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The Effects of Isoprene Emission from Native and Invasive Trees on Local Air Quality

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The Effects of Isoprene Emission from Native and Invasive Trees on Local Air Quality

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ABSTRACT Biogenic volatile organic compounds (BVOCs) are the most abundant category of reactive gasses emitted into the atmosphere by the biosphere. Isoprene is one type of BVOC produced in combination with the process of photosynthesis from certain plant species. Isoprene released into the atmosphere leads to the production of tropospheric ozone which is detrimental to regional air quality. Climate change is a concern for air quality because with rising temperatures, BVOC emissions will increase worsening air quality. The trait of isoprene emission combined with tree species abundance affects the air quality of Chicagoland. Invasive trees can alter ecosystem function and negatively impact native tree populations. Invasive tree species in the Chicagoland area can outcompete native tree species. Because isoprene emission is a genus-specific trait, differing isoprene emission patterns between invasive and native trees in the Chicagoland area have the potential to impact regional air quality. To assess the potential contribution of invasive species on air quality, the three most abundant native and non-native species were determined from an existing tree inventory. The three abundant native trees sampled were boxelder (*Acer negundo)*, silver maple (*Acer saccharinum)*, and black walnut (*Juglans nigra*). The three abundant invasive tree species sampled were European buckthorn (*Rhamnus cathartica)*, Norway maple (*Acer platanoides)*, and Siberian elm (*Ulmus pumila)*. There was no statistical difference in isoprene emissions between the most abundant native and invasive tree species sampled at the LaBagh Woods Forest Preserve located in Chicago. Measurements did reveal that European buckthorn, invasive to Illinois, was a strong isoprene emitter.

INTRODUCTION

Isoprene (2- methyl-1, 3-butadiene) is a type of biogenic volatile organic compound (BVOC) emitted from the biosphere by vegetation. Isoprene is the most abundant BVOC emitted into

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the atmosphere. Isoprene is emitted from the leaves of plants in conjunction with the process of photosynthesis. Not all plant species produce isoprene; isoprene emission is a trait found at the genus level. And depending on the species, the plant can be a strong or weak emitter of isoprene (Geron et al. 2001). Isoprene affects air quality because when isoprene interacts with oxides of nitrogen and sunlight, ground-level ozone is produced. Ozone harms human and plant health and therefore isoprene emission can negatively affect air quality (Lee et al. 2006). Climate change factors can led to an increase in isoprene emissions and therefore worsen air quality. The main interaction between climate change and isoprene emission is that an increase in air temperature will increase the production of isoprene.

The invasion of nonnative pioneer species into ecosystems changes the existing native plant species composition. Many pioneer species are often invasive species because pioneer species are aggressive and able to withstand various conditions like disturbance and high light environments (Yates et al. 2004). Native plant species often decline in population because invasive species can outcompete native species for resources and space. Studies have shown the negative consequences of invasive tree species in a nonnative ecosystem. A study conducted by Flanagan et al. (2015) found that invasive plants had a competitive advantage over native plants. Climate-linked environmental variables like temperature and water regime affect plant dispersion patterns. The invasive plants were temperature flexible compared to native plant species (Flanagan et al. 2015). This lead to native plants not dispersing in the ecosystem as rapidly as invasive plants. Invasive plant species can also out-compete native species for resources because of the lack of predation and independent dispersal. Invasive trees can disperse without forming a mutualistic relationship with another organism in an ecosystem (Vilà et al. 2011). These factors make it more likely for invasive trees to become more abundant than native trees.

A study conducted by Sheppard and Stanley (2014) concluded factors associated with climate change will further promote the competitive advantage of invasive species. In their study, the fast-growing invasive plants had a positive response to CO_2 concentration. The invasive plants were able to take more resources from the atmosphere as well as the soil compared to a native plant (Sheppard and Stanley 2014).

