INCREASING FRUIT PRODUCTION IN WILD POPULATIONS OF PAWPAW (*ASIMINA TRILOBA* (L) DUNAL) TREES IN SOUTHERN ONTARIO

by Jessica van Vierzen
1170173

An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management

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ABSTRACT

Farrar, J.L. 2017. Trees in Canada. Natural Resources Canada. Canadian Forest Service and Fitzhenry & Whiteside Limited. Ottawa and Markham. pp.502

Keywords: *Asimina triloba* (L) Dunal, fruit, pawpaw, pollination, Southern Ontario, understory

The pawpaw (*Asimina triloba* (L) Dunal) is a unique native understory tree species found in the Deciduous and Carolinian forest regions in Southern Ontario. It is at the edge of its range in Ontario, most of the population exists in the United States in 26 of the eastern states. It is the only member of the tropical family *Annonaceae* to reside in North America and its large drooping leaves allow it to stand out in a forest setting. The pawpaw tree bears the largest fruit of any tree species in Ontario. The fruit is tropical in appearance and flavour. It is a food resource for both humans and wildlife. Studies conducted previously in pawpaw stands have noted that pollination and the subsequent fruit set have been low or non-existent. Although there is no concrete evidence suggesting why this may be, a loss of genetic diversity, habitat fragmentation and anthropogenic forces such as development may be contributing factors. This may be especially true for naturally occurring stands in Southern Ontario. Here, the pawpaw tree has a small population of wild trees. This species has high value and preservation through efforts such as habitat protection, increased genetic diversity through plantings, agroforestry, and even assisted migration could help to improve population numbers. This may help to increase pollination rates and fruit yields, allowing the pawpaw tree to continue its important role within the forests of Southern Ontario.

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ACKNOWLEDGEMENTS

This paper could not have been written without the continued love and support of my friends and family. They know who they are. I would like to dedicate this paper to my mother who consistently encourages me to learn, pursue my dreams, and reminds me of what really matters in life. I would also like to thank a previous teacher of mine and my now friend, Daniel Pantaleo for allowing me to use his personal photos of pawpaw-related subjects, and for introducing me to the world of the pawpaw tree and all its wonders. My final thank you is to Dr. Mat Leitch for being an excellent supervisor and for sharing his knowledge and life lessons.

INTRODUCTION

The pawpaw (*Asimina triloba* (L.) Dunal) is a small deciduous tree with elongated, simple leaves and commonly found in the understory or at the edge of forests (Bowden and Miller 1951; Willson and Schemske 1980; Lagrange and Tramer 1985; Layne 1996; Robles-Diaz-de-Leon and Nava Tudela 1998; Ontario Ministry of Natural Resources 2000; Lyle 2006; Hormaza 2014; Farrar 2017; Wyatt 2019; Judd 2019). It is a single-stemmed tree with a broad crown and pyramidal form (Layne 1996; Lyle 2006; Hormaza 2014; Farrar 2017; Judd 2019). In Southern Ontario, the pawpaw tree is restricted to the Deciduous and Carolinian forest regions and does not occur in natural stands in the Great Lakes-St. Lawrence Forest region (Bowden and Miller 1951; Layne 1996; OMNR 2000; Hormaza 2014; Hormaza et al. 2017; Farrar 2017; Wyatt 2019; Ontario Tree Atlas Project 2021). Southern Ontario is the most northern range limit for this species; in the United States, it is native to 26 eastern states including the northern states of New York and Michigan, and occurs as far south as Florida and Texas (Bowden and Miller 1951; Lagrange and Tramer 1985; Callaway 1993; Layne 1996; Robles-Diaz-de-Leon and Nava Tudela 1998; OMNR 2000; Lyle 2006; Hormaza 2014; Hormaza et al. 2017; Farrar 2017; Wyatt 2019; Judd 2019). The pawpaw tree can live up to 60 years (OMNR 2000).

The pawpaw tree belongs to the tropical family *Annonaceae* and the genus *Asimina* is the only representative in North America (a cool temperate region) for this family (Bowden and Miller 1951; Willson and Schemske 1980;

Lagrange and Tramer 1985; Callaway 1993; Layne 1996; Robles-Diaz-de-Leon and Nava Tudela 1998; Lyle 2006; Hormaza 2014; Hormaza et al. 2017; Farrar 2017; Wyatt 2019; Judd 2019). Fossils of pawpaw tree ancestors have been found in Toronto in the Don Valley area suggesting that this species was formerly distributed across a greater range within Southern Ontario (Bowden and Miller 1951).

The pawpaw tree produces the largest edible fruit in North America (Bowden and Miller 1951; Callaway 1993; Layne 1996; Hormaza 2014; Hormaza et al. 2017; Wyatt 2019; Judd 2019). The fruit is related to the tropical custard apple (*Annona reticulata* L.), sugar apple (sweetsop) (*Annona squamosa* L.), cherimoya (*Annona cherimola* Mill.), and soursop (*Annona muricata* L.); these fruits also belong to the *Annonaceae* family (Callaway 1993; Layne 1996; Hormaza 2014; Hormaza et al. 2017; Farrar 2017; Wyatt 2019; Judd 2019; Encyclopedia Britannica 2022). The texture of the pawpaw fruit has been described as close to custard and the taste is like a blend of mango and banana (Layne 1996; Robles-Diaz-de-Leon and Nava Tudela 1998; Lyle 2006; Hormaza 2014; Wyatt 2019; Judd 2019).

