or HO, and are therefore not included in this table.

	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	JA	Total:
Arctiidae									
Ctenucha virginica (Esper)			1						1
Hypoprepia fucosa Hübner			2					2	4
Lycaenidae									
Satyrium titus (Fabricius)								1	1
Noctuidae									
Abrostola urentis Guenée				1					1
Amphipyra pyramidoides Guenée	15		1						16
Anagrapha falcifera (Kirby)						1			1
Apamea devastator (Brace)						1			1
Apamea lignicolora (Guenée)			2						2
Catocala ultronia (Hubner)			1						1
Enargia decolor (Walker)								1	1
Euxoa tessellata (Harris)			2			1			3
Feltia jaculifera (Guenée)			1						1
Feltia subgothica (Haworth)			7						7
Hyppa xylinoides (Guenée)	1								1
Lacinipolia olivacea (Morrison)	1								1
Noctua pronuba (Linnaeus)						1			1
Peridroma saucia (Hübner)				1					1
Spaelotis bicava Lafontaine	1		1						2
Spaelotis clandestina (Harris)			1						1
Xestia dolosa Franclemont			2						2
Agrotis sp.			1						1
Eueretagrotis sp.		1	2		1		1		5
Eurois sp.				1					1
Euxoa sp.	1		1	2	1	1			6
Graphiphora sp.	1		1						2
Hypena sp.				3					3
Protolampra sp.				1					1
Nymphalidae									
Enodia anthedon Clark				1					1
Nymphalis antiopa (Linnaeus)			2			1			3

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	BR	CH	EK-CP	EK-WL	LA	LO	TE-CW	JA	Total:
Vanessa atalanta (Linnaeus)			3						3
Sphingidae									
Ceratomia undulosa (Walker)				1					1
Totals:	20	1	31	11	2	6	1	4	76

CODON KEY:
BR: BREWER LAKE CASS COUNTY PARK AND CAMPGROUNDS
CH: CHRISAN SUBDIVISION
EK-CP: ALBERT K. EKRE GRASSLAND PRESERVE - COW PASTURE
EK-WL: ALBERT K. EKRE GRASSLAND PRESERVE - WOODLAND AREA
JA: JAY V. WESSELS SWMA
LA: LAKE ELSIE
LO: LOWER WILD RICE AND RED RIVER CEMETERY
TE-CW: TEWAUKON NWR - CUTLER'S WOODS