BVOC emission potential is a plant trait based on genus. Despite the poorly understood evolutionary origins of BVOC-emitting plants, ecological succession may control how this trait arises in certain plant species. Ecological succession can predict BVOC potential because the growth factors influence phylogenic traits. BVOC emissions are hypothesized to be an adaption in plants that allow pioneer species to survive and retain function in extreme heat events. Several studies have observed that isoprene emissions are the highest in early to middle succession and decrease in late succession. This observation was found in different ecosystems like the savanna- rainforest gradient of central Africa found by Klinger et al. (1998), in the eastern North American temperate forest observed by Martin and Guenther (1995) and in the Amazon rainforest observed by Jardine et al. (2016). Early and middle successional plant species have association with pioneer species, which can be invasive species. Invasive species have a correlation with greater isoprene potential and are more likely to be high emitters of isoprene because isoprene is an adaption that is an advantage in early and middle succession plants. BVOCs are compounds plants use to combat heat stress. BVOC synthesis is a mechanism emitters use to protect the structures responsible for photosynthesis while photosynthesizing during high temperature extremes (Vickers et al. 2009). Invasive species could have the potential to be high isoprene emitters because invasive species often establish in disturbed areas where late stage successional plants cannot establish.

European buckthorn (*Rhamnus cathartica*, L.) is an extremely common invasive species in the Chicagoland region. In growth form, buckthorn is a tall understory shrub that can grow up to 1 meter in height and is a shade tolerant plant (Fagan and Peart, 2004). The physiology of the buckthorn is a possible reason for its abundance and competitive edge over native tree species. Studies conducted by Fagan and Peart (2004) researched the impact of the invasive glossy buckthorn (*Rhamnus frangula* L.) on survival and growth of shade tolerant seedlings and saplings of canopy tree species. The findings concluded that glossy buckthorn reduced the growth and survival of all the tree species. European buckthorn has also been shown to alter soil composition (Heneghan et al., 2006). Their study concluded in areas where European buckthorn was abundant, the soil had a higher percentage of nitrogen and carbon, modified nitrogen mineralization, elevated pH and soil moisture. Areas without European buckthorn did not have the same soil composition. This could be a possible mechanism the European buckthorn uses to dominate and increase in abundance.

Because isoprene emission is genus- and sometimes species-specific, abundance of emitting species is a key factor for driving regional isoprene emissions. This ties the process of invasion to regional isoprene production and hence air quality. The relative contribution of isoprene produced by invasive and native tree species lacks research in the Chicago area. The focus of this research project was to determine whether or not there is a significant difference in isoprene emission rates between the most abundant invasive and native tree species in the Chicagoland area. If invasive trees produce more isoprene than native trees which are displaced, then the process of invasion would worsen local air quality. The hypothesis is that there will be a significant difference in the rate of isoprene emitted from abundant native and invasive trees.

METHOD

The three most abundant native tree species sampled were boxelder (*Acer negundo)*, silver maple (*Acer saccharinum)*, and black walnut (*Juglans nigra*). The three most abundant invasive tree species sampled were European buckthorn (*Rhamnus cathartica)*, Norway maple (*Acer platanoides)*, and Siberian elm (*Ulmus pumila)* (Nowak et al. 2013). The six trees were selected based on the presence of the trait for BVOC emissions and the highest percentage of total leaf area (three highest native; three highest invasive) from the most recent USDA Chicago region tree survey. BVOC emissions potential was determined based on the tree genus, however growth factor of each tree was not a consideration. Simply, tree species with the greatest leaf area were selected, since tree species with large leaf area have an increased emission potential. Table 1 shows the selected trees with the percentage of the population and percent of total leaf area. The trees were sampled from May to August of 2016 in the LaBagh Woods Forest Preserve of Cook County, **(**41.9796° N, 87.7438° W).

Table 1. The percent population (%Pop) and the percent of total leaf area (%LA) are shown for the trees used in the experiment (Nowak et al. 2013).

Population statistics for study trees			
Tree Species	**Type**	**%Pop**	**%LA**
Siberian elm	Invasive	1.40	3.24
European buckthorn	Invasive	28.20	6.50
Norway maple	Invasive	1.20	3.57
Boxelder	Native	5.5	7.9
Silver maple	Native	2	8.3
Black walnut	Native	1.6	5.7

In the field portion of the experiment, two trees from each species were located and marked on a map using GPS. A total of six samples were collected for each species: three samples from each individual. Samples were taken during daylight hours in the field when the average air temperature range was between 23˚C and 32˚C. A Licor LI-6400 leaf-gas exchange system was used to measure photosynthesis and control leaf environmental conditions within a cuvette. One sunlit leaf in a healthy condition was clamped into the Licor cuvette. The cuvette controlled cuvette air flow (400 μmol s^{-1}), leaf temperature (30˚C), CO_2 concentration (400 ppm) and artificial light (PAR = 1000 μmol m^{-2} s^{-1}). Photosynthesis rates are directly calculated by comparing the CO_2 concentration of air entering and exiting the cuvette. The rates are not reported but were monitored to ensure the leaf was healthy (that is, positive photosynthesis rate). Three BVOC samples were collected for each leaf: two with full light exposure and one without light. BVOCs are light dependent, so in principle, BVOC should only be present in the samples taken in the light. The blank sample was used to remove any VOCs that were coming from the equipment or incoming air.

