Spatial and Temporal Trends in the Economic Value of Biotic Pollination Services in Georgia 2009-2017

by

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(Under the Direction of Susana Ferreira)

ABSTRACT

This paper updates and expands the estimated value of biotic pollination for Georgia's agriculture in 2009 as reported in Barfield et al. (2015) to cover years 2010-2017. We use a production function approach to calculate three figures at the county level and the state as a whole: the economic value of pollination, the crop vulnerability ratio, and pollination's contribution to total farm gate value. We find the economic value of pollination increased from $425 million in 2009 to $488 million in 2017 in real terms. Our study then uses GIS analysis to reveal spatial patterns within the state as well as to examine temporal trends in the data ranging from 2009 to 2017. We also use GIS to visualize newly released pollinator density data and are able to compare the locations of biotic pollinators to the areas they bring the most economic value to.

INDEX WORDS: Pollination, Agriculture, Bee Population, GIS, Insect Populations, Economic Valuation, Colony Collapse Disorder, Pollination Dependency, Wild Pollinators

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CHAPTER 1

INTRODUCTION

Problem Statement

Pollination uses either biotic factors (such as insects, birds, or bats) or abiotic factors (primarily wind or water) to move pollen from the male structures (anthers) of flowers to the female structure (stigma) of the same plant species. Biotic pollination is both a factor of production and a vital ecosystem service that pollinates a wide variety of plants. In production, bee colonies can be purchased or rented in exchange for their pollination services. In this case, there is a market demand for pollination in agriculture in excess of the services provided by wild pollinators.

Globally, biotic pollination contributes to 87 major food crops which account for over 35 percent of the world food supply. These crops provide vital nutrients as well as diversity to the human diet (van der Slujis and Vaage 2016). It is important to note that while nearly three quarters of crops benefit in some way from biotic pollination, only 10 percent of these rely fully on pollinators to produce fruits and seeds for production while the others are partially dependent (Aizen et al. 2009). Pollinators are also able to improve the quality and commercial value of crops, as well as encourage genetic diversity among plant species.

Georgia's agricultural sector is a key component to its economy, contributing US$73.7 billion in output to its US$1 trillion economy and more than 392,400 jobs in 2017 alone (Kane 2019). The total farm gate value in the state, or the market value of all food and fiber production when it leaves the farm (net of marketing costs), grew from US$13.04 billion in 2009 to US$13.75 billion in 2017 (in 2017 US$). Within the state's food and fiber production, there are 22 crops used directly for human consumption that are reliant on biotic pollinators. In 2009 these crops accounted for 18 percent of Georgia's total agricultural value and this figure grew to 21 percent in 2017 (Boatwright and McKissick 2010, Wolfe and Stubbs 2018).

Wild pollinators comprise a majority of pollinator species in North America and consist of roughly 4000 species of native bees. They are able to efficiently pollinate a wider variety of flowers than managed pollinators because of the slight differences between each species and their adaptation to local conditions. However, it is very difficult to estimate the economic value of their services due to a lack of understanding of their contribution to Georgia's agriculture. (Kremen et al. 2002, Spivak et al. 2011, Goulson 2003).

In the southeast, honey bees (*Apis mellifera*), bumble bees (*Bombus spp.),* southeastern blueberry bees (*Habropoda labrosia*), Mason bees (*Osmia spp*), and squash bees (Peponapis pruinosa, Xenoglossa spp.) are among the largest contributors to biotic pollination (Delaplane et al. 2010). Bees are especially efficient pollinators as pollen and nectar serve as their only food source, they can visit multiple flowers on one trip, and they are able to collect pollen grains easily due to their body hair.

The social species of bees, which include both honey bees and bumble bees, are often easier to manage and are the primary pollinators of many fruits grown in Georgia (Delaplane, Thomas, & McLaurin, 2010). The bumble bee and honey bee have been the two most researched in recent years and there has been a documented decline in their populations. In 2006, a historically large decrease in honey bee populations was reported in North America with some beekeepers reporting the loss of 90% of their colonies. The symptoms of these losses were called

Colony Collapse Disorder (CCD) by the apicultural community. The losses caused by CCD are significant environmentally as well as economically considering the increasing demand for pollination in a growing agricultural sector (Ellis et al. 2010, Thomson, 2016). While the losses caused specifically by CCD have been decreasing since 2010, the beekeeping industry has continued to report high loss percentages each year due to pathogens, parasites, pests, exposure to pesticides, and poor nutrition. The current consensus among the bee community regarding the cause of CCD is that it is multifactorial and cannot be explained by one single cause (Rucker et al. 2019). Between 2007 and 2014, winter colony loss rates in the U.S averaged 30 percent, double the average rates prior to CCD. While research is still being done on the causes and economic impacts of CCD, the U.S government has taken action to reverse pollinator losses such as the 2014 Pollinator Health Task Force under the Obama administration. These rates fell to 24 percent from 2015 to 2017 (Rucker et al. 2019, U.S Department of Agriculture [USDA] 2019).

