Analysis of cpA Nerve-Blocking Compounds to Inhibit Functionality of Carbon Dioxide-Sensitive Receptors in Mosquitoes

Authors: Sophie Bullen, Ryan Dempsey, Aneesh Mazumder, Danial Pitafi, and Edward Thomas

STEM Enhancement in Earth Sciences

STEM Enhancement in Earth Sciences, The Texas Space Grant Consortium

STEM Enhancement in Earth Sciences, The University of Texas at Austin

Abstract

Extensive literature suggests that mosquitoes identify hosts based on carbon dioxide (CO2) levels, with higher CO2 levels being associated with the presence of a viable host. To represent this relationship on a global scale, we extracted data from the GLOBE Observer and Collect Earth Online AOI (area of interest) points, layered maps of CO2 Emissions, Population Density, and the Ecological Niches of multiple mosquito species using open-source data from open source data from the CDC, the Georgia Department of Public Health, the Census and ArcGIS. Here, five (5) chemical compounds were analyzed which have promising applications in cpA-nerve blocking for health, economic, and social applications, especially in contexts of developing countries and high socioeconomic vulnerability, and recommend a mechanism through which these compounds may be administered to produce an inhibitory effect on potentially harmful mosquito-host interactions, and by translation, the possible spread of vector-borne disease. After analyzing the correlations in this data, the conclusion was reached that ethyl pyruvate would be an appropriate choice to use as a mosquito repellent, as well as the mix of 2,3 Butanedione 1-Butanal 1-Hexanol and 1-Pentanal in areas where the *Culex quinquefasciatus* mosquito is abundant. Appropriate public health measures should be taken in the form of informing the public on their choices of mosquito repellent in order to limit the spread of vector-borne diseases throughout the state of Georgia in the United States.

Key Words: CO_2 emissions, vector-borne disease, Georgia, diffusible compound

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Intro and Review of Literature

We aimed to answer two questions while working on this project: “how might mosquitoes be affected by changes of CO_2 concentration in the Earth’s atmosphere?”, and “which chemical compounds are most adapted for the inhibition of a mosquito’s cpA nerves from functioning and detecting the CO_2 that humans exhale?” These are important questions to answer because CO_2 levels are rising across the world due to climate change and other factors, altering the environments that billions of humans live in. We sought to increase awareness and accessibility for vector-borne disease prevention using the information we’d find, along with existing data on mosquito populations across the state of Georgia. We’d accomplish this by means of developing a prototype diffuser and researching the different compounds that inhibit different mosquito species’ cpA nerves from detecting CO_2. We hypothesized that if atmospheric concentration of CO_2 in an area is higher on average, there will be a greater density of mosquitoes present in that area. A study conducted in 2013 found that host-seeking stimuli in the species *Aedes aegypti* were affected by different background levels of CO_2 (Majeed et al., 2013) via waveform analysis. However, the concentrations of CO_2 in that study exceed existing fluctuations of concentration by a considerable margin. Trials measured anomalies in host-seeking stimuli with background ppm measuring at 400, 600, and 1200, while at the time of the study, 2013, global CO_2 concentration was at about 390 ppm (Scott, 2018). A year after the study was conducted, XCO_2 anomaly in Georgia was shown to differ no more than 3 ppm. While different background levels of CO_2 concentration were shown to certainly affect primary ethological behaviors in *Aedes aegypti,* it seemed inconclusive to attribute CO_2 concentration in the atmosphere to major shifts in mosquito behavior because the levels of CO_2 in the study were unnaturally high, while on the local scale levels of concentration remained much more consistent. This leads to the conclusion that the effects of atmospheric CO_2 concentrations on mosquitoes are overridden by more localized moments of CO_2 emissions, such as human exhalation. Other external factors probably play a bigger role in mosquito species density and behavior, such as mosquitoes' environmental preferences along with the combination of global warming and climate change.

The organs present in mosquitoes are covered in small hairs called sensilla, and the sensilla called the capitate peg sensilla is sensitive to carbon dioxide (Potter, 2014). Chemical compounds that have been shown to reduce the stimuli created by the smell of CO_2 include ethyl pyruvate, butyryl chloride, methyl pyruvate, citronella, and a mix of 2, 3 butanedione 1-butanal 1-hexanol and 1-pentanal (Turner et al., 2011). The most commonly used compound used in other similar investigations was ethyl pyruvate, primarily due to its tolerable scent, making it usable indoors and outdoors and alongside children.

Carbon Dioxide Concentration Data

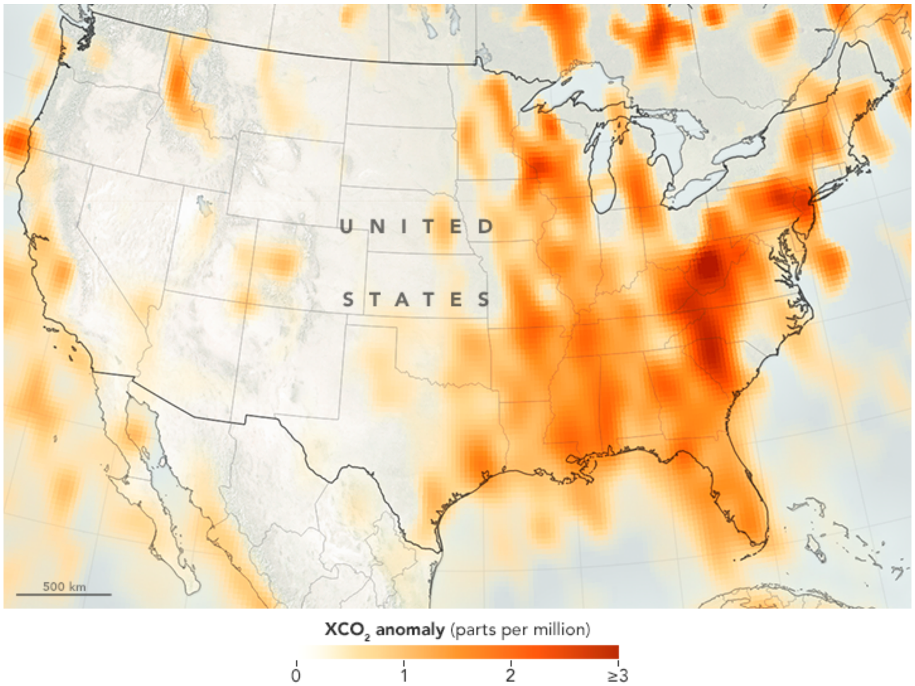


Figure 1: Map of carbon dioxide anomalies in the atmosphere between 2014 and 2016. From Janne Hakkarainen and colleagues at FMI, NASA Earth Observatory.