Wild-growing specimens of this fruit tree that have shown to be superior in the areas of fruit size, shape, and texture have been used to develop hybrids to improve upon inconsistencies noted in wild populations (Willson and Schemske 1980; Lagrange and Tramer 1985; Layne 1996; Peterson 2003; Judd 2019). In 1993 there were a total of 68 cultivars developed and 19 were commercially available (Callaway 1993). As of 2019, the number of available

cultivars in nurseries had increased to 40 (Judd 2019). The pawpaw fruit has been popular in the United States, where most of the population exists, for many centuries (Layne 1996; Hormaza 2014; Judd 2019). It has been a food source for humans and wildlife for thousands of years (Bowden and Miller 1951; Layne 1996; OMNR 2000; Lyle 2006; Hormaza 2014; Wyatt 2019; Judd 2019).

Objective

The objective of this written work is to examine the available literature about the pawpaw tree and provide further insight into the following topics: species range within Canada, biology, habitat requirements, non-timber qualities (i.e., fruit or wildlife value), cultural significance, flower pollination, and fruit production, and how the pawpaw tree may be utilized in the urban landscape. The key discussion of this paper will be on how fruit production may be enhanced in wild pawpaw tree populations in Southern Ontario and why it is important. There will also be suggestions on how to preserve and potentially expand this rare Ontario species' range through efforts such as assisted population migration. The literature for this paper will be sourced from peer-reviewed articles, books, and other scholarly resources.

LITERATURE REVIEW

1.1 Species Range

The pawpaw tree grows best in the USDA hardiness zones 5 through 8 (Hormaza 2014). Judd (2019) notes that in the U.S. the most successful fruiting happens through zones 5b to 9a. In Canada, the ideal growing areas for the

pawpaw tree are in the plant hardiness zones 7a to 6a (Natural Resources Canada 2021). It is considered a rare species in Canada; in Ontario, the tree is at its northernmost limit and can only be found growing wildly in small groups across several regions around Lake Erie including Middlesex, Essex, Kent, and Haldimand-Norfolk (Bowden and Miller 1951; Farrar 2017; OMNR 2000). It can also be found growing in the Niagara Region in isolated stands (OMNR 2000; Ontario Tree Atlas Project 2021). Surveys of existing wild populations were conducted for The Ontario Tree Atlas Project between 1994 and 2006 (Ontario Tree Atlas Project 2021). The results can be seen in Figure 1. Individual pawpaw trees can be found outside the hardiness zone planted on private property (OMNR 2000; Farrar 2017).

The Ontario Tree Atlas Project was conducted to better understand the range and abundance of Ontario's tree species (Ontario Tree Atlas Project 2021). The green squares represent greater than or equal to 100 non-panted individuals surveyed and the yellow squares represent low survey numbers of less than 100 individuals (Ontario Tree Atlas Project 2021).