The BVOCs were collected by diverting a portion of the air leaving the leaf cuvette through a solid absorbent cartridge (TENAX) with a portable pump. Sample cartridges were kept cool to minimize desorption of BVOCs during transportation before analysis. Analysis of the cartridges was done using thermal desorption and a gas chromatograph with a flame ionization detector (GC-FID). Chromatographs produced by the GC-FID identified isoprene by the elution time. The elution time of isoprene was determined with a authigenic standard. The two light samples were compared with the blank to determine if other BVOCs were emitted. The light sample concentrations were averaged and the blank subtracted to derive the other BVOCs (non-isoprene BVOCs). After averaging the results across the two samples from each species, each species was considered as the experimental unit. A two sample T-Test assuming unequal variances was used to analyze the results and the standard error was calculated for graphical interpretation (n = 3, the number of invasive and native species).

Lacking a reliable standard, all results are based on peak areas from the FID and are therefore relative. Peak area is assumed to be proportional to the mass of carbon for isoprene and the BVOCs. Because the air flow rate through the cuvette was constant, these relative peak areas are also proportional to the BVOC emission rates.

RESULTS

There was no statistical difference between isoprene or non-isoprene BVOCs emitted from the native and invasive trees. The p-value for isoprene was 0.43 and for non-isoprene BVOCs the p-value was 0.66 (Figures 1 and 2; Tables 2, 3, 4 and 5). Some species did not emit any detectable quantities, and their emission rate is given as zero in the tables below.

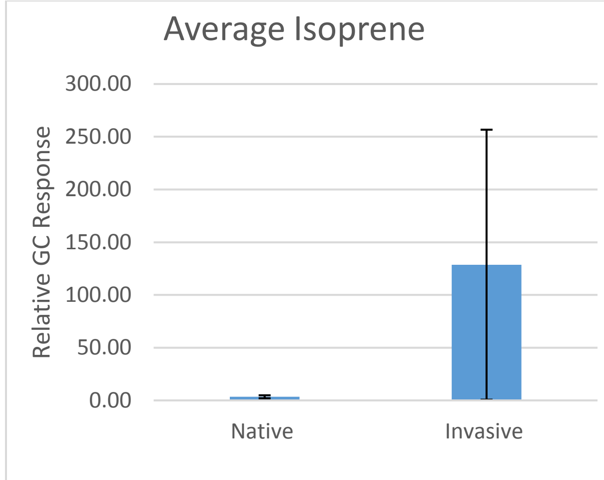

Figure 1. The average isoprene emission rate from native and invasive trees. There was no statistical difference. Invasive trees were dominated by the strong emitter, Buckthorn. GC response was based on peak area.

Table 2. Mean isoprene is the total average of all the native trees. St. error is the standard error.

Isoprene Emissions from Native Trees		
Species	**Mean (peak area)**	**St. Error (peak area)**
Black walnut	5.73	--
Silver maple	3.72	--
Boxelder	0.79	--
Mean Isoprene	3.41	1.43

Table 3. Mean isoprene is the total average of all the invasive trees. St. error is the standard error.