This map displays anomalies in carbon dioxide concentration in the Earth's atmosphere between the years 2014 and 2016. Global concentration of CO_2 reached upwards of 400 Parts Per Million (ppm) in 2017 (Scott, 2018), and the graphic shows that CO_2 levels are rising above the average rate in areas with darker shades of red. Regions of note include Atlanta's, Valdosta's, and Savannah's metropolitan areas, which account for roughly 57% of the state's total population as of 2017 ("American Community Survey," 2022). Common mosquito species found in these areas include *Culex quinquefasciatus* and *Culex salinarius.* It's difficult to establish CO_2 concentration as a major driving factor for specific mosquito species diffusion across Georgia because atmospheric anomalies in CO_2 levels is a much broader piece of data. Both *Culex* *quinquefasciatus* and *Aedes albopictus* species are surveyed in some of Georgia's least populated counties, which are also regions with lower XCO_2 anomaly compared to the more populated regions of Georgia as shown previously. Trends might be more prevalent on a smaller scale as mosquitoes' cpA neurons detect exhaled carbon dioxide from humans. Other factors to look for might include the varying ecosystems, precipitation, temperature, humidity, and elevation throughout the state.

GLOBE data

As part of the wider SEES Earth System's Explorers program, interns were to locate a grid measuring 3x3 kilometers near a place of interest and document land cover features for 37 individual nodes within that area using satellite imagery. One such dataset happened to be located in Forsyth county, a north-central county that lies within the Atlanta Metropolitan Area. This data was extracted from the GLOBE Collect Earth AOI data collection through Streamlit. Extracted data for mosquito species' population in the state of Georgia (see in "*Mosquito Compared to Human Density in Georgia, USA*" below) shows that the most common species found in this county are of the *Culex* genus and *Aedes albopictus,* common in Northeast counties in the state. Land cover identification of the dataset is comparable to other suburban AOIs. Tree canopy cover makes up approximately 61% of the documented area, while impervious surfaces along with buildings make up 24%. The remaining percentages were attributed to both cultivated and uncultivated vegetation, along with very small bodies of water that might serve as a breeding ground for mosquitoes.

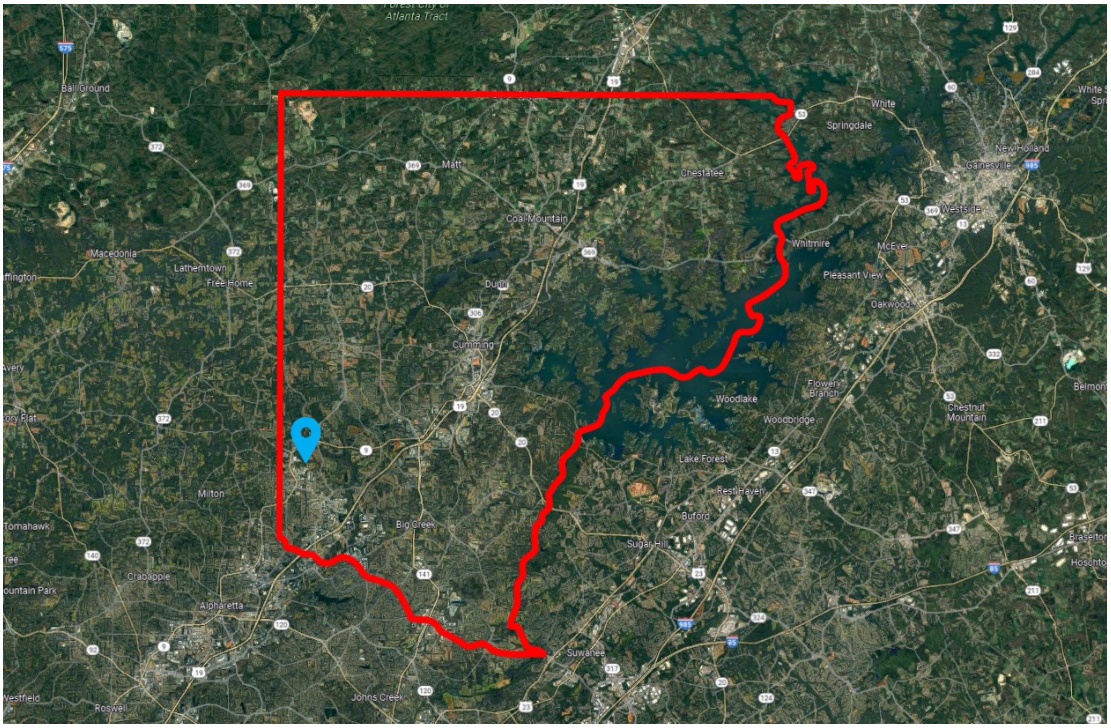


Figure 2: Location of AOI centroid (blue marker) within Forsyth county, Georgia USA Retrieved from Google Maps, 2022. Additional detailing done in Adobe Photoshop

Counties with a similar ratio of mosquito species include Coweta county, Banks county, and Quitman county, all with fairly comparable demographics to Forsyth. However, there does not seem to be any evident patterns between mosquito populations and land cover observations using the GLOBE Collect Earth Online parameters measured. Factors not included in the GLOBE analysis on land cover which play a role in mosquito populations include humidity, precipitation, and temperature. In the state of Georgia, there was inconclusive evidence of any patterns using available average precipitation and humidity data. However, there is a noticeable trend using temperature as a metric in the state of Georgia. The *Culex nigripalpus* species is found almost exclusively in Southern counties where temperatures reach higher averages. *Culex* *quinquefasciatus* also appears more frequently in this region, indicating a possible preference for higher temperatures compared to other species.