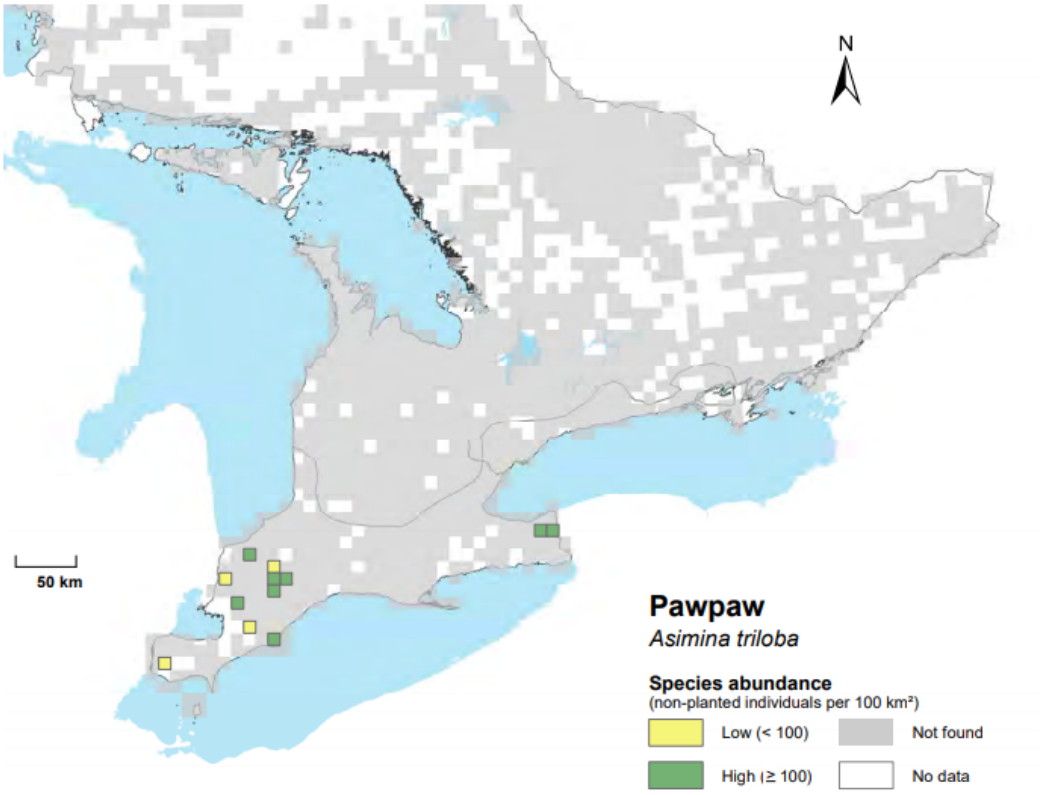

Figure 1. Map showing the pawpaw tree distribution in Southern Ontario (Source: Ontario Tree Atlas Project 2021).

1.2 Biology

Farrar (2017) describes the pawpaw tree as a “small deciduous tree that grows up to 10 m high”. Height can vary depending on factors such as soil and light availability; trees may not reach full height potential in poor growth conditions (Lyle 2006; Judd 2019).

The leaves of the pawpaw tree are large, widest above the middle, and tapered toward the base (Farrar 2017) (see Figure 2). Crushed leaves give off an unpleasant odour (Lyle 2006). The bark of a mature tree is grey and rough, while a young tree has dark brown, shiny, smooth bark (Farrar 2017).

As is common with many understory tree species, the pawpaw is very shade tolerant and will still grow in low light conditions (Robles-Diaz-de-Leon and Nava Tudela 1998; OMNR 2000; Farrar 2017; Judd 2019). In natural stands it is often found growing in small groups or thickets; root suckering is a key form of regeneration for this species (as seen in Figure 3) (Bowden and Miller 1951; Willson and Schemske 1980; Layne 1996; OMNR 2000; Lyle 2006; Farrar 2017; Wyatt 2019; Judd 2019).

Figure 2. The leaf shape and size give the pawpaw tree a tropical look even with saplings. (Source: Pantaleo, 2014).

Figure 3. Root suckers from a planted pawpaw tree (Source: Pantaleo, 2019).

Species distribution research in Southern Ontario by Bowden and Miller (1951) found that in a single area, there could be “ten trees or several hundred in one location; the roots spread underground and shoots come up around the larger trees”.

Several authors describe the flowers of the pawpaw tree as perfect, a dark red (burgundy) colour (see Figure 5) and occurring on previous years’ twig growth as clusters of singles (Bowden and Miller 1951; Willson and Schemske

1980; Lagrange and Tramer 1985; Layne 1996; Gottsberger 1999; Hormaza 2014; Hormaza et al. 2017; Farrar 2017; Judd 2019). The flowers emerge in mid-spring as a brown velvet bud before the leaves (see Figure 4) (Bowden and Miller 1951; Willson and Schemske 1980; Lagrange and Tramer 1985; Layne 1996; Lyle 2006; Hormaza 2014; Farrar 2017; Judd 2019). The immature flower is greenish-yellow in colour (Bowden and Miller 1951; Willson and Schemske 1980; Gottsberger 1999; Hormaza 2014). The flower can grow up to 5cm in size with an inner and outer layer of three petals (see Figure 5) (Lagrange and Tramer 1985; Layne 1996; Hormaza 2014; Hormaza et al. 2017; Farrar 2017).

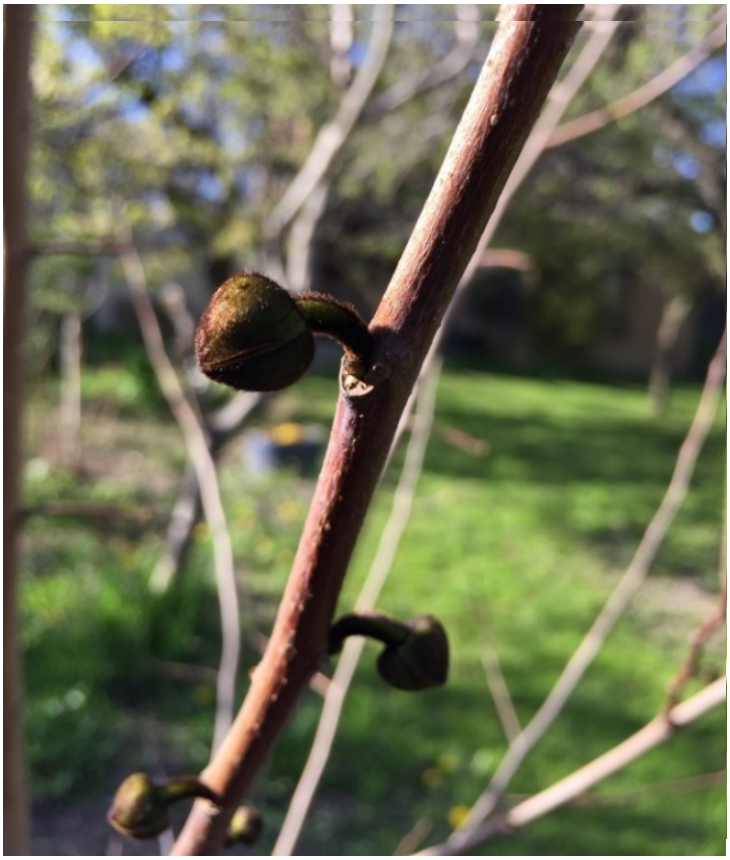

Figure 4. Velvet brown buds of emerging pawpaw flowers (Source: Pantaleo, 2019).

