ANISOTA SENATORIA HABITAT SELECTION ANALYSIS IN PINERY PROVINCIAL PARK, ONTARIO, CANADA

by

Jacob Perfect

Source: Jacob A. Perfect
Pinery Provincial Park
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FACULTY OF NATURAL RESOURCES MANAGEMENT
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ANISOTA SENATORIA HABITAT ANALYSIS IN

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Jacob A. Perfect

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Major Advisor: Dr. Don Henne Second Reader: Dr. Lense Meyer

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ABSTRACT

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Keywords: orange-striped oakworm, *Anisota senatoria* J.E. Smith, red oak (*Q. rubra* L.), habitat selection analysis, Pinery Provincial Park, Ontario.

The orange-striped oakworm, *Anisota senatoria* J.E. Smith, is a late-season defoliator of oaks in eastern North America, and occasionally causes severe defoliation during outbreaks. However, little is known about host selection characteristics of this insect. *A. senatoria* typically feeds on the oak family, and red oak (*Q. rubra* L.) is considered a preferred host. The purpose of this thesis project is to statistically analyze possible relationships between habitat attributes and the habitat selection of orange-striped oakworm larvae in Pinery Provincial Park, Ontario. The collection of quantitative data related to the specific habitat qualities where *A. senatoria* larvae were present as well as absent, were recorded within Pinery Provincial Park. This created an opportunity to quantitatively analyze possible relationships existing between habitat selection and local habitat qualities, within tree and stand level areas. A habitat selection index is what is hoped to be produced and further compared to current as well as past literature on *A. senatoria* habitat selection. At Pinery Provincial Park, *A. senatoria* was found on the lower branches of the host tree and increases its feeding in response to low nitrogen leaf content. Trees selected by *A. senatoria* were found in plots with at least 46.6.% red oak composition or more, a plot density of 6.2 stems per 10 metres squared, and lower branches with late season red oak foliage at 3.88 metres from the ground with an ordinal range between 90-270^{0}.

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INTRODUCTION

The geographic region occupied by the oak family (*Quercus*) in Ontario, is distributed as far north as northwestern Ontario and as south as the Windsor-Sarnia region. The more northern the region, the fewer oak species will be found. In Ontario, bur oak (*Quercus macrocarpa* Michx.), is one of the most widely distributed species in the oak family (upland and lowland) with northern red oak (*Q. rubra* L.), a mesic-upland species, next in line.

Red oak reaches the northern and southern limits of the oak family distribution range in Ontario. Red oaks are found in rare forest types in the southern regions of Ontario (*i.e.*, oak savanna) and as a part of hardwood mixed-wood forests in the central regions of Ontario (Natural resources Canada 2015, Government of Ontario. 2019). Red oak is an important species for timber products as it is rich in colour, very strong and durable, and has excellent grain. These qualities make it perfect for interior design products such as cabinetry, furniture and flooring (Government of Ontario. 2019). Because of this, red oak is of economic importance and should be managed properly for economic as well as ecological purposes.

Ecologically, red oak provides habitat and food sources to many forms of native wildlife species (Land Owner Resource Center and OMNR 1995). Roughly a third of its distribution is found on private land sectors of Ontario, and the other two thirds in the central Great Lakes St. Lawrence (GLSL) regions.

In the GLSL region, forest management units are present. There are forest management plan guides attributed to the specific unit and contain specific guidelines for governed oak forest management. The private landscape sectors have no such provincial government manuals for silviculture, nor any pest management protocol (Government of Ontario 2019). Since red oak is an important species and a large portion of its distribution is on private land, it is crucial to develop an understanding of its pests' habitat selection, biology and behaviour. With this locality-based understanding, the threat of possible insect outbreaks in the urban forest landscape, fragmentated natural landscapes, and within private oak woodlots may be alleviated or better understood. Oak populations in southern Ontario are at risk of degradation on the landscape due to many stresses. Their ecology should be better understood by landowners simply for the purpose of adding depth to knowledge surrounding the dynamic interspecific interactions which exist between insects and trees, specifically the oak family. This, in turn, will provide knowledge for protection and production management decisions (Land Owner Resource Center and OMNR 1995, Elliot 1998).

Oaks are favored hostplants by many species of insects, some of which are known to have spectacular outbreaks that cause widespread defoliation of many species of oaks. One such insect, the orangestriped oakworm, (*Anisota senatoria* J.E. Smith) (Lepidoptera: Saturniidae), tends to select the oak family for its host plants, and occasionally causes severe defoliation of oaks. It is distributed across eastern North America (Ferguson 1971) and red oak is one its preferred hosts (Coffelt and Schultz 1993).

This thesis project analyzed the relationship between the presence of orangestriped oakworm and various habitat elements where they are located: 1. diameter at breast height of the occupied tree, 2. percent composition of host trees within the occupied plot, 3. number of stems within the occupied plot, 4. height of the occupied branch from the ground, and 5. the cardinal orientation of the occupied branch. *A. senatoria* tends to be found on the lower branches of the host tree (Hitchcock 1958, Coffelt 1992) and increases its feeding in response to low nitrogen leaf content (Lawson et al.1984).

The aim of this thesis project is to provide further ecological knowledge on *A. senatoria* and to develop a habitat selection index for larval *A. senatoria*. A habitat selection index would provide landowners, or for conservation experts interested in monitoring native insect populations, a place to start in their pest management practice. This “place to start” is where the larval population begins its foliar feeding process, identified by the habitat selection correlation tests provided. This way *A. senatroria* larval populations may be promptly located by landowners and conservation scientists. They then can be monitored throughout the growing season for effective management decisions.

In order to quantify the relationships between *A. senatoria* larval habitat selection and specific habitat qualities (listed above), data was first collected in three forested locations in southwestern Ontario. Inventories of these three separate forest areas were conducted in order to quantify and analyze the candidate habitat, using differences in certain variables. Tree species composition, stem density and diameter at breast height were recorded in 10 m by 10 m plots in each forest. Presence or absence of *A. senatoria* larvae was observed and recorded. Of the three forests, *A. senatoria* was only found to be present in the Pinery Provincial Park forest, on red oak trees. Within tree data was collected on all oak species for habitat attributes such as the lowest branch height (m), branch orientation (cardinal direction - 360°), dbh (cm), and tree species type; where *A. senatoria* was present as well as absent. An inventory of the surrounding 10 m^2 plot was also conducted following the previous protocol. Understory notes and photographs were taken for the purpose of identifying keys features coinciding with larval presence.

OBJECTIVES

The objective of this undergraduate thesis project is to analyse the correlation strength between *A. senatoria* larval habitat selection (presence) and specific habitat variables (lowest live branch height, plot density, dbh, lowest branch orientation, and percent red oak composition).

HYPOTHESIS

It was hypothesized that *A. senatoria* larval presence does not have any existing or notable correlations with the identified local habitat features; within the tree or at the stand level

LITERATURE REVIEW

DESCRIPTION

Late instar larvae of *A. senatoria*, displayed in figure 1.1, are conspicuously different from larvae of other species in the genus *Anisota*, except for *A. finlaysoni*, which looks very similar to *A. senatoria* but has much shorter thoracic horns and occurs further east in Ontario. Larvae of *A. senatoria* are almost entirely black, including the head, and have eight yellow or orange brightly coloured lines running longitudinally along the body. The spines of the body are not much bigger than small tubercles. The thoracic horns are well developed and can be variable in length (Ferguson 1971, Riotte and Peigler 1980, Coffelt 1992).

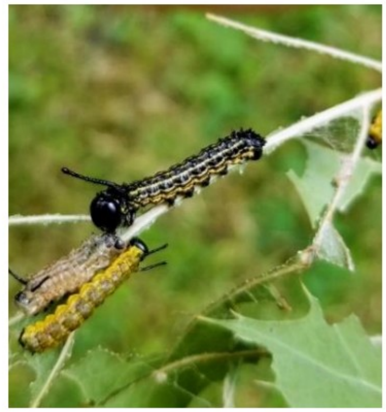

Figure 1.1 *Anisota senatoria* larvae, late instars. Source: Jacob Perfect, Pinery Provincial Park (late August, 2019)

LIFE CYCLE

Adult moths

Adults of *A. senatoria* are active from late June until early August. It is a thick moth, covered densely in fine yellow reddish hairs over its body (Hitchcock 1958, Ferguson 1971, Coffelt 1992). The wings are an orange purple spanning 5-6 cm in females and 2.5-3 cm in males (Hitchcock 1958, Siegert and McCullough 1998). There is a prominent single white spot and multiple black spots located on the fore wings (Hitchcock 1958, Ferguson 1971, Riotte and Peigler 1980, Coffelt 1992, Porter 199, Siegert and McCullough 1998). The male moth has feathery antenna and is of a brighter colouring than the larger female moth (Hitchcock 1958, Ferguson 1971, Siegert and McCullough 1998). The adults are known to mate on low lying structures in the forest such as tree trunks, low bushes, and or blades of grass (Hitchcock 1958 and Coffelt 1992).

Figure 1.2 Anisota senatoria, male (right) and female (left) moth.
Source: Moth photographers group Mississippi State University, Jim Vargo.