The USDA is tracking national honey bee population counts, but 2019 data is inconsistent due to several months in which tracking was suspended. Preliminary results by the University of Maryland found managed honey bee colonies faced a 40 percent decline from 2018 to 2019, with the winter losses being the highest since 2006 (Bruckner et al. 2019). In Georgia specifically, commercial beekeepers' operations losses averaged between 20 and 30 percent while some backyard beekeepers experiencing over 80 percent loss in 2019. The primary contributor to these losses is a mite called Varroa Destructor. This mite, along with starvation and excessive extraction by managed colony operators, can cause colonies to perish (Berry 2020).

This decline raises concern about the ability to meet the biotic pollination demand for U.S crops which continues to grow each year. CCD, however, is not the sole contributor to honeybee decline and honeybees are not the only pollinator to Georgia crops. Along with managed bees, wild bee populations have faced similar declines and health risks, with some species going extinct in recent years (Cameron et al. 2011). When provided with sufficient nesting a foraging habitat, wild bees are capable of efficiently meeting the full pollination demand for several native crops (Spivak et al. 2011). While CCD has received a great deal of attention from the agricultural sector, the stability of other pollinators must be considered as well when evaluating the ability of pollinators to meet the agricultural sector's pollination demand in the future. In particular, it is important to consider habitat conservation for wild species that are efficient pollinators.

Research Objectives

In the face of pollinator decline, policymakers and researchers alike need to be aware of the potential economic losses of this decline. To determine the economic value of pollination services in Georgia, we follow and expand Barfield et al. (2015), who apply a conceptual model based on the bioeconomic approach. We identify the crops dependent on biotic pollination, collect quantitative production value data on agricultural goods rendered by pollination services, and use these data to estimate three economic values (the economic value of pollination, the crop vulnerability ratio, and pollination's contribution to total farm gate value) for each county and the state of Georgia from 2009 to 2017. By using the county-year as the unit of analysis, we are able to apply GIS to conduct a spatio-temporal analysis and reveal patterns of economic value both within the state and over time. In addition, we use new pollinator density data sorted at the county level to look for a relationship between pollinator locations and where they have the highest economic contribution to agriculture.

CHAPTER 2

CONCEPTUAL BACKGROUND

Ecosystem Services: Valuation Methods

Countless tangible items produced by the natural earth are used for human consumption. Crops, lumber, livestock, seafood, minerals, and herbs are all examples of these products that can be physically counted and transacted in markets. Meanwhile, in addition to these, natural ecosystems provide vital services that enable life-supporting processes such as carbon sequestration, water filtration, protection of biodiversity, climate regulation, and pollination. Because these natural services are not able to be packaged and sold directly in markets, their value is often discounted (Daily 2003). Therefore, ecosystem services are frequently threatened as they have no price to directly affect markets and bring attention to their deterioration.

Ecosystem services are the direct or indirect contributions of ecosystems to human welfare (TEEB 2010). Functions and processes can be included as ecosystem services, as they connect ecosystems to the well-being of humans through natural systems (Fisher and Turner, 2008). It is important to integrate both the economic and ecological values in order to acknowledge tradeoffs and better influence decision making and policies (Pandeya et al. 2016). Because of this, when determining the economic value of an ecosystem service, it is crucial to utilize an application specific valuation model that is meaningful and information-based.

While there are many existing valuation approaches, it is difficult to choose just one approach that is able to encapsulate all of the complexities of an ecosystem service and the role it plays in the natural environment. When evaluating these approaches, one must first decide if they would like the results to be in monetary terms or in non-monetary (cultural or ecological) terms. Monetary approaches tend to have more influence on policy as their results can be directly translated into economic impact. However, economic valuations may not truly capture all real values of ecosystem services (Laurans and Mermet, 2014). In order to accurately put a natural system into monetary terms, a very large number of externalities and possible environmental impacts must be accounted for.

The total economic value (TEV) of an ecosystem service is typically divided into use and non-use value. Use values include both direct use values such as water, minerals, and recreation, and indirect use such as mangrove trees protecting against coastal erosion. To determine the monetary value of these natural features, they are often compared to an actual marketed good or service that is comparable and assessed that way. Because market solutions do not always capture the true social and environmental value, studies such as consumer willingness to pay for ecosystem services are often conducted. Common methods of economic valuation techniques in this case are travel cost, hedonic pricing models, or contingent valuation (Farber et al. 2002). In some cases, the most accurate valuation method may involve a combination of several of these approaches in order to correctly represent the true value of the service.