Figure 5. A mature pawpaw flower's distinct colour and bowl shape (Source: Pantaleo, 2018).

The flowers of the pawpaw tree are protogynous and rarely if ever, self-pollinate (Willson and Schemske 1980; Lagrange and Tramer 1985; Layne 1996; Gottsberger 1999; Lyle 2006; Hormaza 2014; Hormaza et al. 2017; Wyatt 2019; Judd 2019). Judd (2019) explains that "…the flowers, typically, are self-infertile because the female pistils and the male stamens ripen at different times in the same flower".

Pawpaw seeds can be up to 3cm long and are bean-shaped with a brown colour (Lagrange and Tramer 1985; Callaway 1993; Layne 1996; Lyle 2006; Hormaza 2014; Farrar 2017; Judd 2019).

The seeds of the pawpaw tree were discovered to be buoyant in a study by Bowden and Miller (1951), and they deduced that dispersal over water may be another factor alongside animals and man for this species' distribution into Ontario.

1.3 Habitat Requirements

The pawpaw tree grows best in rich, moist, fertile soils along waterbodies such as rivers and streams or on floodplains (Bowden and Miller 1951; Lagrange and Tramer 1985; Callaway 1993; Layne 1996; Robles-Diaz-de-Leon and Nava Tudela 1998; OMNR 2000; Lyle 2006; Hormaza 2014; Farrar 2017; Wyatt 2019; Judd 2019). Naturally occurring stands are usually found growing in soils that have clay content, occasionally sand, and a pH range of 5.0-5.7 (OMNR 2000; Lyle 2006). Anthropogenic plantings of pawpaw trees will tolerate a pH range of 4.5-7.5 and will establish best in fertile, well-drained, slightly acidic soil (Judd 2019).

A well-developed and established root system is key to successful pawpaw tree growth (Callaway 1993; Lyle 2006; Judd 2019). Judd (2019) notes in his manual on growing pawpaw trees that "…the pawpaw's deep tap root helps to maintain moisture needs once established in drier soils".

1.4 Flower Pollination and Fruit Production

The fragrance of the pawpaw flower has been described by authors in various ways including Hormaza (2014) stating that it smelled of "…decaying organic matter…", and Gottsberger (1999) saying it was "strong fruity, spicy, or

even unpleasant". Judd (2019) notes that the smell is "akin to sourdough yeast". The distinct odour of the flower is believed to be an attractant to beetles and flies (Willson and Schemske 1980; Lagrange and Tramer 1985; Layne 1996; Gottsberger 1999; Hormaza 2014; Hormaza et al. 2017; Judd 2019; Wojcik 2021).

Beetles and flies have been observed as the main pollinators of the pawpaw flower (Willson and Schemske 1980; Lagrange and Tramer 1985; Layne 1996; Gottsberger 1999; OMNR 2000; Hormaza 2014; Hormaza et al. 2017; Farrar 2017; Wyatt 2019; Judd 2019). Beetles are one of the oldest pollinating insects and fossil evidence suggests they were pollinating ancient angiosperms during the Mesozoic period (about 200 million years ago) (United States Department of Agricultural n.d; Gottsberger 1999; Wojcik 2021). There is fossil evidence showing that beetles were pollinating as early as the Jurassic and Cretaceous periods (Gottsberger 1999; Wojcik 2021). The methods through which beetles pollinate present-day flowers of the magnolia family have changed little since then (Wojcik 2021). Table 1 (page 13) compares flower shape, size, colour, odour, and pollen or nectar presence and the preferences of four pollinating insects for comparison: beetles, flies, bees, and butterflies.

The fruit of the pawpaw tree is categorized as a berry, is oblong in shape, and forms clusters (Bowden and Miller 1951; Callaway 1993; Layne 1996; Lyle 2006; Hormaza 2014; Farrar 2017; Judd 2019). Figure 6 shows several fruits forming where a single flower once was while Figure 7 shows maturing fruits. The fruit can be 5 to 12 cm long and 3 to 10 cm in width (Layne 1996; Lyle 2006;

Farrar 2017; Judd 2019). The skin will turn brownish-black when ripe (Figure 8) (Callaway 1993; Layne 1996; Lyle 2006; Farrar 2017; Judd 2019). The flesh is a range of shades of white, yellow, and orange (Bowden and Miller 1951; Lagrange and Tramer 1985; Callaway 1993; Layne 1996; Lyle 2006; Farrar 2017; Judd 2019).