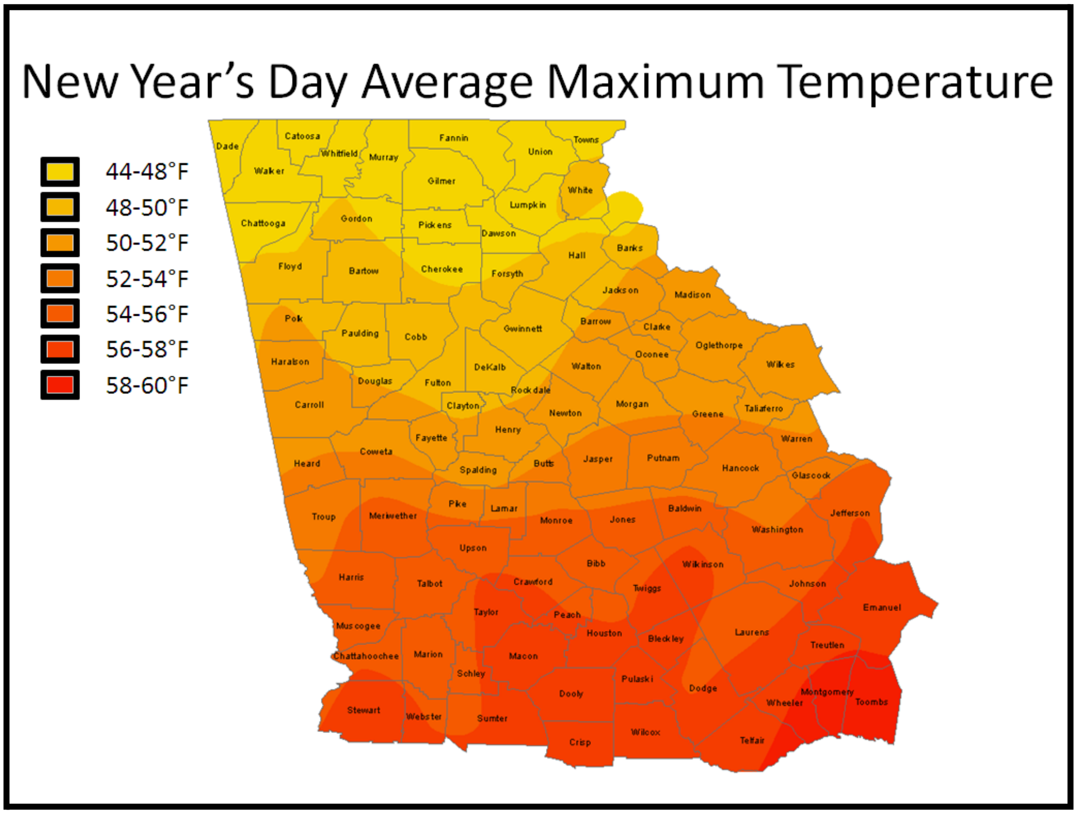


Figure 3: New Year's Day Average Maximum Temperature in the State of Georgia Retrieved from the National Weather Service

While no apparent patterns were found in regards to mosquito species density using extracted GLOBE data, existing ethological patterns are reinforced by data on changes in temperature, climate, and the existing map of mosquito populations in the state of Georgia. This further reiterates the importance of continuing research to further support conclusions made in the present with available data.

Mosquito Compared to Human Density in Georgia, USA

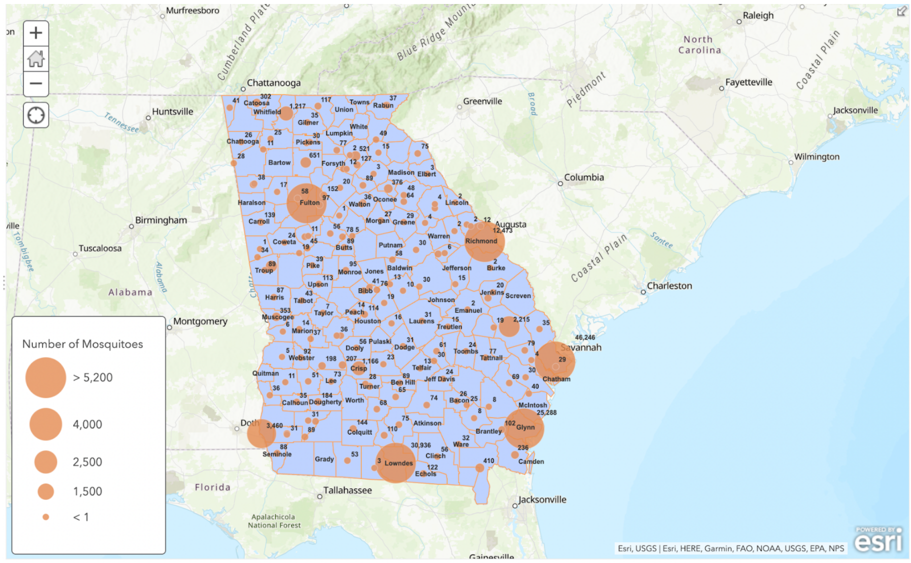


Figure 4: Map of Mosquito Density using ArcGIS and Mosquito Data from the Georgia Department of Public Health in 2017