Eggs

The adult female of *A. senatoria* lays clutches of eggs, roughly 200-700 per clutch (Hitchcock 1958), on the underside of oak leaves. Females are said to be weak fliers and therefore 90% of the clutches are laid within three to five metres from the ground, on terminal twigs (Hitchcock 1958, Coffelt 1992, Porter 1997). Eggs are yellow and eclose in 7-10 days (Riotte and Peigler 1980, Coffelt 1992).

Larvae

Fifth instar larvae of *Anisota* are less gregarious than the early instars (Coffelt 1992, Porter 1997,) but they consume entire leaves except for the main vein (Hitchcock 1958, Coffelt 1992,). Defoliation occurs in late August through September, which classifies the Orange-striped oakworm as a late season defoliator. *Anisota senatoria* larvae have the ability to assimilate nitrogen from oak leaves more efficiently than early season defoliators. Therefore, they select leaves to feed on that have a low nitrogen content. This is without having to sacrifice their growth rates. The larvae will actually increase their consumption rates in response to decreased nitrogen content in leaves (Lawson 1984). During the months of September and October the mature larva drop to the forest floor and penetrate the leaf litter layer until they are obstructed by a layer of rootlets and humus. The larva searches out a place to pupate in the soil and burrow 7-10 cm beneath the surface (Hitchcock 1958, Ferguson 1971, Coffelt 1992).

Pupae

There is no cocoon spun once mature larvae have reached their destination and there is no cell excavated for the pupa to occupy (Hitchcock 1958). The pupa is brown and roughly 2-3 cm in length. They are covered with short spines and have sharp bifid cremaster which are slightly turned outwards (Hitchcock 1958, Ferguson 1971, Riotte and Peigler 1980, Coffelt 1992, Porter 1997). Pupae overwinter, then use their spines to maneuver and protrude through the soil in late June (Coffelt 1992)

DISTRIBUTION

North America

Anisota senatoria has a large distribution across North America. The southern limits of its range include the Gulf Coast states: Florida, Georgia, Virginia, Mississippi and west to Texas. The mideastern to midwestern range of its distribution as reported includes Connecticut, Massachusetts, Rhode Island, Iowa, Wisconsin and St. Louis. (Ferguson 1971 and Coffelt 1992). The northern ranges of its distribution include southwestern Ontario (Coffelt 1992).

Ontario

In order to delineate the historical distribution and the most recent recorded distribution of *A. senatoria* within Ontario, Forest Insect and Disease Reports published by the Canadian Forest Insect and Disease Surveys of Napanee, Wingham, Niagara, and Chatham regions, and the Province of Ontario from 1950-1980 were reviewed, as well as any other forest insect and disease reports available for Ontario published by the Ontario Ministry of Natural Resources.

Between 1950 and 1960, *A. senatoria* was present in Ontario within the Napanee, Wingham, Niagara, and Chatham regions. Within the Napanee region of southwestern Ontario, *A. senatoria* was reported along the Trent river in South Hastings county (1951), and in Sidney, Thurlow, Richmond and Sophiasburg Townships in 1952. It was reported in Richmond and Camden townships in 1953. From 1954-1955 it was present in Portland, Kingston, and both North and South Fredericksburg townships. From 1955 to 1959 it was located in the following locations: Shannonville (Tyendinaga Twp.), as well as Ameliasburgh and Sophiasburgh townships., north and south Fredericksburgh townships., and Thurlow, Hilliard and Ameliasburgh townships. Within the Wingham region during this time it was reported in the townships of Hay and Stephen. It was not reported at all from 1954 - 1980. The region of Niagara had reports of *A. senatoria* in the following regions from 1950-1960; Bertie township and the Dunnville area. The Chatham region had reports of *A. senatoria* in north and south Colchester townships, Essex County, and Bosanquet township.

Between 1960 and 1970 *A. senatoria* was located in the following regions; Napanee, Niagara and Chatham. Within the Napanee region, it was reported in the following areas; Sidney, Thurlow, Tyendinaga and Hallowell townships. In 1960 heavy pockets of infestation across the entire district were reported, but by 1961 populations had declined to small pockets of defoliation scattered across the region. In the Niagara region within this time frame it was located in; Seneca, Wainfleet, Bertie, Canborough, and Caistor townships. In the Chatham region between 1960 and 1970 it was located in Ridgetown in Howard township, Pinery Provincial Park in Bosanquet township and in Dawn township.

From 1970 to 1980 *A. senatoria* was reported in the regions of Napanee and Chatham. In Napanee, it was not reported from 1969-1974 but, following 1974 caterpillars of *A. senatoria* were reported in Kingston, Gananoque and along roads in Richmond, Tyendinaga, Thurlow and Sophiasburgh townships. In the Chatham region *A. senatoria* was not reported between 1968-1976. Following 1976 there was severe defoliation observed on white oak in Tilbury Township and light defoliation occurred on single open-grown oak trees at Rondeau Provincial Park.

In a 1966 report titled "The Status of Insects in the Lake Erie District", *A. senatoria* was reported increasing in intensity at Pinery Provincial Park. Defoliation was heavy on a small red oak at the Park entrance, moderate to heavy on six small trees along nature trails and moderate on individual red oak trees along roadsides in the Park. Along Highway 21 in this area occasional red oaks under 4-m in height were severely defoliated. At several points as many as four trees on one side of one mile of roadside were completely stripped. Moderate defoliation recurred on the lower branches of two mature bur oak trees near Glencoe, and on the lower branches of a mature open-grown white oak near Smithville.

In the 2006 Ontario-wide Forest Health and Condition Report (FHC), *A. senatoria* had high populations and caused up to 100% defoliation on the lower branches of mature oak trees and completely stripped juvenile oak trees along the edge of a spruce-pine woodlot near Brantford airport in Brant County, Guelph District. In the same report from 2007 *A. senatoria* was reported causing severe defoliation of juvenile bur and red oaks in the understory of a wooded area within the city of London, Aylmer District. Moderate defoliation occurred on mature red oaks within the same stand, leaving the lower branches completely bare. In 2008 the Ontario Forest Health and Condition report noted that *A. senatoria* caused moderate defoliation on oaks at Pinery Provincial Park, Aylmer District. Defoliation averaged 30% on the host (Figure 1.3).

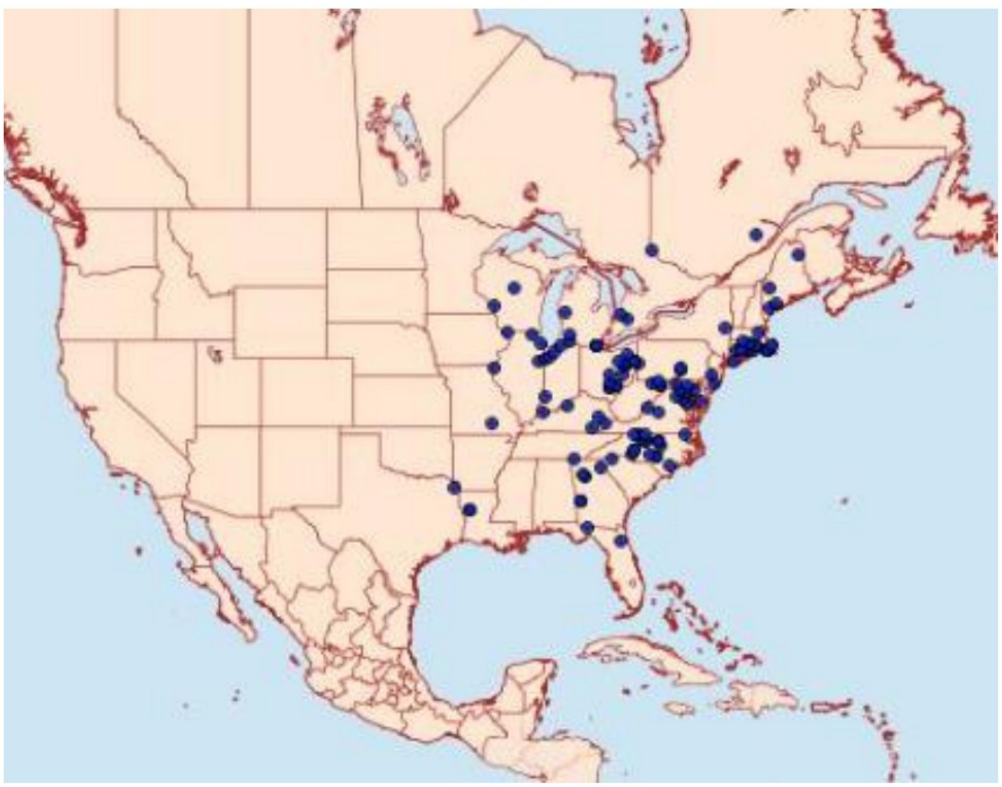

Figure 1.3 *Anisota senatoria* distribution in North America.
Source: Moth photographers group Mississippi State University.