Flowers and fruit typically appear on trees that are 4 to 6 years old and trees that are in optimal growing conditions can yield 50 to 100 fruits per tree (OMNR 2000; Lyle 2006; Judd 2019). Judd (2019) notes that the ideal harvesting time for pawpaw fruit can vary depending on factors such as weather, genetics, and location but usually occurs between late summer and the first autumn frost.

Research by the OMNR (2000) concluded that the fruit of Ontario-based pawpaw populations tends to not be as flavourful as the more southern U.S based populations.

Figure 6. Fruits form where the flower once was (Source: Pantaleo 2019).

Table 1. A simple comparison of the flowers visited by four different insect pollinators: beetles, flies, bees, and butterflies (Source: United States Department of Agricultural n.d; Wojcik 2021).

Insect	Flower Shape	Flower Size	Flower Colour	Odour Attractant Descriptor	Presence of Pollen or Nectar in Flower
Beetle	Bowl-shaped	Solitary and large/small and clustered	Pale green or white	Spicey, fruity, sweet, or strong (e.g., fermented)	Nectar present
Fly	Funnel (may have traps within)	Varied	Dull, pale, browns, dark reds, or purple	Very strong (e.g., decaying flesh)	Pollen present
Bee	Tubular (with a landing platform)	Varied	Bright (blue or yellow is preferred)	Sweet or minty	Nectar present
Butterfly	Clustered (landing platform present)	Usually small	Bright (orange, red, or yellow preferred)	Unknown. (Butterflies have a weak sense of smell but are often attracted to flowers that other butterflies have emitted an odour on)	Nectar present

.

Figure 7. The clustered growth of maturing pawpaw fruits (Source: Trees of Joy 2011).

Figure 8. Typical blackish-brown skin of ripe pawpaw fruit. Note the brown bean-shaped seeds and flesh colour (Source: Trees of Joy 2011).

1.5 Cultural Values

Many Indigenous groups in Southern Ontario and the U.S. relied on the pawpaw as a food source and the fibrous bark was good for tools such as fish nets and baskets (Layne 1996; Robles-Diaz-de-Leon and Nava Tudela 1998; Hormaza 2014; Judd 2019). Hormaza (2014) notes that the name of *Asimina* was a variation on the "…native Algonquian word assimin/rassimin/racemin, via Cajun French assiminier". The word "min" is Algonquian for fruit (Hormaza 2014). Early colonial farm establishments often led to the destruction of areas where Indigenous groups were cultivating pawpaw fruit from wild stands (Robles-Diaz-de-Leon and Nava Tudela 1998).

The pawpaw tree has more of a recorded history in the United States than it does in Canada and Layne (1996) describes it as having "a well-established place in folklore and American history". The first recordings of the pawpaw tree in the United States go as far back as 1541 and were done by a Portuguese officer with a Spanish expeditionary force in the southeastern states (Hormaza 2014). There were recorded observations of Indigenous peoples cultivating the pawpaw fruit (Hormaza 2014).

There are very few written records of the pawpaw tree in Canada, one of them being from a Jesuit priest Joseph de Bonnecamps who gave a detailed description of the fruit and noted it was a common food source for the Indigenous peoples and Canadians, but he personally found the taste "…an unendurable insipidity" (Hormaza 2014).

1.6 Non-timber Values

The pawpaw tree is the only host for the zebra swallowtail butterfly (*Eurytides marcellus),* a very rare and endangered species in Ontario (Layne 1996; OMNR 2000, Hormaza 2014; Judd 2019). Judd (2019) has noted that leaf damage from the larvae is considered minor.

It is suggested that stands of naturally occurring pawpaw trees in Southern Ontario should be protected and monitored for this butterfly species (OMNR 2000). Mammals such as opossums (*Didelphis virginiana* Kerr), raccoons (*Procyon lotor* (L.) Elliot), and red foxes (*Vulpes fulvus* Desmarest) Merriam) use the fruits as a food source (Layne 1996; OMNR 2000; Lyle 2006; Hormaza 2014; Wyatt 2019; Judd 2019). Birds have also been documented foraging on the fruits (OMNR 2000; Lyle 2006).

Layne (1996) stated that the pawpaw tree is an excellent species for "…habitat restoration and biodiversification in parks, wood lots, and forests". Robles-Diaz-de-Leon and Nava Tudela (1998) note that the pawpaw tree is an ideal candidate for riparian zone restoration as it is well suited to wet soil conditions and adapts well to low-light conditions under larger trees.

One of the most significant qualities of the pawpaw tree can be found in its bark, twigs, and leaves. Annonaceous acetogenins have been sourced in these tree components and research is being conducted to determine the benefits of acetogenins in anti-tumor medications and pesticides (Lyle 2006; Hormaza 2014; Sellers 2017; Attiq et al. 2017; Judd 2019). These compounds

give the pawpaw tree high resistance to diseases and insects (Lyle 2006; Hormaza 2014; Sellers 2017; Judd 2019). Hormaza (2014) notes however that the caterpillar stage of the zebra swallowtail butterfly is not affected by the acetogenic compounds, suggesting that it may have coevolved with the pawpaw tree.