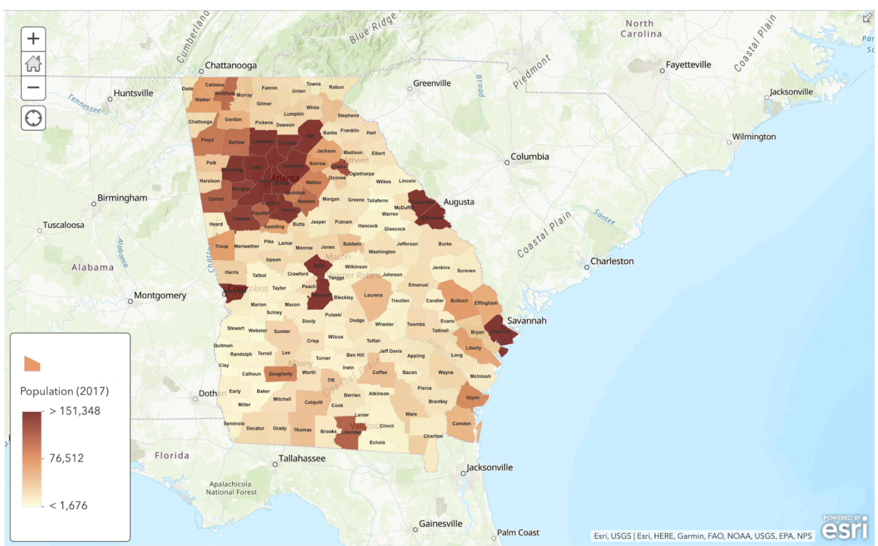


Figure 5: Map Showing the Human Population Density from 2017 in each county of Georgia using ArcGIS. Map name: USA Counties (Generalized) by ESRI

The map from *figure 4* shows the number of mosquitoes per county in the state of Georgia. The map was created using ArcGIS online and by manually extracting the data collected by the Georgia Department of Public Health and Environmental Health from 2017. When collecting their data, they used three different types of traps: the gravid trap, the light trap and the BG sentinel trap. For each county, the number of mosquitoes for each species found was tallied. To make the map on ArcGIS, a spreadsheet was made with three columns: the state, the county, and the total number of mosquitoes found in that particular county. This spreadsheet was saved as a CSV file and uploaded as a layer to ArcGIS online, on top of a map showing the county boundaries in Georgia. This type of map is a bubble map, which means the size of the point in each county is proportional to the number of mosquitoes. As indicated by the map, most of the counties have a similar amount of mosquitoes, and it's not a high amount. The range of the data is 46,245 which was found by subtracting the highest number of mosquitoes (from Chatham county) from the lowest number of mosquitoes (from Franklin). Further mathematical processes were used to analyze the distribution of the data. The mean of the data was calculated to be approximately 879, however the median value for this data set is 40. By looking at the data, the median is a better approximation of the average for this data set. The high mean in contrast to the low median shows that the data set is highly skewed to the right, which means that there aren't many counties with an abundance of mosquitoes above the mean.

Generally, all the counties around the city of Atlanta have high human population density, but the county with the highest mosquito density is Fulton. The capital of Atlanta is located within this county, which does explain the high human density. Likewise, the extensive human population could be the reason for the large mosquito population density, due to the increase in exhaled carbon dioxide which mosquitoes are attracted to. The data from both maps do seem to generally support this theory as there seems to be a proportional correlation between the number of mosquitoes in a county and the human density. There are not many anomalous points from this data, but the county Crisp could be viewed as one due to its low human population density (22,712 people), and the relatively high mosquito abundance (1,166 mosquitoes).