Within tree distribution

Anisota senatoria has been studied for many years, at least from 1797 when Dr. James Edward Smith first described it, to the present (Lawson *et al.* 1984, Coffelt 1992, FHC 2008). There are reports of the specific host trees that it selects in different geographic regions of its distribution, the forest types in which it is located (Ferguson 1971), the characteristics of selected trees (open grown and juveniles), and the physical locations on the trees and branches that are occupied by larvae of *A. senatoria*. (Hitchcock 1958, FIDS 1950-1980, FHC 2006-2008).

The within tree distribution of *A. senatoria* was mentioned by Coffelt (1992) while studying the chronological distribution patterns of *A. senatoria* larvae through its instar stages. In Coffelt (1992) it is stated oviposition occurs on branches 3-4 metres from the ground (Hitchcock 1958), low stadia in the canopy ranging between (1.7-3.6 m), middle (3.7-5.5 m) and high (5.6-7.6 m). The distribution distances were greatest in early instars and lowest in adults (Coffelt 1992). In Lawson *et al.* (1984) there was a comparison of the feeding patterns and digestive qualities of *A. pomentaria*, the early season defoliator and *A. senatoria*, the late season defoliator. It was determined that *A. senatoria* increases consumption rates in response to lower nitrogen content in tree leaves and that its growth rate is independent of nitrogen content.

HOST TREE SPECIES AND SUITABILITY

The host tree species of *A. senatoria* have been noted by many experts over the past century and is known to most often be within the oak genus (*Quercus spp.*) (Ferguson 1971). *Anisota senatoria* was also thought to feed on the raspberry family

(*Rubus spp*.). Such alternate host selection for feeding has not since been observed and therefore has been discredited (Ferguson 1971).

Anisota senatoria feeds primarily on white oaks, red oak, black (*Q. nigra* L.), pin (*Quercus palustris* Münchh.), bur, scarlet (*Q. coccinea Muenchh.*), scrub and swamp white oak (*Q. bicolor* Willd.) (Ferguson 1971, Coffelt 1992). The particular oak species *A. senatoria* chooses as a host, seems to have no observable or hierarchical pattern, considering its distribution as a whole (Hitchcock 1958, Ferguson 1971, Coffelt 1992). However, the specific geographic region where a particular *A. senatoria* population occurs seems to determine which species of oak the adult female moth will select for oviposition and, ultimately, larval feeding (Ferguson 1971, Coffelt 1992).

In the southern parts of its range along the Gulf Coast states *A. senatoria* has been known to select *Q. palustris* and *Q. phellos* as preferred oak host tree species. In the mid east to mid western ranges of its distribution (Connecticut, Massachusetts, Rhode Island, Iowa, Wisconsin, St. Louis) *A. senatoria* has been reported to feed on most of the oak species (Ferguson 1971 and Coffelt 1992). In Pennsylvania, *senatoria* was reported feeding on *Q. velutina, Q. ilicifolia* and *Q. coccinea*. In New York it was reported feeding on *Q. ilicifolia* and *Q. prinus.* In the northern ranges of its distribution, reaching into south western Ontario, *A. senatoria* has been known to select white oak (*Q. alba* L.) and red oak as its preferred host species (Coffelt 1992).

Anisota appears to prefer species from the oak family that do not have tough, pubescent or evergreen leaves (Riotte and Peigler 1980, Coffelt 1992). Though, *A. senatoria* is known to select hosts exclusively from the oak family, in years of heavy outbreak populations, *A. senatoria* will select host tree species from other families.

Anisota senatoria have been reported from *Betula spp*., *Acer spp*., *Corylus spp*., *Carya spp*., *Castanea spp*., and *Fagus spp*. (Hitchcock 1958, 1961a, 1961b; Ferguson 1971; Coffelt 1992). An article by Coffelt and Schultz (1993) describes a study conducted to determine host plant suitability of *A. senatoria*. It was determined by tree defoliation, percentage survival, developmental rate, pupal weight and oviposition that the most suitable hosts in order from most suitable to least: pin oak, scarlet oak, willow oak (*Q. phellos L.*), northern red oak (*Q. rubra borealis* L.), and sawtooth, oak (*Q. acutissima* Carruth.); intermediate in swamp white oak, chestnut oak (*Q. prinus* Willd.), southern red oak (*Q.falcata* L.), bur oak (*Q. macrocarpa*), water oak (*Q. nigra* L.) and least in white oak (*Q. alba*). The study determined that planting less suitable species in the urban landscape, like white oak, may contribute to lower *A. senatoria* populations. It was also noted that those tree species which were highly suitable to *A. senatoria* (pin oak, scarlet oak, willow oak, northern red oak, and sawtooth oak) showed significant difference from the lower two, less suitable tiers.

IMPACTS

Economic and social

Hitchcock (1958) reported on the severity and damage caused from the orange-striped oakworm in Connecticut. He described *A. senatoria* outbreaks as sporadic and quite localized and included the Thames River Valley as well as private woodlots throughout Connecticut. Outbreaks appeared consistently in the same areas, a pattern which has been observed in other regions of the United States and Canada. He noted that damage was primarily defoliation ranging in severity and coinciding effects. Serious defoliation does not occur until late August or September, which is only a few months before oak trees would lose their leaves anyway. This results in little permanent damage to mature oak trees. However, sapling oaks that are completely defoliated earlier in the season suffer more damage than mature oaks. Saplings most often suffer complete defoliation which deprives them of important growing days. Hitchcock notes that little attention has been given to these outbreaks as they are were typically in isolated woodlots. However, when infestations occurred within inhabited woodlands and on urban yard trees other concerns arose. The outbreaks leave a large number of droppings on one's lawn, and larvae creep up the sides of homes near outbreak sites and sometimes inside the walls. Though it was noted as a nuisance it is not harmful to humans.

Coffelt, and Schultz (1991) noted that when citizens were shown a photograph of *A. senatoria* fifth instar stage and asked "Has this insect been a serious problem to the trees in your yard?" the majority of residents (98.5%) responded "yes". The data indicates that citizens identified *A. senatoria* as the major shade tree defoliator in Norfolk, Virginia and that most citizens were willing to tolerate up to 70% defoliation. When citizens were asked if they ever called city officials to request *A. senatoria* pesticide application and 61% responded "yes". This was a public service provided at no cost. However, over half of citizens (54%) would hire a professional to treat their private or city trees if city officials did not spray. The results of the study indicate that citizens attitudes towards host aesthetics were that tree care was important as well as applying regular water and fertilization treatments. When asked if *A. senatoria* defoliation would kill their trees, 73% of citizens responded "yes". Citizens felt that defoliation in August and September was serious and that mortality may occur. This contradicts research which indicates late season defoliation has less physiological impact on tree vigor than early season defoliation. Though Coffelt and Schultz (1988) note within their article (1991), three mature oak trees which had received four years of successive *A. senatoria* defoliation died, other factors such as physiological stress and disease may have contributed to tree mortality. The results of the study towards IPM show a citizenship which accepts the concept of tolerance levels for *A. senatoria* defoliation finds natural control as acceptable. These responses indicated to Coffelt and Schultz (1988) that IPM tactics such as aesthetic thresholds and injury levels are viable options for urban insect management strategies.

Effect of defoliation on host

Coffelt (1992) reported on the impact of late season *A. senatoria* defoliation on oak tree growth and vigor. It was found that *Q. palustris* that experienced 100% defoliation for 3-5 consecutive years had significantly lower starch when compared with undefoliated trees on all sample dates. *Q. palustris* sampled in September, after 3-5 years of consecutive defoliation, had 56 and 76% lower starch levels when compared to undefoliated. Trees which had 24% percent defoliation did not show significant differences in starch content when compared to undefoliated trees.

PREDATORS AND PARASITES

Hitchcock (1961) reported on parasitism of *A. senatoria* in Connecticut. He studied egg mass populations and larval survivorship of *A. senatoria* during the period of an outbreak. Areas of infestation were surveyed at regular intervals to assess *A. senatoria* populations and their associated predators and parasites. In 1959 he found an average of 69-216 eggs per mass, 23-74 percent of which were parasitized by *Trichogramma pretiosa* and/or *Podisus* sp. There was a major drop observed in average percent parasitism from 1959 to 1960 (59%- 24%). Hitchcock hypothesized that this was due to the fact that an insecticide spray was applied in 1959 in order to control the larval population of *A. senatoria*. The spray process had faults and resulted in little to no population reduction of the larvae. However, Hitchcock (1961) stated that it was possible that the spray reduced population levels of the parasites back to normal levels from 1959. Hitchcock suggests that insecticides may have actually ended up increasing larval populations of *A. senatoria*, due to the fact that natural enemy populations were drastically lowered by a poorly timed spray. The results from the larval survivorship experiments showed a larger percentage of larval mortality occurred in early instars with small larval populations whereas very little loss occurred in the early instars at the higher population levels (Hitchcock 1960).