1.7 Pawpaw Preservation

Many factors can attribute to the current range of the pawpaw tree in Ontario, one of them being the result of seed dispersal by both man and other mammals (Bowden and Miller 1951; Layne 1996; OMNR 2000; Hormaza 2014; Wyatt 2019; Judd 2019). Wyatt (2019) notes in his study on phylogeography and population genetics of the pawpaw tree in both wild and anthropogenic populations, that trading amongst Indigenous groups throughout Eastern North America for thousands of years was likely a factor in how the pawpaw tree became established across such an extensive range.

In their study of pawpaw tree distribution in Southern Ontario, Bowden and Miller (1951) noted that the “natural range of the pawpaw is correlated with low elevation and with areas that have a sufficiently long frost-free period to permit the development of fruit”. Layne (1996), Lyle (2006), and Judd (2019) all note that the pawpaw tree is cold tolerant between -25 to -30 °C and requires a minimum of 160 frost-free days to grow successfully.

One of the methods that may be used to expand the range of the pawpaw species is through assisted population migration. In the literature by Winder et

al. (2011) assisted population migration is described as “the human-assisted movement of populations (genotypes) within a species’ established range to maximize adaptation to climate change”. Natural Resources Canada (2022) states that there are three types of assisted migration; assisted population migration, assisted range expansion, and assisted long-distance migration.

Assisted population migration works with low-risk species and utilizes humans to move seed within an established range (NRC 2022). Assisted range expansion is used with intermediate-risk species and uses human-assisted movement to expand the species range just outside the established range in an area that mimics the current habitat (NRC 2022). Assisted long-distance migration is used for high-risk species and uses human-assisted movement to move that species far beyond its natural dispersal range (NRC 2022).

There is potential for ecological implications when moving tree species into new ranges and it is important, however, if these risks are managed appropriately through careful management of the species and smaller transfer distances, then assisted migration may prove a suitable option for some species (Winder et al. 2011).

The Forest Gene Conservation Association (FGCA) is an Ontario-based organization focusing on gene conservation within forests and is working towards stabilizing at-risk tree species such as butternut (Forest Gene Conservation Association 2023). Assisted population migration is being used in “trials to monitor the performance of stock sourced locally and from southern sources based on predicted Climate Change analysis” (FGCA 2023). This is

being used for species within their natural ranges and will help determine how local populations and their seed sources may respond to a warming climate (FGCA 2023).

The University of Guelph in Southwestern Ontario is home to a substantial collection of trees within its arboretum. Common and rare woody plants can be found here, including the pawpaw tree. As of 2018, there were 12 individual trees located within the arboretum (University of Guelph n.d). In 1970 the first steps towards creating a living archive through gene banks were established (University of Guelph n.d).

The Rare Woody Plants of Ontario Program, also known as Picking up the Pawpaws was launched in 1979 with the intention "…to survey and document the status of rare woody plant species in Ontario and inform landowners of the significance of the plants on their property" (University of Guelph n.d). Materials such as cuttings and seeds were collected from wild populations "…with the goal of establishing an ex-situ conservation stand for each species as a genetic back up in case in-situ conservation efforts did not maintain survival of the remnant populations" (University of Guelph n.d).

In 2018, The International Union for Conservation of Nature (IUCN) ranked the pawpaw tree on its Red List of Threatened Species on a global scale as G5 (very common) and its occurrence as "Least Concern" (IUCN 2023). However, in the collected data it was noted that populations were severely fragmented, and many subpopulations, habitat quality, and availability were in decline (IUCN 2023). Despite the global ranking, data collected from The Rare

Woody Plants of Ontario Program could argue for the rarity of the Southern Ontario populations. Fox (2012) notes in his paper on The Rare Woody Plants of Ontario Program, that a globally common species may still need conservation efforts and that many species are not considered to be high priority resulting in a poor "…representation of diverse genetic material archived in ex-situ collections…". The pawpaw tree is not currently listed in Canada's Species at Risk Act (SARA) (Government of Canada 2023).

1.8 Pawpaw Trees in Agroforestry

Robles-Diaz-de-Leon and Nava Tudela (1998) state that the many qualities of the pawpaw tree make it "…an ideal choice for an agroforestry project in the temperate region". Judd (2019) describes the pawpaw tree as an ideal candidate for agroforestry as it combines well with other tree and shrub species and its leaves are unpalatable to grazing livestock; goats included. Agroforestry combines agricultural crops, cultivated tree species (and other woody perennials), and animals to create a dynamic multi-use landscape (Robles-Diaz-de-Leon and Nava Tudela 1998; Judd 2019).

In his manual on growing pawpaw trees, Judd (2019) writes "food forests are not about growing food *in* the forest, but, rather *like* the forest". He goes on to say that landscape planning should be influenced by forest structure and should include the elements of "overstory trees, midstory trees, understory trees, shrubs, groundcovers, vines…" (Judd 2019). The pawpaw tree is well suited to be a proponent of a food forest.

Layne (1996) also describes the pawpaw tree as being a valuable "component in residential 'edible' landscapes". The fruits are very nutritious, surpassing grapes, apples, and peaches, with high levels of vitamins (including A and C) minerals, and protein (Callaway 1993; Layne 1996; Lyle 2006; Hormaza 2014; Sellers 2017; Wyatt 2019; Judd 2019). Unfortunately, the shelf life of the pawpaw fruit is short, typically lasting only 2 to 3 days (Layne 1996; Hormaza 2014; Judd 2019). However, if kept refrigerated it can last up to 3 weeks (Layne 1996; Hormaza 2014; Judd 2019).