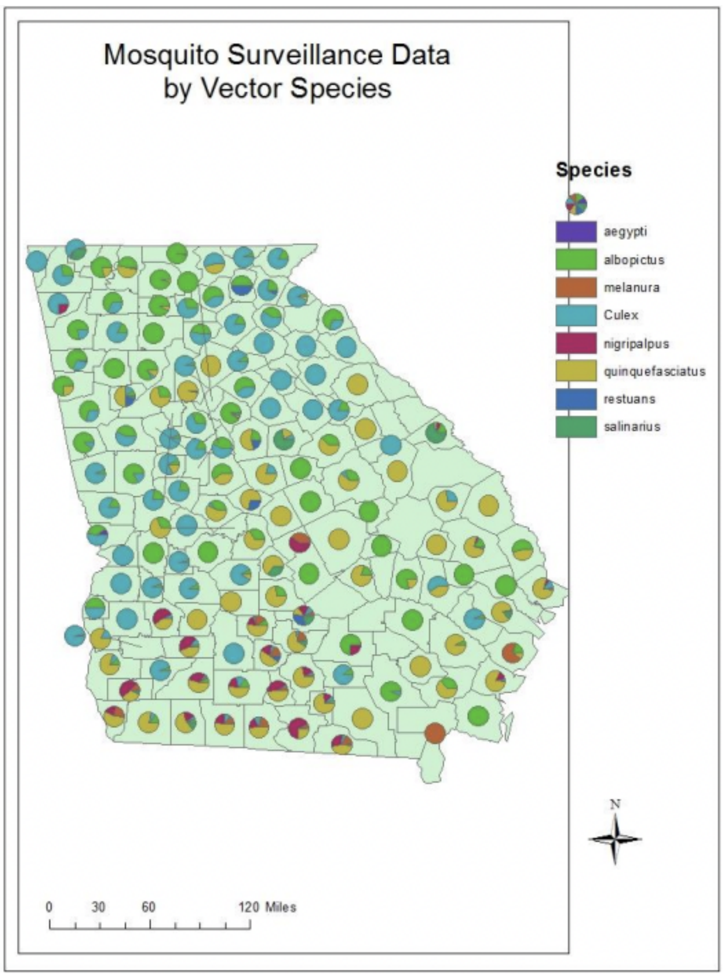


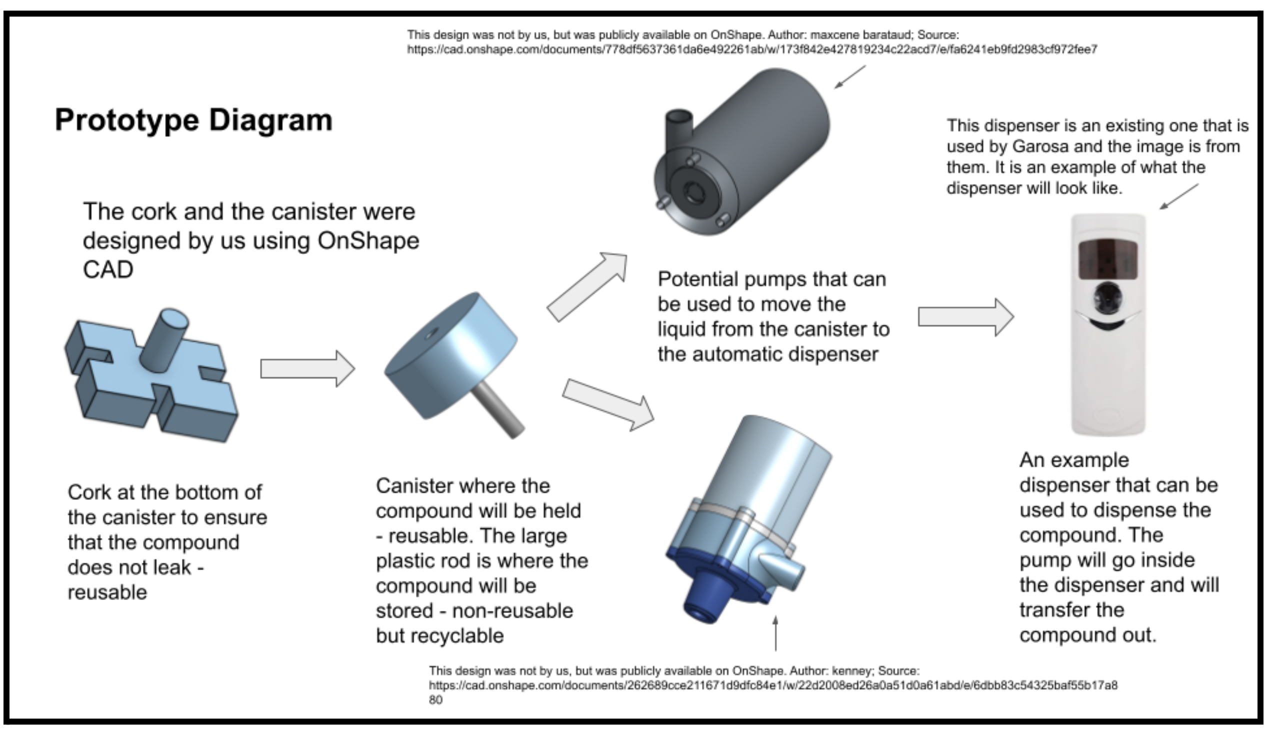
Figure 6: Abundance of Individual Mosquito Species Throughout the State of Georgia. Map from the Georgia Department of Public Health. 2017

During the manual extraction of this data, all species of mosquitoes were included in the total number of mosquitoes found in the county. However, once connections were made between the abundance of all mosquito species and the human population density, three genera of mosquitoes were focused on: the *Culex*, *Aedes*, and *Anopheles* mosquito species. This map made by the Georgia Department of Public Health shows the abundance of the individual mosquito species per county. For this analysis, the abundance of all the listed mosquito species except melanura mosquitoes were taken into consideration. This is because the melanura species is a part of the culiseta genus, which means it’s not a part of the three most dangerous species of mosquitoes (Rozenbaum, 2021). One of the main vector-borne diseases in Georgia is Lacrosse encephalitis, which is thought to be transferred by culex restuans (Harris et al., 2015). Not many areas on the map seem to display a high abundance of this mosquito species, which gives cause to believe there is another species able to transmit this virus. The tree hole mosquito, also known as *Aedes triseriatus* is the primary vector which transmits this disease (*La Crosse Encephalitis Fact Sheet - Minnesota Dept. Of Health*, n.d.) Even though it is not seen in the map, this species of mosquito is plentiful in the northern counties of Georgia, which explains why the lacrosse virus is affecting a large part of Georgia’s population. To further support these findings, *figure 5* can be used to show how the northern counties in Georgia have high human population density, which could also explain why it’s one of the most common vector transmitted diseases (Georgia Department of Public Health, 2018).

Furthermore, the *Culex quinquefasciatus* is a main transmitter of the West Nile Virus, a prominent disease found throughout Georgia and other parts of the United States (New Zealand Biosecure, 2008). Looking at the map in *figure 6*, there seems to be a high amount of this species in approximately 50% of the counties of Georgia. This gives reason to believe that this species is one of the main ones responsible for the 48 cases of West Nile Virus reported to the CDC in 2017 (CDC, 2020).

Another abundant species according to the map in *figure 6* is the *Aedes* genus, more specifically *Aedes aegypti* and *Aedes albopictus*. One interesting result on the map is that there seems to be a very high abundance of *Aedes albopictus* in many counties throughout Georgia. The main diseases transmitted by this species are dengue and chikungunya virus. According to the Georgia Department of Public Health, dengue is very rare to get in Georgia, and less than five cases are recorded each year (Georgia Department of Public Health, n.d.). Chikungunya virus is also not very common in Georgia, and most of the reported cases are due to infection from travelers coming from areas where the virus is prevalent (Georgia Department of Public Health, n.d.).

Prototype Design



To create the prototype, we looked at different means of aerosol production. This included looking at industrial solutions to germ prevention because it was the closest to what we were trying to do. Following this, we looked at how we could most effectively automate the spray of the compound. The existing devices were looked at and then a plan of a prototype was decided based on what we saw and read in the literature. We used OnShape to create the prototype and Google Slides was used to create the diagram.