MATERIALS AND METHODS

Presence and absence surveys for *A. senatoria* in Pinery Provincial Park were conducted first. This was a matter of researching current and past literature on local habitat selection of *A. senatoria* and then applying this knowledge to aid in searching for larvae within the park. An illustrative park map (Pinery Provincial Park visitors map, 2020) provided information on the different trail routes which might be taken take in order to cause the least amount of damage to the local fauna and ground cover while conducting surveys. Next, contact was with a park official, Tanya Berkers, a Resource Management Group Leader at the park, who provided this thesis with information on the forest types and the locations of such within the park. With knowledge of the forest types in the park, and previously reported *A. senatoria* preferences within Ontario the author was able to refine the search. Each trail was walked and the underside of oak leaves (white, black and red) were checked along the way. Binoculars were used to scout the higher branches and leaves. When larvae were located, the GPS coordinates and position within a specific google map were recorded. A total of four sites were located along the cedar trail and one site in the nearby parking lot island, close to the park's information center entrance.

The next day the author returned to the cedar trail and followed the marked coordinates in order to complete a habitat analysis of each tree and plot where the larvae were located. Host tree species type were evaluated using Farrar (1995). Next, the host tree diameter (dbh; cm) was measured using a standard 5-m dbh. tape.

The branch height from the ground of those branches selected by *A. senatoria*, were measured using a 100 m tape. A stick was tied to one end so it the tape could be thrown over the branch, similar to a light a grapple, to tighten it

Figure 2.1 Reading height measurements. Source: Jacob Perfect, P.P.P., 2019.

Figure 2.2 Height measurement method. Source: Jacob Perfect, P.P.P., 2019.

This was done in order to reduce slack in the line for the most accurate and precise branch height readings (see figure 2.1 and 2.2 above). The number of centimetres which the tied knot occupied on the tape was recorded at 15 cm. Therefore, each measurement had to have 15 cm subtracted from the original reading (see figure 2.3 below)

Next, orientation of the branches occupied by *A. sentaoria* were recorded. This was done by following Luckai and Luckai (2012) and standing directly below the branch with the author's back against the stem of the tree and aligning the compass with the terminal twig direction and recording the compass reading. Adjustments were made for magnetic declination at negative (west) eight degrees.

Figure 2.3 Measuring tape used for height sampling (grapple method).
Source: Jacob Perfect, Pinery Provincial Park (late August, 2019).

Immediately following the habitat analysis of each individual host tree, an inventory of the surrounding 10 m^2 plot was conducted. Pictures were taken of each inventory plot. The tree species, dbh, and number of trees within each plot were recorded using Farrar (1995) and a standard dbh tape. Understory notes and observations were made as to species types, ground cover amounts, and general topography notes to evaluate the possibility for correlation with habitat selection of *A. senatoria*.

After the habitat analysis of individual trees and the associated 10 m^2 plot inventories were completed, the identical analysis/inventory for *A. senatoria*-absent sites was done for the *A. senatoria* present sites. ive other sites along the cedar trail which were absent of *A. senatoria* but which looked similar to the sites where *A. senatoria* was present were chosen This was done in order to highlight specific attributes between habitat selection and habitat variable measurement ranges. Individual tree measurements as well as inventories within two other forests where *A. senatoria* was not found were also done. This was completed using the same methods described above and was done in order to add depth to significance testing. The first of the two "*A. senatoria*-

absent" forests were an oak overstory forest type which borders Pinery Provincial Park. The other forest was located within a different county in southern Ontario (Elgin County) and is not an oak forest type but more of a hardwood mixed-wood with some red oak composition.

All of the recorded data was transferred into Excel using the proper format to be statistically analyzed. The recorded variables from the individual trees where *A. senatoria* larvae were present (dbh, occupied branch height, and occupied branch orientation) as well as the plot data (number of stems per plot and percent red oak composition). The expected variables are the averages from; the five trees and corresponding plots where *A. senatoria* was present, all of the oak species, and all of the red oak trees alone. The lowest live branch height, rather than "occupied" branch height was used for trees that did not have *A. senatoria* presence. This was done because it was observed that *A. senatoria* selected the lowest branch of all five trees on which it was found.

The statistical analysis involved performing chi-squared significance tests where habitat attributes (% red oak composition, # stems/plot, height of the lowest branch from the ground, orientation of lowest branch, and diameter at breast height) from those trees selected by *A. senatoria* against the average from within that group (the five inhabited trees) were done. Habitat attributes from all oaks measured against habitat attribute values from all red oaks measured were also conducted. This was completed for all habitat characteristics separately. This was done in order to compare the significance of distribution of the habitat attributes against one another.

RESULTS

STUDY AREA DISCRIPTIONS

Site 1: Pinery Provincial Park.

Figure 3.1 Pinery Provincial Park (plot 3 image).

Common features observed throughout Pinery Provincial Park (see figure 3.1) were recorded as an overstory consisting of *Quercus* spp., an understory generally consisting of grasses, plant litter, and sedges. The soils were sandy, with little organic soil layer, coarse woody debris was prevalent, and topography was consistent with ancient dune structures.

Table 1.1 displays the plot summary data collected from all of the plots located within Pinery Provincial Park. The first five plots are the plots which had a tree within them which supported an *A. senatoria* population. It should be noted that the lowest branch of each selected tree was the branch occupied by *A. senatoria* populations. There was a range of 6-11 stems per plot. The percentage red oak per plot ranged from 0- 50%. The diameter at breast height ranged between 10 -44 cm dbh. The lowest live branch height (the height of the occupied branch from the ground) ranged from 1.7- 5.5 m. The orientation of the lowest live branch/occupied branch ranged between 159- 290^0

Table1.1 Pinery Provincial Park plot data. (* = *A. senatoria* presence, S.P.P. = Stems per plot, R.O.P. = red oak composition percent per plot (%), O.A.DBH = Oak average dbh (cm), L.L.B.H. = average of the oaks lowest branch height per plot (m), L.L.B.O. = The lowest live branch orientation of oaks within the plot (360^0)).

Plot	*S.P.P.*	*R.O.P.*	*O.Dbh*	*L.L.B.H.*	*L.L.B.O.*
**1*	6	50	14	1.7	159
**2*	4	50	44	3.5	216
**3*	8	50	20	2.3	229
**4*	4	50	23	2.5	147
**5*	9	33	24	3.6	175
6	11	0.0	43	4.5	216
7	5	0.0	37	3.6	281
8	4	0.0	35	3.8	243
9	9	0.0	10	2.9	290
10	3	0.0	29	5.5	223

Source: Pinery Provincial Park August 26th, 27th, 28th 2020 and APPENDIX I.

Figure 3.2 displays the plots located along the cedar trail. This study's data collection design followed a survey type format. Therefore, the plots were not systematically placed nor completely randomly placed. Rather, the plots were selected as the best representation of the forest conditions which were desired for testing against one another.

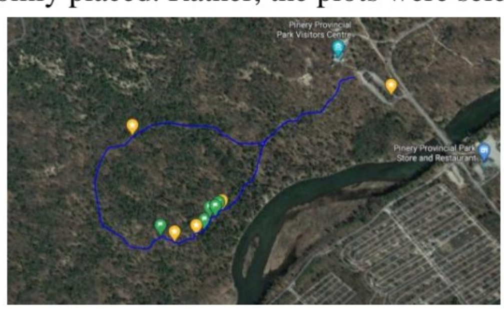

Figure 3.2 Pinery Provincial Park trail plot locations (yellow = selected)
Source: Jacob A. Perfect August, 2019 and Google maps

Site 2: Privately owned forested land bordering Pinery Provincial Park.

Figure 4.1 Privately owned forested land bordering Site 1. (canopy and understory). Source: Jacob A. Perfect August 2019.

Common features observed throughout the privately-owned forested land bordering Pinery Provincial Park were a canopy consisting of red, white, and black oak with scattered white pine and black cherry. There was more advanced regrowth in the private wood lot and the spacing of trees was slightly denser than in Pinery Provincial Park. Chinquapin oak was not seen to be present. The understory consisted of grasses, sedges and oak regrowth typically under two metres in height in canopy openings, but where the canopy was completely closed there was prevalent underbrush observed. Soils and topography were very similar to the Pinery Provincial Park site except the steepness of slope was greater.

Table 1.2 displays the plot summary data recorded for the private forested land bordering Pinery Provincial Park. There was a range of 2 – 18 stems per plot which were both a higher mode and lower minimum than the Pinery Provincial Park plots. The percent of red oak ranged between 0- 40%. The mode is ten percent less than the mode of the Pinery Provincial park plots (see table 1.1 above). The diameter at breast height ranged between 10- 43 cm. The mode diameter at breast height recorded for this site is 1 cm less than the mode of Pinery Provincial Park plots. The lowest live branch height ranged from 2.12- 4.6 m. This is range is narrower than the Pinery Provincial park lowest live branch range. The average orientation of the lowest branches ranged from 170- 306°. This range is slightly wider than the Pinery Provincial Park range

Table 1.2. Plot data averages for the privately-owned forested land bordering Pinery Provincial Park. (INT = plot located within the interior of forest, EXT= plot located along exterior perimeter of forest.). Source: Pinery Provincial Park August 26th, 27th, 28th 2020 and APPENDIX I.