DISCUSSION

It has been noted in studies that fruit set amongst wild populations of pawpaw trees is lacking or non-existent, which could be a result of several factors (Willson and Schemske 1980; Lagrange and Tramer 1985; Layne 1996; Hormaza 2014; Wyatt 2019; Judd 2019). It could be due to a lack of pollinating insects, habitat loss, or lack of new genetic material in populations (University of Guelph n.d; Willson and Schemske 1980; Lagrange and Tramer 1985; Layne 1996; Fox 2012; Hormaza 2014; Wyatt 2019; Judd 2019). These factors offer several challenges for populations of tree species in Southern Ontario that are considered rare, including the pawpaw.

Cloning is a common form of reproduction among riparian tree species and may be seen as an adaptation to living in areas of flooding; one of the key habitats of the pawpaw tree (Wyatt 2019). The clonal habit of the pawpaw tree may be one of the more pressing issues in terms of successful pollination and trees receiving pollen via insects from genetically different individuals may need

to travel quite a distance (Lagrange and Tramer 1985; Wyatt 2019). Cross-pollination with another genetically different tree is required for a successful fruit set in the pawpaw tree and the lack of new genetic material being introduced in a stand of pawpaw trees is likely another factor in the issue of low fruit production (Willson and Schemske 1980; Lagrange and Tramer 1985; Layne 1996; Lyle 2006; Judd 2019). Planting genetically different individuals within proximity to naturally occurring stands may help in the movement of new genetic material via the key pollinating insects. Kearns and Inouye (1997) noted that habitat fragmentation will often isolate plant populations and endangered plants will often lack genetic diversity if surrounded by unsuitable habitats.

In Southern Ontario, habitat loss is often the result of land clearing for housing or agriculture (University of Guelph n.d; Fox 2012). In a study by Bailey et al. (2010) on habitat fragmentation in traditional apple (*Malus domestica*) orchards in Switzerland, it was noted that between 2001 and 1951 land use for agricultural purposes resulted in an estimated 80% loss of traditional orchards resulting in severe fragmentation in the landscape leading to a loss of important habitat and biodiversity. In areas of intense management and cultivation, there are instances of fewer varieties of insects including crucial pollinator species (Kearns and Inouye 1997; Bailey et al. 2010; Cornille et al. 2015).

Although land clearing for agriculture has proved detrimental for many flora and fauna species, agroforestry may be a useful system to aid in the re-establishment of pawpaw trees in their natural habitat. In the study by Bhagwat et al. (2008), the impacts of deforestation on tropical forests were discussed and

it was determined that agroforestry was a beneficial tool to aid in the biodiversity and conservation of remaining forests by providing corridors in fragmented landscapes and enhancing habitat for certain species of both flora and fauna. In tropical regions, coffee plantations in the shade of native species mimic a forest stand by providing the benefits of the coffee plant as a resource for humans and a habitat for many species of flora and fauna (Bhagwat et al. 2008). The pawpaw tree already thrives as an understory species and would potentially adapt well to plantings beneath mature shade-providing trees. Cornille et al. (2010) also studied the positive impacts of agroforestry in their study on gene flow between wild European apples (*Malus sylvestris)* and the cultivated apple (*Malus domestica).* The experiment of integrating wild apples into agroforestry systems was deemed to be useful for breeding programs and provided additional genetic material to orchards of cultivated apple varieties (Cornille et al. 2010).

Agroforestry can also provide a buffer to pre-existing conservation areas and create connections through corridors for the movement of flora and fauna species (Bhagwat et al. 2008). In their work, Kearns and Inouye (1997) and Bailey et al. (2010) also noted the importance of creating connectivity between habitats in landscapes that are impacted by habitat loss due to developments such as agriculture. Without suitable corridors, vital pollinator species may become isolated from habitats such as forests or meadows resulting in low pollen delivery and quality, often leading to pollinators choosing to bypass an area if there are not enough resources available (Kearns and Inouye 1997).

Bailey et al. (2010) concluded that in areas with higher connectivity between isolated fruit orchards, species richness remained high compared to areas with little to no connectivity between orchards.

Connectivity between pawpaw stands may prove beneficial for both pollinating insects and the rare zebra swallowtail butterfly, which as noted in the reviewed literature, uses the pawpaw tree as its host and provides a food source for the larvae. Bailey et al. (2010) noted that there has been more research on the effects of fragmentation on birds compared to insects and further studies are suggested to continue to understand the full effect of fragmentation on insects.

Kearns and Inouye (1997), Bhagwat et al. (2008), Bailey et al. (2010), and Cornille et al. (2010) provide valuable insight into the beneficial impacts that agroforestry can provide for trees providing food resources and the impacts of habitat fragmentation on flora and fauna species including vital pollinators. These studies could be used as references for creating agroforestry systems as a means of conservation for the pawpaw tree. Lands adjacent to existing pawpaw stands could be protected and plantings of both shade-providing species and the understory pawpaw trees could be completed. Establishing corridors between forests with other pawpaw individuals could prove beneficial as limited connectivity between stands for the pollinating beetles and flies may currently be a factor towards the low or no occurrence of fruit.