The prototype adopts an easily re-usable design to allow the user to easily change the tube in which the compound is stored. Additionally, everything on the design is either reusable or recyclable making the prototype more environmentally friendly. On top of that, the design will be cheap and portable for the user. The cork helps to ensure that the compound does not leak through the bottom and the canister ensures that there is a place to store the compound when needed to be used. The two examples of pumps are potential ideas to help move the compound out of the dispenser. The way that the pump will work is to suck up the compound from the tube through one hole and channel it through the other hole into the dispenser to automatically dispense the compound. The compound will go from the bottom end of the pump up to the upper end of the pump. Then it will go through the automated dispenser which will pump out in intervals as industrially available. The chosen compound that is recommended will be stored in one of the recyclable tubes and will be placed into the canister, screwed in by the cork at the bottom.

Like the Garosa dispenser, it is recommended that the dispenser is placed at the top of a room. It is important that it is also where there is a high risk of the spread of vector-borne diseases or for prevention measures. It is important that a dispenser is placed in an area in which there is a large amount of people. This way it will be more efficient and all people are being protected from vector-borne disease carriers. The easy use of our design and re-usability will allow anybody to use the dispenser to protect themselves especially if they are in an area of high risk for vector-borne diseases. No expertise is needed to operate it, only a couple minutes to set it up and the user is ready to use the device.

CpA Neuron Inhibiting Compounds

Mosquitoes rely on their sense of smell to detect humans; as anthropophilic creatures, humans are mosquitoes' favorite source of blood (Potter, 2014). Certain human smells such as lactic acid, 1-octen-3-ol, and CO_2 have been shown to be attractants for mosquitoes, CO_2 being the dominant stimulant. The cpA receptor in mosquitoes is a neuron that attracts them to carbon dioxide. The organs which control a mosquito's sense of smell are covered in small hairs called sensilla. Each sensilla has two or three olfactory neurons. The sensilla which are sensitive to carbon dioxide is called the capitate peg (cp) sensilla (Potter, 2014). CpA neurons are housed in the capitate peg sensilla on the maxillary palps and express the CO_2 receptor. It is composed of three members of the Gustatory receptor (Gr) gene family: Gr1, Gr2, and Gr3 ((Tauxe et al., 2013b). More specifically, the A neuron is the one that is attracted to carbon dioxide, therefore prohibiting its functionality should significantly decrease a mosquito's responsiveness to exhaled carbon dioxide, which is approximately 4% concentrated (Potter, 2014).

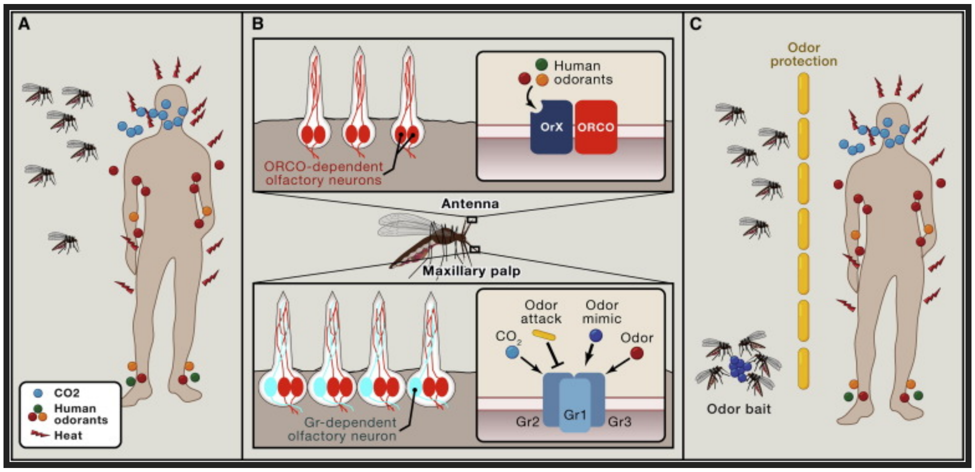


Figure 7 illustrates the attraction of human carbon dioxide through the cpA receptor. Image taken from a study done by John Hopkins University School of Medicine.

When it comes to sensing human systems, understanding how the receptor works becomes more complicated. This is primarily due to the complex nature of human sensing as we have a broad range of volatiles on our body. However, the cpA neuron has been shown to be attracted to the odor of human skin, especially through means of carbon dioxide. The cpA neuron can be a good receptor to target when it comes to altering the behavior of mosquitoes and could stop the spread of deadly diseases. The following compounds: ethyl pyruvate, butyryl chloride, methyl pyruvate, citronella, and a mix of 2,3 butanedione 1-butanal 1-hexanol and 1-pentanal have been shown to reduce the stimuli created by the smell of CO_2. These will be explained and evaluated below.

Ethyl Pyruvate

Ethyl Pyruvate is an efficient mosquito repellent, as it's able to block mosquitoes' sensors from detecting CO_2. In addition to this, it's been shown that it decreases a mosquitoes' ability to sense other human exposing odors, like skin odor (Turner et al., 2011). This guarantees a higher protection level against these mosquitoes as this compound can stop the cpA neurons from detecting multiple smells, which provides better chances of masking the presence of humans from a mosquito. Additionally, ethyl pyruvate was said to have an acceptable smell, described as sweet and fruity, which would make it suitable to be used indoors and outdoors without inconveniences (Tauxe, Genevieve M et al.,2013).

Butyryl Chloride

Butyryl chloride is made up of the two strongest cpA neuron deterrences: butyraldehyde and butyric acid. Only 3 minutes of exposure to a small concentration of this compound will stop cpA nerves from detecting exhaled CO_2, which has a concentration of about 4%. This effect is decently long-lasting as the sensory nerves will only return to normal after 12-24 hours. Additionally, if a mosquito is exposed to butyryl chloride, the cpA neurons will not be responsive to foot odors. However, the compound does not affect the responsiveness of cpB or cpC neurons, which means the mosquitoes will still be able to detect humans just not to the same extent (Turner et all., 2011). Butyryl chloride itself is said to be flammable, which means that it could potentially be considered a safety hazard if used in common households. Additionally, the smell is said to be quite strong. The compound itself is said to be toxic when ingested or inhaled, which means it would have to be specially synthesized in order to make it safe to use (NIH, 2022).