Isoprene Emissions from Invasive Trees		
Species	**Mean (peak area)**	**St. Error (peak area)**
European buckthorn	384.72	--
Siberian elm	1.27	--
Norway maple	0.00	--
Mean Isoprene	128.66	128.03

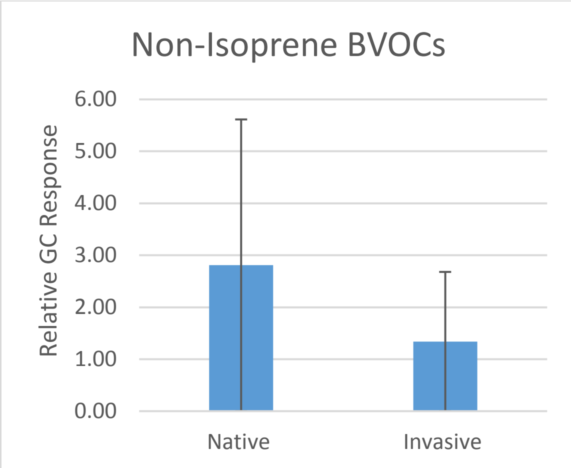

Figure 2. Non-Isoprene BVOCs had no statistical difference between native and invasive trees. Rates for each were much lower compared to rates from Buckthorn. GC response was based on peak area.

Table 4. Mean Non-Isoprene is the total average of all the native trees. St. error is the standard error.

Non-Isoprene Emissions from Native Trees		
Species	**Mean (peak area)**	**St. Error (peak area)**
Black walnut	8.42	--
Silver maple	0.00	--
Boxelder	0.00	--
Mean Non-Isoprene	2.81	2.81

Table 5. Mean Non-Isoprene is the total average of all the invasive trees. St. error is the standard error.

Non-Isoprene Emissions from Invasive Trees		
Species	**Mean (peak area)**	**St. Error (peak area)**
European buckthorn	0.00	--
Siberian elm	4.02	--
Norway maple	0.00	--
Mean Non-Isoprene	1.34	1.34

DISCUSSION

There was no significant difference between the isoprene emissions from abundant native and invasive species. However, the trees sampled in the study do vary in their potential to emit isoprene. In particular, the high emission rates from buckthorn have implications for current and future air quality.

The potential for isoprene emission is a trait that occurs at the genus level. The genera *Acer*, *Juglans* and *Ulmas* are known weak isoprene emitters. For this reason, the three most abundant native Chicagoland area trees, boxelder, black walnut and silver maple, would not be expected to be strong emitters of isoprene. The results of this study confirm this expectation.

Invasive trees like Siberian elm and Norway maple also are known weak emitters of isoprene. Norway maple had the lowest measured emission of isoprene. Norway maple was sampled in a shaded region (understory) of LaBagh Woods. Passing sunlight and partial shade potentially reduced the rate of photosynthesis from the leaf. For this reason, the low expected rate from Norway maple is driven even lower. The Siberian elm was exposed to full sunlight, which might explain its relatively higher rate compared to Norway maple.

Buckthorn was the strongest emitter of isoprene. The locations where European Buckthorn were found promoted high isoprene emission rates. European buckthorn was mainly found in open spaces where the plant had sufficient sunlight to photosynthesize. European buckthorn does emit high amounts of isoprene and therefore its invasion into the Chicagoland area has the potential to negatively impact air quality.

Oaks are a dominant native tree species in the Midwest and are also high isoprene emitters (Geron et al. 2001; Schulte et al. 2011). However, oak trees are not one of the three most abundant trees in Cook County by leaf area. In North American forest and woodlands, oak populations are on the decline. Invasive plants like European buckthorn are competing with oak saplings for soil nutrients, resources and light. (Schulte et al. 2011). An invasive plant species can have a long-term negative impact on oak regeneration (William et al. 2006). Despite an abundant population of established oak trees in the over story, oak saplings compete with invasive European buckthorn. The buckthorn plants may alter the soil conditions in its favor (Heneghan et al. 2006) and the shaded dense shrub layer impacts the establishment of oak saplings (Fagan and Peart, 2004). Because in some cases buckthorn shrubs are replacing oak trees, the oak decline could offset the increase in European buckthorn since they are both strong isoprene emitters.

The abundance and spread of the invasive plants is also a concern for future forest composition and air quality because of interactions with climate change. Because invasive plant species have a wider range of tolerance, climate change will benefit invasive plants (Dukes et al. 2009). Warmer temperatures are also predicted to increase invasive plant diversity (Schulte et al. 2011). In addition, warmer temperatures drive more BVOCs emissions. All these factors would combine to increase BVOC emissions and diminish air quality as the climate warms.

Because European buckthorn is abundant in the Chicagoland area and is a high isoprene emitter, the expansion of the shrub can negatively impact air quality. Therefore, efforts to remove European buckthorn would not only help restore native ecosystems but would also help improve air quality.

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