PLOT	S.P.P.	R.O.P. %	O.DBH (CM)	L.L.B.H. (M)	L.L.B.O. (360^0)
1 (INT)	25	0.0	43	4.52	216
2 (INT)	17	0.0	37	3.59	281
3 (INT)	18	0.0	35	3.76	243
4 (INT)	9	0.0	10	2.86	290
5 (INT)	10	0.0	29	5.51	223
6 (EXT)	2	16	16	2.12	292
7 (EXT)	6	0.0	18	2.20	289

PLOT	S.P.P.	R.O.P. %	O.Dbh (cm)	L.L.B.H. (m)	L.L.B.O. (360^0)
8 (EXT)	8	0.0	20	3.45	306
9 (EXT)	11	11	37	3.05	300
10 (EXT)	5	40	22	4.61	170

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Figure 4.2 below displays the plots locations in the privately owned forested land bordering Pinery Provincial Park plot overview the blue line is the “Savanna bicycle trail”.

Figure 4.2 Privately owned forested land bordering Pinery Provincial Park plot overview

Site 3: Thames river tributary forested gulley (Elgin County).

Common features of the understory found throughout the Thames river forested gully were a canopy consisting of *Populus spp., Fagus spp*., *Acer spp*. and *Quercus spp*. The understory generally consisted of regenerating trees and shrubs such as osage orange (*Maclura pomifera* (Raf.) Schneid , *Malus spp*. and *Prunus spp*. The soils were rich, clayey, and a moisture gradient through the gully slope (field notes, August 2019). At the top of the gully is a farm field (rolling hills, points of saturation, tillage) along which a field edge is present. The field edge (roughly 10-15 m of flat ground before the slope of the gully begins) supports grasses, shrubs and the encroaching forest tree species. There were points of openness in the field edge, as well as a closed canopy up to the till line.

Table 1.3 above displays the plot data sampled from the Thames river tributary forested gully site. Five plots were measured and sampled on this site. The number of stems per plot ranged between 2 and 22. The percent red oak ranged between 0 and 100%. The oak diameter at breast height, averaged per plot, ranged between 11-17 cm. This was a narrower range compared to the distribution of oak dbh at the other two sites. The average lowest live branch height of oaks, range, on this site is between 2.52 metres and 3.58 metres. This range is comparable to the other sites. The range of the lowest live branch orientation on oaks at this site was 144-236°, a much narrower range compared to the other sites.

Table 1.3. Plot data averaged for the Thames river tributary, forested gulley plots (Elgin County). Source: Pinery Provincial Park August 26th, 27th, 28th 2020 and APPENDIX I.

PLOT	S.P.P.	R.O.P. %	O.DBH (CM)	L.L.B.H. (M)	L.L.B.O. (360^0)
1	13	15	13	2.52	201
2	19	50	11	3.06	236
3	2	100	17	3.04	144
4	7	43	15	3.31	213
5	22	32	17	3.58	218

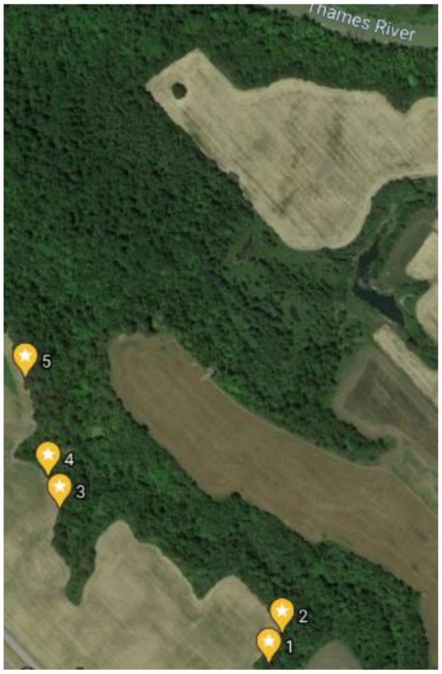

Figure 5.1 Thames river tributary forested gulley (Elgin County) plot overview.

The image displayed to the left is a screen shot grabbed from the google map used to mark plot locations. The Thames River can be viewed in the top right portion of the image. The tributary stream runs through the forested section which has been left preserved from agriculture due to the steepness of slope and associated hydrological conditions. There are tillage drainage systems running from the field located on the left of the plots into the gully.

ANISOTA SENATORIA HABITAT SELECTION

Table 2.1 shows the habitat range and characteristic values recorded from the five plots in which *A. senatoria* occurred within Pinery Provincial Park. *A. senatoria* occupied trees in plots which had six to nine stems per plot. The percent of red oaks within the plots that *A. senatoria* selected was between 33 and 50%. The average diameter at breast height of oaks within the plots occupied by *A. senatoria* was found to range between 14 and 44 cm. The lowest oak live branch height from the ground ranged between 1.7 -3.6 m in the plots with *A. senatoria* populations. The orientation of lowest live branch of oaks occupied by *A. senatoria* was between 147-229°.

Table 2.1 Plot characteristics and ranges found suitable for *A. senatoria* habitat selection. Source: Pinery Provincial Park, August 26th, 27th, 28th 2020 and APPENDIX 1.

S.P.P.	R.O.P.	O.DBH	L.L.B.H.	L.L.B.O
6-9	33 - 50%	14-44 cm	1.7-3.6 m	$147\text{-}229^0$

Table 2.2 displays the data measured and recorded from the five individual trees that supported *A. senatoria* populations in Pinery Provincial Park. The selected trees were of the same oak species, red oak (*Quercus rubra*). The diameter at breast height of the habitat trees ranged from 26- 58 cm. The lowest live branch height from the ground, which was always the selected habitat branch, ranged from 3.08- 4.38 m from the ground. The orientation range of the occupied branch, also the lowest live branch in all cases, was between 141-243°.

Table 2.2. Characteristics of individual trees supporting A. senatoria larval populations. Source: Pinery Provincial Park, August 26th, 27th, 28th 2020 and APPENDIX 1

PLOT	SPECIES	D.B.H.	L.L.B.H.	L.L.B.O
1	Red oak	40	4.92	141
2	Red oak	57	3.14	198
3	Red oak	26	3.87	243
4	Red oak	58	3.08	152
5	Red oak	38	4.38	163

Table 2.3 displays these ranges in a manner which makes them easy to view and compare. The diameter at breast height range (26-44 cm) is more concentrated and generally higher in respect to the minimum, than the other sites which had the following ranges (site 1: 10-44 cm, site 2: 10-43 cm, site 3: 11-17 cm). The range of the lowest live branch height from the ground (3.08-4.38 cm) is generally higher than the others in

respects of the minimum height for lowest live branch (site 1: 1.7- 5.5 m, site 2: 2.12- 4.6 m, site 3: 2.52- 3.58 m). The lowest live branch range of the inhabited trees (141- 243°) was more condensed around a 180° orientation than the other sites, site 3 was very similar though (site 1: 159-290°, site 2: 170-306°, site 3: 144-236°).

Table 2.3. Characteristic ranges of individual trees supporting *A. senatoria* larvae populations. Source: Pinery Provincial Park, August 26th, 27th, 28th 2020 and APPENDIX 1.

Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360°)
Red oak	26-58	3.08-4.38	141-243

ANISOTA SENATORIA HABITAT SELECTION ANALYSIS

Table 3.1 displays the Chi-squared significance test results. Percent red oak composition of occupied trees was found to be correlated around the expected value within the occupied group (46.6%), but was significantly distributed in the all oaks category. Stems per plot was not significantly distributed from the expected value, within the group or when compared against all of the oaks combined. The distribution of the lowest live branch height from the ground was nonsignificant in distribution from the expected ($P>0.05$), either within the group, when compared to all oaks or when compared to all of the red oaks. Orientation of the lowest live branch had significance in distribution when tested within the group, against all oaks and against all red oaks. The diameter at breast height had similar results and showed significance in distribution between the group itself, all of the oaks and with all red oaks

Table 3.1 Chi-square test results of the characteristic values for the five host trees (plot and single tree characteristics). Df = ([1]=4, [2]=109, [3]=45), *= statistically correlated to expected value, at p value >= 0.05 Source: Table 1.1, Table 2.2, APPENDIX I, APPENDIX 11, and APPENDIX II

Tree and plot characteristics		Expected	Chi-squared test (p-value)	
Red oak composition percent	[1]Within	46.6	0.310	*
	[2]All oaks	23.4	<0.0001	
Stems per plot	[1]Within	6.20	0.500	*
	[2]All oaks	9.48	0.097	
Height of the lowest branch from the ground	[1]Within	3.88	0.957	*
	[3]Against all red oak	3.34	0.879	*
	[2]Against all oaks	3.24	0.843	*
Orientation of lowest branch	[1]Within	179.40	<0.0001	
	[3]Against all red oak	211.89	<0.0001	
	[2]Against all oaks	221.75	<0.0001	
Diameter at breast height	[1]Within	43.80	0.002	
	[3]Against all red oak	20.96	<0.0001	
	[2]Against all oaks	20.12	<0.0001	

Table 3.2 summarizes the Chi-square tests for significance of the distribution of *A. senatoria* on the lowest live branch orientation in the occupied trees. around a south facing direction (180°). The Chi-square test results from the occupied oak branches located in Pinery Provincial Park, shows a highly significant distribution of the occupied branches orientation away from a south facing direction. The chi-test value from all of the oaks shows a very significant distribution away from a 180° south orientation as does the significance test on the subgroup of all red oaks.