Methyl Pyruvate

Methyl Pyruvate was also able to block cpA receptors in mosquitoes from detecting exhaled carbon dioxide. A relatively low concentration of this compound is needed, for instance it can be just as efficient as 1-hexanol at one-tenth the concentration (Turner et all., 2011). The compound itself is also flammable in the gaseous form and could cause irritation to human eyes. Therefore, further processing would need to be necessary to make this a safe option to use.

<u>Citronella Candles</u>

This is a more natural prohibitor of CO_2 detecting neurons. According to a report published in the Journal of Vector Ecology, citronella diffusers are 68% effective at repelling mosquitoes (Müller et al., 2009). Citronella also comes in the form of essential oils, which suggests that the smell isn't unappealing and could easily be diffused. Additionally, the citronella candles have been used since the 1940s, which could make one assume that they are accessible and generally affordable, which would make this a convenient choice for consumers who are from lower-income households (Baker et al., no date).

<u>Mix of 2,3 Butanedione 1-Butanal 1-Hexanol and 1-Pentanal</u>

This mix was created as a long-term option to mask human exhaled carbon dioxide from mosquitoes. This specific blend was seen to completely impair cpA neurons in the *Aedes aegypti* and *Culex quinquefasciatus* mosquito species (Turner et al., 2011). However, in other studies it was shown that 2,3 butanedione on its own cannot deter a mosquito from finding the source of CO_2, which could mean that humans would be slightly exposed to mosquitoes with this compound (Zhou, 2018). 2,3 Butanedione has also been reported to be slightly toxic to mammals, which doesn't make it an enticing option for a product which will be used regularly in potentially family homes and around children (Zhou, 2018).

Conclusion

Final Analysis and Recommendation of Compounds

To determine which compound to recommend, success criteria needed to be created in order to best judge each cpA neuron inhibitor. Each compound was evaluated against the following criteria: cost, accessibility, smell, and efficiency of the compound. It was taken into account that different households throughout the state of Georgia may have different financial circumstances, which emphasizes the need to make the product as accessible and cost reasonable as possible. This would allow the part of the population living in high mosquito density areas to be protected against any potential vector transmitted diseases regardless of their social or financial status. Additionally, making the product affordable will aid in closing any potential wealth gaps. If lower-income households did not have access to this product, they would likely be more affected by vector-borne diseases, and this could decrease the health of these lower-income workers, worsening their socioeconomic situations.

The compound which seems most commonly mentioned in other works of literature is ethyl pyruvate. It has a sweet smell which makes it convenient to use indoors or outdoors, as well as around children. However, the mix of 2,3 Butanedione, 1-Butanal, 1-Hexanol, and 1-Pentanal could be used in areas where *Culex quinquefasciatus* mosquitoes are found in abundance as this compound is said to completely impair the functionality of their cpA nerves, and for a longer duration of time. The compounds which would likely benefit from this compound instead of ethyl pyruvate would be Wilkes county, Gwinnett county, and Clinch county, where the species of mosquitoes found are only *Culex quinquefasciatus* (Georgia Department of Public Health, 2018). For those in any county who prefer a more natural repellent, citronella can be used. However, maximal coverage cannot be guaranteed, which means it's not completely protective against vector-borne diseases. However, given how rare it is that mosquito bites result in an illness, citronella can still help prevent the likeliness of this situation. It can also be a noteworthy option to use in addition to another compound such as ethyl pyruvate, as this also decreases the chances that mosquitoes develop a resistance to these compounds.

The results did not exactly support the hypothesis as there was no direct link found between the levels of CO_2 concentration in the atmosphere and the number of mosquitoes in an area. This is also because other factors such as temperature, precipitation and land cover affect the number of mosquitoes in an area, so they need to be taken into account. However, there was a link between the human density and mosquito density as stated previously, which shows that more densely populated counties generally have higher amounts of mosquitoes.

Working with project mentors greatly facilitated the process of understanding the required structure for this paper. With the given resources, it was made possible to examine previous projects and see how past SEES interns have organized their research.

Target Audience

The counties which stand out by having a higher abundance of mosquitoes are Chatham, Glynn, Lowndes, Richmond, and Fulton, with more than 4,000 mosquitoes in each county. Looking at *figure 4*, it can be seen that Chatham, Fulton, and Richmond are some of the densest counties in terms of human population, as well as three of the 5 most dense counties for mosquito populations. This means that the people living in these three counties have the highest risk of being bitten and infected by a vector-borne disease. Additionally, with a higher population density comes a higher percentage of children and pregnant women. Lacrosse encephalitis does primarily affect children, which further proves the need for this product in highly populated zones, as children 18 years and younger make up 17.6% of the population in Atlanta only (*QuickFacts: Atlanta City, Georgia*, 2018). The county of Forsyth, where the previously used AOI point was located, was named the wealthiest county in Georgia (*Highest-Earning Counties in Georgia*, 2022). This means that there would likely be no cost issues for residents of this county when procuring this mosquito repelling diffuser. Even though the abundance of mosquitoes in this county is low, the species which are the most abundant are *Culex* mosquitoes and *Aedes albopictus* mosquitoes, which are considered some of the most dangerous species. This makes this a county that would benefit from the marketing of this product, as it would help decrease the occurrence of vector-borne diseases. Fulton is ranked the 12th wealthiest county in Georgia, which also suggests that residents won't have any issue affording the product. The most common mosquito species is the *Culex coronator*. Even though this species isn't known to be particularly harmful, there have been cases of transmitted diseases from this species (Georgia Department of Public Health, 2018). Chatham and Richmond counties are also in the top 20% of wealthiest counties, so the product would likely be accessible to those residents in need of it.