Mass plantings of pawpaw trees and preserving ideal habitats might aid in the expansion of the current range of the pawpaw tree. If more corridors are created between forested areas with pawpaw trees, it may provide an opportunity for the fruits and subsequent seeds to travel beyond these areas via humans or animals. Human-assisted migration as discussed in the literature review would be a key component in the establishment of genetically diverse pawpaw trees within and beyond their current range.

It is important to note that the pawpaw tree may not be able to handle extreme migration as the cold tolerance was noted by Layne (1996), Lyle (2006), and Judd (2019) to be between -25 to -30 °C. Varieties with a higher cold tolerance will need to be developed to see the pawpaw tree growing naturally in forest stands further north in Ontario. Bowden and Miller (1951) determined in their study of pawpaw trees in Southern Ontario that successful fruiting was linked to trees that were established in areas of lower elevation and subsequently had more frost-free days. Fox (2012) notes that in the face of inevitable climate change, species such as the pawpaw tree which are at their northernmost range should be conserved as they have become adapted to much colder environments than individuals in Southern provenances (e.g. the U.S.A).

Cornille et al. (2015) noted that fruit trees are key components in temperate ecosystems, essential in food production, and economically important. Even traditional fruit orchards, such as those that have existed in Europe for centuries, play a vital role in providing habitat for many flora and

fauna species including insects and birds, especially in areas of intense agriculture (Bailey et al. 2010). It is likely that pawpaw trees play a similar role in the forest stands where they exist.

Through efforts such as agroforestry systems, habitat preservation, the introduction of new genetic material, and species migration efforts, pawpaw tree populations could become far more established in the wild and once again become a valuable and reliable source of food for both people and animals while also providing diversity and refuge for other rare species such as the zebra swallowtail butterfly.

CONCLUSION

The pawpaw tree is one of Ontario's rarest trees, its wild populations existing in small pockets of forest in some of the most human-impacted landscapes in the province. The fruit of the pawpaw tree is unique in both size, texture, and flavour, and as a member of the family *Annonaceae*, it offers a nutritious food source for both wildlife and humans and has been a key diet component for thousands of years. The fruit is the largest that can be found in Ontario's wild fruit-bearing trees. The form and characteristics of the pawpaw tree give the tree an exotic look, making it an impressive understory tree and dynamic addition to urban landscapes and food forests. Its value goes beyond its fruit, with the leaves, twigs, and bark containing acetogenins, a powerful compound that is being tested for use in pesticides and anti-tumour medications. The pawpaw tree plays an ecologically significant role as the only known host

for the rare zebra swallowtail butterfly. Its continued presence could very well be linked to the survival of this species.

It would be beneficial if additional studies were conducted on the wild populations of pawpaw trees in Southern Ontario, as much of the current literature and knowledge is based on populations in the United States, where the range of the pawpaw is more extensive. Updated information on the state of fruiting within Ontario's populations could help to determine which course of action may be most beneficial. At the most northern part of its range in Southern Ontario, the pawpaw tree faces many challenges including habitat destruction, loss of genetic diversity, and fragmentation among populations. The low fruit set noted in the reviewed studies may also be attributed to these factors.

There are several practices that could be put into place to help improve the populations of pawpaw trees in Ontario. Through the act of agroforestry, the tree could be integrated into existing forests which may sit on agricultural land, thus encouraging the establishment of more individuals and creating optimal habitats. Incorporating agroforestry could also help with habitat fragmentation which is a common factor leading to loss of habitat and species diversity. Preservation and establishment of habitat will also be vital for the pollinating insects which visit the flowers of the pawpaw tree (beetles and flies mainly).

Forest stands which are currently home to pawpaw trees could be preserved and new genetic material could be brought in through the planting of unrelated specimens. This could help combat one of the key issues with the pawpaw tree, which is its tendency towards root suckers, which can potentially

cause large thickets of trees that are related, thus resulting in little to no fruit set (as discussed in the literature, pawpaw trees need two genetically different individuals for successful pollination).

Assisted migration through the efforts of humans may be beneficial to help expand the range of the pawpaw tree resulting in increased wild populations, however, it is important to note that this is not a quick-fix solution and it will take many years to determine if the results are a success. It is still an option worth considering.

The pawpaw tree's continued existence in the wild is important, not only for its highly nutritious fruit, but the species plays a valuable role in the forest understory, and it holds powerful medicinal qualities. The pawpaw tree is at its northernmost range in Southern Ontario, but with continued research and raising awareness about its many qualities, its populations may begin to expand thus making it a more common sight and no longer a rarity. A healthy and abundant pawpaw tree population will bring all manners of benefits to those who know where to find them and are willing to share knowledge about its many virtues. There is truly nothing comparable to the experience of eating a pawpaw fruit and it is a species worthy of preservation throughout Ontario.

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APPENDICES