Table 3.2 Chi-square test results for the orientation of branches occupied by A. s enatoria. Significance of branch orientation of all oaks, and particularly red oaks, towards a south facing direction (180°). Df = (^{1}=4, ^{2}=109, ^{3}=45), *= correlated to expected, at p value >= 0.05. Source: Table 1.1, Table 2.2, APPENDIX I, APPENDIX 11, and APPENDIX III

	Chi-squared (test value)
^{1}Orientation of occupied branch- tested for significance against a south facing direction (180°)	<0.0001
^{2}All oaks lowest live branch orientation	<0.0001
^{3}Red oak lowest live branch orientation	<0.0001

The expected distribution in the Table 3.3 is an even distribution between each ordinal category, one per category, and one category with two branch orientations within the categorical range (or, averaged at 1.25 branches per category). However, the results above display three occupied branch orientations in the ordinal category of 90-180^{0} and two branch orientations within the 180-270^{0} range. The chi-square test run on the number of observed orientations found under each ordinal category (0, 3, 2, 0) respectively, against the expected per each category (1.25) showed significant distribution from the expected values (0.15). When the same test was run on all red oak lowest live branches (df= 49, expected = 12.25) the distribution was found to be even.

Table 3.3 Observed orientations of occupied branches placed into ordinal categories in order to complete chi-square tests on categorical distribution. * = the observed orientation of occupied branch was found within that ordinal category. Source: APPENDIX I

Observed orientations of occupied branches	**Ordinal categories**			
	$0\text{-}90^0$	$90\text{-}180^0$	$180\text{-}270^0$	$270\text{-}360^0$
141^0		*		
198^0			*	
243^0			*	
152^0		*		
163^0		*		
Total	0	3	2	0

DISSCUSSION

From the results obtained, the null hypothesis that *A. senatoria* presence on oak trees are not correlated with the identified local habitat features (within the tree or on the stand level), was rejected. The fact that *A. senatoria* was a located exclusively on a red oak tree species, and also exclusively on the lowest live branch, gives reason to reject the null hypothesis.

When viewing the significance tests found in Table 3.1 it can be seen that there are notable distinguishable features to the sampled oak trees, red oaks specifically, and the plot characteristics selected by *A. senatoria*. The chi-square test summary shows that in all of the plots tested which had presence of oak, there was statistically significant distribution around the expected value of 9.48 stems per plot, a relatively low plot density. The table also shows that the red oak trees selected specifically by *A. senatoria* were located in plots with a correlation toward a plot density of 6.2 stems per $10m^2$. This was a slightly open oak canopy in comparison to the plots where *A. senatoria* was not found.

Table 3.1 shows that all oaks have a correlation toward lowest live branches at 3.24 metres from the ground, red oaks at 3.34 metres from the ground, and that those red oaks selected by *A. senatoria* at 3.88 metres from the ground. This shows that *A.senatoria* habitat selection is correlated to branches at 3.88 metres from the ground, *A.senatoria* is known to prefer low lying structures (lower branches) and that oaks, as well as red oak, show correlation to supporting lower branches in a 3.24- 3.34 metre range from the ground. The average range of the lowest live branch height from the ground, for all oaks and red oak is very close to the branch height from the ground which *A. senatoria* was shown to select (3.88 m). This signifies a possible relationship between oaks and red oaks, supporting lower branches at a height from the ground which *A. senatoria* prefers as habitat.

From Table 3.1, it may be seen that the study sites sampled signify no notable direction toward an average red oak composition percent and that the sites selected by *A. senatoria* had a fairly strong correlation toward a 46.6% red oak composition. This means that the forests sampled did not have any predictable percentages of red oak percentages per plot. The plots selected by *A.senatoria,* by the rule of this thesis, should have 46.6.% red oak composition or more, a plot density of 6.2 stems per 10 metres squared, and lower branches with late season red oak foliage at 3.88 metres from the ground with an ordinal range between 90-270^0 displayed in Table 3.3.

After analyzing the data it appears that *A.senatoria* bases habitat selection off of the availability of late season foliage, the availability of low lying structures near to late season foliage in an ordinal range between 90-270^0 and a stem density allowing sunlight to support low lying structures (branches) near to late season foliage. It also appears that the physiological attributes of the oak family, specifically the red oak species, on the forest and single tree level, possess the habitat qualities (late season foliage, moderate plot stem densities, and coinciding low lying structures) preferred by *A. senatoria* for habitat selection. It would appear that these qualities support preferential habitat attributes to *A.senatoria*, but the deciding factors to whether or not the site will be selected are; the amount of the preferred habitat qualities (late season foliage, moderate stem densities and coinciding low lying structures) available within a given area (red oak composition percent) and the ordinal range of the red oaks lowest live branch. If the composition percent of the plot was less than 46.6% red oak, *A. senatoria* was not found, and if the ordinal range was between 0-90^0 or 270-360^0 *A. senatoria* was not found.

In order to highlight the significance of the results found, it is beneficial to view the environment in a dynamic manner. A tree's resource allocation may respond to the orientation of the sun in the sky through the growing days of its life to maximize photosynthate production (Beaudet and Messier 1998, De Jong and Doyle 1985). For example, red oak late season foliage and retained lower branches in open canopy structures. Or how an insect which feeds on the leaves of these branches most often pursues the most succulent foliage (Caldwell, Read and Sanson 2016). How those insects which can digest the rough mature leaves, partition themselves from other similar species resource's needs and digestive capabilities by increasing consumption in response to low nitrogen leaf content (Lawson *et al*. 1984). Also, how humans may tolerate a degree of annoyance and partition themselves from these insects for the benefit of all (Coffelt and Schultz 1991).

CONCLUSION

This knowledge may prove useful to conservation strategies as well as pest management strategies for private woodlots and urban forests. It provides possible opportunities to be applied through a habitat modeling program in a southwestern Ontario forest inventory to produce visual, geographic reference points as to where *A. senatoria* preferred habitat may be found and to what degree. This would be based on the habitat attributes which *A. senatoria* has been proven to select for within southwestern Ontario, specifically Pinery Provincial Park, and the existing forest attributes across the landscape in southwestern Ontario.

If we analyze and identify the environment which *A. senatoria* selects as habitat within Ontario, it is possible to identify key habitat features which are essential to the survival of this native insect species in Ontario, for example *Quercus rubra*.

Every living thing holds value, significance, and the power to affect the environment while offering the opportunity toward understanding, if there is the desire to peruse the knowledge. With knowledge gained by identifying specific key features of the environment selected by *A. senatoria*, we may begin to analyze how significant these features are to the survival of the native insect species. This added understanding of the environmental features associated with *A. senatoria* survival could be applied to conservation management and pest management strategies. If *A. senatoria* populations are dwindling across the landscape, preserving the environmental features which orangestriped oakworm selects as habitat (red oak composition greater than 46 percent in plots with less than 6.2 stems per 10 m^2, holding branches around 3.88 metres from the ground between the ordinal directions of 90-270^0) could assist in the conservation and preservation of this native insect species within Ontario. If *A. senatoria* populations are reaching outbreak status, pest management strategies based on key habitat features could be applied in order to reduce the populations across the landscape, stand level or individual trees. This may prove to be very beneficial in the urban forest setting of cities.

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APPENDICES

APPENDIX I

Plot #	Count	Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360^0)	Stems per plot	Red oak %
*1	1	Red oak	40	4.92	141	6	0.50
1	2	Red oak	11	1.12	221	6	0.50
1	3	Red oak	2	0.35	176	6	0.50
1	4	Chinquapin oak	4	0.42	98	6	0.50
1	5	Red pine	44			6	0.50
1	6	White pine	17			6	0.50
*2	1	Red oak	58	4.45	219	4	0.50
2	2	Chinquapin oak	17	2.98	232	4	0.50
2	3	Red oak	57	3.14	198	4	0.50
2	4	White pine	31			4	0.50
*3	1	Red oak	26	3.87	243	8	0.50
3	2	Red oak	31	2.78	307	8	0.50
3	3	Red oak	22	2.45	78	8	0.50
3	4	Black cherry	16			8	0.50
3	5	Chinquapin oak	11	2.03	232	8	0.50
3	6	Chinquapin oak	10	1.36	334	8	0.50
3	7	Chinquapin oak	9	1.17	97	8	0.50
3	8	Red oak	28	2.12	312	8	0.50
*4	1	Red oak	58	3.08	152	4	0.50
4	2	Red oak	10	2.22	85	4	0.50
4	3	Black oak	9	1.89	340	4	0.50
4	4	Black oak	13	2.67	12	4	0.50
*5	1	Black cherry	5			9	0.33
5	2	Black cherry	7			9	0.33
5	3	Black cherry	7			9	0.33
5	4	White pine	34			9	0.33
5	5	Red oak	38	4.38	163	9	0.33
5	6	Red oak	23	5.14	256	9	0.33
5	7	Red oak	10	1.17	105	9	0.33
5	8	Juniper	9			9	0.33
5	9	Juniper	10			9	0.33
6	1	Juniper	10			11	0.00
6	2	Juniper	17			11	0.00
6	3	Juniper	19			11	0.00
6	4	Juniper	14			11	0.00
6	5	Juniper	8			11	0.00
6	6	Juniper	11			11	0.00
6	7	Black oak	56	5.84	192	11	0.00
6	8	Black cherry	22			11	0.00
6	9	Black oak	29	3.2	240	11	0.00
6	10	Maple	5			11	0.00
6	11	Juniper	12			11	0.00