<u>Improvements</u>

A limitation to this method of data collection is that only one intern this year had an AOI located in Georgia, which was used to examine surrounding land cover for the county of Forsyth. Only having one data point limits the perspective and the reliability of the data, as there could have been external factors influencing the results for this AOI. The land cover classifications were done manually, which also limits the accuracy of this data point, especially since there was only 67.57% agreement in the Secondary Sampling Unit (SSU) Summary. Using data from past

SEES interns would have potentially increased the reliability of the conclusions as there could have been multiple points to analyze the land cover.

Another source of error stems from the fact that mosquitoes have other olfactory neurons which can detect smells other than CO_2 such as lactic acid, and 1-octen-3-ol as stated previously, which can allow a mosquito to detect a human (DeGennaro et al., 2013). The compounds evaluated above specifically target cpA neurons, which detect CO_2. By not blocking the sensory neurons such as the cpB or cpC, mosquitoes can still detect humans, just not to the same extent.

Many mosquito repellent products have been synthesized and marketed as a way to protect people from these vector-borne diseases. However, there has been a growing issue of insecticide resistance, as mosquitoes reproduce quickly and therefore can adapt quickly to function with the use of repellents. Organizations have been created such as the Worldwide Insecticide Resistance Network to discuss solutions to this insecticide resistance (IR). The five steps that this organization is promoting include: surveillance and monitoring, further understanding of vectors through research, decision-making based on risk assessment, innovation, and sharing knowledge with those who can fund any projects (Richards et al., 2020). This exemplifies the importance of projects like these which aim to share research conducted and utilized to make a physical product that can be fabricated and distributed to help combat vector-borne diseases.

Public Health Plan

Diseases transmitted by vectors in Georgia range from the West Nile virus, Eastern Equine encephalitis virus, and LaCrosse virus (Georgia Department of Public Health, 2018). One recommendation which is made by the Georgia Department of Public Health is to use oil that contains lemon eucalyptus. The main compound in lemon eucalyptus is citronella, which as mentioned above is only 68% efficient when diffused (Müller et al., 2008). Although this option could still be used, in order to maximize protection against these vector-borne diseases another diffusible compound should be used correspondingly. This emphasizes the need for trying out other compounds such as ethyl pyruvate as a recommendation to the citizens of Georgia. Even though many citizens are likely to own some kind of mosquito spray at home, these are usually sprayed directly on the skin, and therefore any harsh chemicals have the potential to be absorbed into the skin, which would cause additional harm to any hosts. Informing the public of their options in combating these vectors could be the most helpful in order to protect the public.

Badges

"I am a STEM Professional": Without the help of Dr. Andrew Clark, with whom we attended office hours, we wouldn't have been able to compile and create layered maps using ArcGIS. Those maps enhanced our study on human populations and mosquito populations within the state of Georgia. With the combination of other sources of data including demographics and socioeconomic backgrounds, we were able to formulate a comprehensive public health initiative for the prevention of vector-borne diseases in different counties in the state of Georgia. Our project benefited greatly from Dr. Clark's collaboration and guidance.

"I am an Engineer": Using the ArcGIS maps we created, we were able to better understand mosquito densities across the populated counties in the state of Georgia. This narrowed our results to identify specific compounds that are usable in different regions using our prototype diffuser designed in OnShape CAD. Our design presents a practical solution for vector-borne disease prevention, as the design is affordable, safe, and accessible across a wide variety of citizens.

"I Make an Impact": Issues of affordability, accessibility, and high mosquito population helped drive our project initiative. After our research was completed, we were able to suggest specific recommendations for different public health situations. Ethyl pyruvate was found to be effective in most situations, but a mix of 2,3 Butanedione, 1-Butanal, 1-Hexanol, and 1-Pentanal could be used in areas where *Culex quinquefasciatus* mosquitoes are found in abundance. Wilkes county, Gwinnett county, and Clinch county would benefit greatly from the latter compound because *Culex quinquefasciatus* has an abundant population in those counties.

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This project included: Sophie Bullen, Ryan Dempsey, Aneesh Mazumder, Danial Pitafi, and Edward Thomas.

Sophie Bullen attended all team meetings and scheduled office hours when necessary, and was included in the early stages of planning the research for this paper. She found the data from the Georgia Department of Public Health with the number and species of mosquitoes per county, and with the help of our mentor Andrew Clarke, was able to create two maps using ArcGIS to show the mosquito and human density per county in Georgia. The sections written by her include Human compared to Mosquito Density in Georgia USA, cpA Inhibiting Compounds, and the Conclusion.

Ryan Dempsey researched the effect of carbon dioxide concentrations on the abundance of mosquitoes in an area. He also looked at the effect of temperature on the number of mosquitoes in certain counties. Additionally, he used the GLOBE data and was able to find the AOI point located in Georgia and then examine the land cover surrounding the AOI using Collect Earth Online and the Secondary Sampling Unit Summary to assume the preferable conditions for mosquitoes to live in. Ryan wrote the literature review, the inclusion of the GLOBE data and

CO_2 concentration, helped with proofreading and compiling citations, and was a part of discussions on how to best structure the paper.

Aneesh Mazumder researched already existing diffuser designs and was able to find one which would suit our product and its use against mosquitoes. He also conducted research on how the cpA neuron works to detect humans, which allows readers to better understand the concept of the product that has been designed. The sections that were written by Aneesh include About the cpA neuron, and the Prototype section of this research paper. He was also included in most discussions about the structure and content of the paper.

Danial Pitafi was present for many discussions about the structure and content of the paper, and attended the scheduled office hours with the mentors. Unfortunately, he was unable to contribute to his full capability due to medical reasons.

Edward Thomas was helpful with initial planning and setting deadlines for the project. He wrote the abstract and contributed data about mosquito density throughout the world as well as CO_2 data from the Earth Data NASA Pathways Finder. He was also working with another group on their project, which limited the time he could spend working with us, but all contributions made were well appreciated and beneficial for our paper.

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