Plot #	Count	Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360^0)	Stems per plot	Red oak %
7	1	Juniper	5			5	0.00
7	2	Juniper	9			5	0.00
7	3	Black oak	41	4.3	272	5	0.00
7	4	Black oak	30	3.58	348	5	0.00
7	5	Black oak	39	2.88	222	5	0.00
8	1	Black oak	40	3.89	193	4	0.00
8	2	Black oak	34	3.66	188	4	0.00
8	3	Black oak	30	3.74	348	4	0.00
8	4	Black cherry	29			4	0.00
9	1	Chinquapin oak	6			9	0.00
9	2	Juniper	20			9	0.00
9	3	Juniper	18			9	0.00
9	4	Juniper	19			9	0.00
9	5	Juniper	6			9	0.00
9	6	Black oak	14	2.86	290	9	0.00
9	7	White pine	29			9	0.00
9	8	Juniper	38			9	0.00
9	9	Juniper	16			9	0.00
10	1	Juniper	19			3	0.00
10	2	Juniper	12			3	0.00
10	3	Black oak	29	5.1	223	3	0.00
11	1	Black oak	28	4.53	275	25	0.16
11	2	Red oak	36	5.16	303	25	0.16
11	3	Red oak	7	1.03	284	25	0.16
11	4	Red oak	12	1.52	312	25	0.16
11	5	Red oak	17	2.34	268	25	0.16
11	6	White oak	8	1.34	341	25	0.16
11	7	White oak	10	1.65	322	25	0.16
11	8	White oak	11	1.61	287	25	0.16
11	9	White oak	12	1.72	326	25	0.16
11	10	White oak	20	1.97	219	25	0.16
11	11	White oak	4	0.3	278	25	0.16
11	12	White oak	24	2.21	115	25	0.16
11	13	Cherry	2			25	0.16
11	14	Cherry	4			25	0.16
11	15	Cherry	4			25	0.16
11	16	Cherry	5			25	0.16
11	17	Cherry	3			25	0.16
11	18	Cherry	2			25	0.16
11	19	Cherry	4			25	0.16
11	20	Cherry	5			25	0.16

Plot #	Count	Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360^0)	Stems per plot	Red oak %
11	21	Cherry	7			25	0.16
11	22	Cherry	5			25	0.16
11	23	Cherry	2			25	0.16
11	24	Cherry	3			25	0.16
11	25	Red pine	15			25	0.16
12	1	Black oak	17	2.25	278	17	0.00
12	2	Black oak	21	2.76	294	17	0.00
12	3	White oak	15	1.87	301	17	0.00
12	4	White oak	18	1.92	281	17	0.00
12	5	Cherry	2			17	0.00
12	6	Cherry	2			17	0.00
12	7	Cherry	2			17	0.00
12	8	Cherry	3			17	0.00
12	9	Cherry	5			17	0.00
12	10	Cherry	3			17	0.00
12	11	Cherry	2			17	0.00
12	12	Cherry	3			17	0.00
12	13	Cherry	4			17	0.00
12	14	Cherry	2			17	0.00
12	15	Cherry	2			17	0.00
12	16	Cherry	2			17	0.00
12	17	White pine	7			17	0.00
13	1	Black oak	23	4.37	300	18	0.00
13	2	Black oak	18	3.21	346	18	0.00
13	3	Black oak	20	4.75	270	18	0.00
13	4	White oak	15	2.34	360	18	0.00
13	5	White oak	18	2.78	355	18	0.00
13	6	White oak	23	3.24	205	18	0.00
13	7	Cherry	2			18	0.00
13	8	Cherry	3			18	0.00
13	9	Cherry	3			18	0.00
13	10	Cherry	2			18	0.00
13	11	Cherry	2			18	0.00
13	12	Cherry	2			18	0.00
13	13	Cherry	2			18	0.00
13	14	Cherry	3			18	0.00
13	15	Cherry	3			18	0.00
13	16	Cherry	4			18	0.00
13	17	Cherry	3			18	0.00
13	18	White pine	3			18	0.00
14	1	Black oak	54	3.12	297	9	0.11

Plot #	Count	Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360^0)	Stems per plot	Red oak %
14	2	White oak	26	2.57	321	9	0.11
14	3	Red oak	32	3.45	283	9	0.11
14	4	Cherry	2			9	0.11
14	5	Cherry	3			9	0.11
14	6	Cherry	2			9	0.11
14	7	Cherry	1			9	0.11
14	8	White pine	10			9	0.11
14	9	White pine	12			9	0.11
15	1	White oak	18	4.37	183	10	0.40
15	2	White oak	16	4.12	112	10	0.40
15	3	White oak	41	7.24	172	10	0.40
15	4	White oak	13	2.96	198	10	0.40
15	5	White oak	22	3.98	221	10	0.40
15	6	Red oak	14	3.8	189	10	0.40
15	7	Red oak	22	3.96	172	10	0.40
15	8	Red oak	16	3.91	137	10	0.40
15	9	Red oak	33	6.23	245	10	0.40
15	10	Black oak	20	5.51	72	10	0.40
16	1	White oak	42	5.26	75	2	0.00
16	2	White oak	27	2.84	134	2	0.00
17	1	White oak	25	1.7	202	6	0.33
17	2	Red oak	27	8.17	250	6	0.33
17	3	Red oak	20	2.14	259	6	0.33
17	4	White pine	18			6	0.33
17	5	Juniper	5			6	0.33
17	6	Black cherry	16			6	0.33
18	1	Red pine	18			8	0.13
18	2	Red pine	14			8	0.13
18	3	White pine	21			8	0.13
18	4	White pine	16			8	0.13
18	5	Red oak	19	5.15	5	8	0.13
18	6	White oak	25	2.12	128	8	0.13
18	7	White oak	37	8.57	228	8	0.13
18	8	White oak	23	2.01	137	8	0.13
19	1	White oak	27	3.25	254	11	0.00
19	2	White oak	21	2.79	171	11	0.00
19	3	Black oak	14	4.56	234	11	0.00
19	4	Black oak	27	3.27	212	11	0.00
19	5	Black oak	32	6.14	192	11	0.00
19	6	Cherry	2			11	0.00
19	7	Cherry	2			11	0.00
19	8	Cherry	2			11	0.00

Plot #	Count	Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360^0)	Stems per plot	Red oak %
19	9	Cherry	3			11	0.00
19	10	Cherry	3			11	0.00
19	11	Cherry	2			11	0.00
20	1	White oak	20	3.11	179	5	0.00
20	2	White pine	10			5	0.00
20	3	White pine	10			5	0.00
20	4	White pine	16			5	0.00
20	5	Black oak	28	4.62	229	5	0.00
21	1	Osage orange	9			13	0.15
21	2	Osage orange	7			13	0.15
21	3	Osage orange	7			13	0.15
21	4	Bur oak	27	4.12	241	13	0.15
21	5	Bur oak	5	2.11	117	13	0.15
21	6	Bur oak	7	3.15	216	13	0.15
21	7	Aspen	32			13	0.15
21	8	Aspen	18			13	0.15
21	9	Aspen	10			13	0.15
21	10	Aspen	14			13	0.15
21	11	Cherry	16			13	0.15
21	12	Red oak	7	1.73	226	13	0.15
21	13	Red oak	18	1.51	204	13	0.15
22	1	Osage orange	9			19	0.50
22	2	Red oak	12	4.23	224	19	0.50
22	3	Red oak	5	4.67	303	19	0.50
22	4	Bur oak	25	3.24	213	19	0.50
22	5	Red oak	15	4.78	245	19	0.50
22	6	Red oak	5	1.112	298	19	0.50
22	7	Red oak	6	6.21	178	19	0.50
22	8	Red oak	7	4.19	234	19	0.50
22	9	Bur oak	13	1.01	156	19	0.50
22	10	Bur oak	7	2.56	343	19	0.50
22	11	Osage orange	8			19	0.50
22	12	Red oak	8	0.78	176	19	0.50
22	13	Red oak	11	1.64	278	19	0.50
22	14	Cherry	15			19	0.50
22	15	Red oak	12	2.34	189	19	0.50
22	16	Beech	4			19	0.50
22	17	Beech	3			19	0.50
22	18	Beech	6			19	0.50
22	19	Beech	6			19	0.50
23	1	Red oak	31	3.96	34	2	1.00
23	2	Red oak	2	2.12	254	2	1.00
24	1	Red oak	26	4.04	240	7	0.43

Plot #	Count	Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360^0)	Stems per plot	Red oak %
24	2	Red oak	12	2.86	226	7	0.43
24	3	Red oak	8	3.02	174	7	0.43
24	4	Cherry	5			7	0.43
24	5	Malus	5			7	0.43
24	6	Cherry	21			7	0.43
24	7	Osage orange	5			7	0.43
25	1	Red oak	27	2.91	161	22	0.32
25	2	Red oak	5	0.69	287	22	0.32
25	3	Red oak	12	2.34	303	22	0.32
25	4	Red oak	13	3.52	196	22	0.32
25	5	Red oak	34	6.23	211	22	0.32
25	6	Balsam poplar	28			22	0.32
25	7	Balsam poplar	22			22	0.32
25	8	Beech	10			22	0.32
25	9	Beech	8			22	0.32
25	10	Red oak	28	6.12	224	22	0.32
25	11	Red oak	13	4.51	155	22	0.32
25	12	Balsam poplar	34			22	0.32
25	13	Balsam poplar	36			22	0.32
25	14	Beech	5			22	0.32
25	15	Beech	5			22	0.32
25	17	Beech	7			22	0.32
25	18	Bur oak	11	3.11	131	22	0.32
25	19	Bur oak	9	2.76	293	22	0.32
25	20	Beech	5			22	0.32
25	21	Beech	3			22	0.32
25	22	Beech	5			22	0.32

Plot #	Count	Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360^0)	Stems per plot	Red oak %
*1	1	Red oak	40	4.92	141	6	0.50
1	2	Red oak	11	1.12	221	6	0.50
1	3	Red oak	2	0.35	176	6	0.50
1	4	Chinquapin oak	4	0.42	98	6	0.50
*2	1	Red oak	58	4.45	219	4	0.50
2	2	Chinquapin oak	17	2.98	232	4	0.50
2	3	Red oak	57	3.14	198	4	0.50
*3	1	Red oak	26	3.87	243	8	0.50
3	2	Red oak	31	2.78	307	8	0.50
3	3	Red oak	22	2.45	78	8	0.50
3	5	Chinquapin oak	11	2.03	232	8	0.50
3	6	Chinquapin oak	10	1.36	334	8	0.50
3	7	Chinquapin oak	9	1.17	97	8	0.50
3	8	Red oak	28	2.12	312	8	0.50
*4	1	Red oak	58	3.08	152	4	0.50
4	2	Red oak	10	2.22	85	4	0.50
4	3	Black oak	9	1.89	340	4	0.50
4	4	Black oak	13	2.67	12	4	0.50
5	5	Red oak	38	4.38	163	9	0.33
5	6	Red oak	23	5.14	256	9	0.33
5	7	Red oak	10	1.17	105	9	0.33
6	7	Black oak	56	5.84	192	11	0.00
6	9	Black oak	29	3.2	240	11	0.00
7	3	Black oak	41	4.3	272	11	0.00
7	4	Black oak	30	3.58	348	11	0.00
7	5	Black oak	39	2.88	222	5	0.00
8	1	Black oak	40	3.89	193	4	0.00
8	2	Black oak	34	3.66	188	4	0.00
8	3	Black oak	30	3.74	348	4	0.00
9	6	Black oak	14	2.86	290	9	0.00
10	3	Black oak	29	5.1	223	3	0.00
11	1	Black oak	28	4.53	275	25	0.16
11	2	Red oak	36	5.16	303	25	0.16
11	3	Red oak	7	1.03	284	25	0.16
11	4	Red oak	12	1.52	312	25	0.16
11	5	Red oak	17	2.34	268	25	0.16
11	6	White oak	8	1.34	341	25	0.16
11	7	White oak	10	1.65	322	25	0.16
11	8	White oak	11	1.61	287	25	0.16
11	9	White oak	12	1.72	326	25	0.16
11	10	White oak	20	1.97	219	25	0.16

APPENDIX II

Plot #	Count	Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360^0)	Stems per plot	Red oak %
11	11	White oak	4	0.3	278	25	0.16
11	12	White oak	24	2.21	115	25	0.16
12	1	Black oak	17	2.25	278	17	0.00
12	2	Black oak	21	2.76	294	17	0.00
12	3	White oak	15	1.87	301	17	0.00
12	4	White oak	18	1.92	281	17	0.00
13	1	Black oak	23	4.37	300	18	0.00
13	2	Black oak	18	3.21	346	18	0.00
13	3	Black oak	20	4.75	270	18	0.00
13	4	White oak	15	2.34	360	18	0.00
13	5	White oak	18	2.78	355	18	0.00
13	6	White oak	23	3.24	205	18	0.00
14	1	Black oak	54	3.12	297	9	0.11
14	2	White oak	26	2.57	321	9	0.11
14	3	Red oak	32	3.45	283	9	0.11
15	1	White oak	18	4.37	183	10	0.40
15	2	White oak	16	4.12	112	10	0.40
15	3	White oak	41	7.24	172	10	0.40
15	4	White oak	13	2.96	198	10	0.40
15	5	White oak	22	3.98	221	10	0.40
15	6	Red oak	14	3.8	189	10	0.40
15	7	Red oak	22	3.96	172	10	0.40
15	8	Red oak	16	3.91	137	10	0.40
15	9	Red oak	33	6.23	245	10	0.40
15	10	Black oak	20	5.51	72	10	0.40
16	1	White oak	42	5.26	75	2	0.00
16	2	White oak	27	2.84	134	2	0.00
17	1	White oak	25	1.7	202	6	0.33
17	2	Red oak	27	8.17	250	6	0.33
17	3	Red oak	20	2.14	259	6	0.33
18	5	Red oak	19	5.15	5	8	0.13
18	6	White oak	25	2.12	128	8	0.13
18	7	White oak	37	8.57	228	8	0.13
18	8	White oak	23	2.01	137	8	0.13
19	1	White oak	27	3.25	254	11	0.00
19	2	White oak	21	2.79	171	11	0.00
19	3	Black oak	14	4.56	234	11	0.00
19	4	Black oak	27	3.27	212	11	0.00
19	5	Black oak	32	6.14	192	11	0.00
20	1	White oak	20	3.11	179	5	0.00
20	5	Black oak	28	4.62	229	5	0.00
21	4	Bur oak	27	4.12	241	13	0.15

Plot #	Count	Tree Species	Dbh (cm)	Lowest live branch height (m)	Lowest live branch orientation (360^0)	Stems per plot	Red oak %
21	5	Bur oak	5	2.11	117	13	0.15
21	6	Bur oak	7	3.15	216	13	0.15
21	12	Red oak	7	1.73	226	13	0.15
21	13	Red oak	18	1.51	204	13	0.15
22	2	Red oak	12	4.23	224	19	0.50
22	3	Red oak	5	4.67	303	19	0.50
22	4	Bur oak	25	3.24	213	19	0.50
22	5	Red oak	15	4.78	245	19	0.50
22	6	Red oak	5	1.112	298	19	0.50
22	7	Red oak	6	6.21	178	19	0.50
22	8	Red oak	7	4.19	234	19	0.50
22	9	Bur oak	13	1.01	156	19	0.50
22	10	Bur oak	7	2.56	343	19	0.50
22	12	Red oak	8	0.78	176	19	0.50
22	13	Red oak	11	1.64	278	19	0.50
22	15	Red oak	12	2.34	189	2	0.50
23	1	Red oak	31	3.96	34	2	1.00
23	2	Red oak	2	2.12	254	2	1.00
24	1	Red oak	26	4.04	240	7	0.43
24	2	Red oak	12	2.86	226	7	0.43
24	3	Red oak	8	3.02	174	7	0.43
25	1	Red oak	27	2.91	161	22	0.32
25	2	Red oak	5	0.69	287	22	0.32
25	3	Red oak	12	2.34	303	22	0.32
25	4	Red oak	13	3.52	196	22	0.32
25	5	Red oak	34	6.23	211	22	0.32
25	10	Red oak	28	6.12	224	22	0.32
25	11	Red oak	13	4.51	155	22	0.32
25	18	Bur oak	11	3.11	131	22	0.32
25	19	Bur oak	9	2.76	293	22	0.32

APPENDIX III

Red Oak

D.B.H.		**Lowest live branch height**		**Lowest live branch ordination**	
Mean	20.12	Mean	3.34	Mean	211.90
Standard Error	2.01	Standard Error	0.25	Standard Error	10.27
Median	16	Median	3.14	Median	224
Mode	12	Mode	2.34	Mode	303
Standard Deviation	14.0588535	Standard Deviation	1.73526983	Standard Deviation	71.8978572
Sample Variance	197.651361	Sample Variance	3.01116137	Sample Variance	5169.30187
Kurtosis	1.04774291	Kurtosis	-0.1083446	Kurtosis	0.62288725
Skewness	1.13049342	Skewness	0.42302299	Skewness	-0.8178649
Range	56	Range	7.82	Range	307
Minimum	2	Minimum	0.35	Minimum	5
Maximum	58	Maximum	8.17	Maximum	312
Sum	986	Sum	163.552	Sum	10383
Count	49	Count	49	Count	49
Largest (1)	58	Largest (1)	8.17	Largest (1)	312
Smallest (1)	2	Smallest (1)	0.35	Smallest (1)	5
Confidence Level (95.0%)	4.0381742	Confidence Level (95.0%)	0.49842769	Confidence Level (95.0%)	20.6514758