Theoretically Appropriate Measures of Value for Pollination Services

The total economic value provided by pollinators can be decomposed into market and non-market values. The market values consist of the contribution they make to the growth of agricultural crops. Non-market values derive from the utility from the aesthetic and cultural benefits of their own existence and the wild flowers and garden plants which rely on pollination services (Hanley et al. 2015).

There is no universally agreed upon method to capture the economic value of pollination services. Valuation methods are divided into those that capture market values and those that capture non-market values. The focus of this study is on the former, since we estimate the contribution of pollinators to Georgia's agriculture. Some of the first pollination valuation studies used the full production value of pollination dependent crop production to illustrate the value of pollinators. Similarly, some used the total rentals of managed bee colonies to determine the total value (Hanley et al. 2015). However, neither of these methods are ideal and may severely over or underestimate the true value of pollination. First, they fail to take into account that most crops dependent on biotic pollination would maintain some level of production even in the absence of pollinators. Because of this, the entire value of the crop should not be attributed to biotic pollination alone. On the other hand, the market for bee colony rentals is still growing and not well established in many areas. While these managed colonies are widely used and beneficial for agricultural production they are not an accurate representation of all biotic pollination taking place in the industry (Garibaldi et al. 2013).

A second and slightly more complex approach is a simplified version of a production function approach which introduces a *pollination dependency ratio* to account for a plant’s partial independence from biotic pollination. These pollination dependency ratios are calculated in an interdisciplinary manner based on field research and introduce a bioeconomic approach to valuation. (Klein et al. 2007). This production method allows for the calculation of Crop Vulnerability Ratios (CVR) which highlight the areas most sensitive to a decline in biotic pollinators. However, a drawback to this method is the lack of inclusion of production and input costs when addressing the value of each crop. In addition, the pollination dependency ratios of several crops are widely disputed, thus resulting in a possible variation in results depending on the D value that is selected for each study (Garibaldi et al. 2013).

A production function approach using dependency ratios can also be expanded to study the impact of a change in pollination services on *consumer surplus* (CS). This approach requires extensive data on the relationship between crop production, crop prices, and consumer welfare. In addition to this limitation, because it is at its core based on dependency ratios, it faces the same limitations as all other methods using D values (Garibaldi et al. 2013).

A more intricate valuation approach is the *replacement cost method* which estimates the cost of replacing biotic pollination with alternative processes. This method, as used by Allsop et al. in 2008, can offer a lower bound estimate of potential value, but under two strict conditions. First, there must be more than one practical way to the same amount of the ecosystem service. In addition, the alternative method must impose a smaller cost on society than the value of losing the ecosystem service, therefore creating an incentive for replacement rather than continuing on without the service at all (Bockstael et al. 2000).

Because each of the previously mentioned valuation methods have notable limitations often resulting in inaccurate estimations, they are often combined in such a way that produces the most accurate estimate possible for each specific case study. One example of this is the use of the *attributable net income method* by Winfree et al. in 2011. This method improves upon previously used methods for valuing insect pollination of crops in several ways. First, it subtracts the cost of inputs in crop production, therefore not overestimating the true value added by the pollinators as seen in the production function method. It also addresses the excess of pollen distributed on a plant and is able to identify the distinct value added by managed versus native pollinators (Winfree et al. 2011). However, this newly developed method requires an immense amount of detailed data that is often not available on a large scale.

CHAPTER 3

EMPIRICAL METHODOLOGY

Data

Our primary data sources are the annual Georgia Farm Gate Value Reports from 2009 to 2017 (Boatright and McKissick 2010, Wolfe and Shepherd 2011-2012, Wolfe and Stubbs 2013-2018). These reports are supplemented by data provided by direct communication with their authors, which provide county level values for each crop that may have been aggregated in the original report.

The Georgia Farm Gate Value Report provides annual production information collected by University of Georgia Cooperative Extension personnel. County extension agents use a survey tool which farmers populate with the crops they grow, the acreage for those crops, and their prices at the time of sale. These suggested prices can be adjusted by the agent based on the conditions of the specific county and are already adjusted for all government payments directly associated with the production of each crop. The average yearly production quantity and value are then drawn from these surveys. We examine 51 row and forage, fruit and vegetable crops for all 159 counties and for the state of Georgia. The resulting dataset is much more precise and extensive than the data available by the USDA, which covers about 34 commodities (Dowdy and Wolfe, 2019).

We also used pollinator density data from the Great Georgia Pollinator Census conducted in August of 2019. In an effort to count pollinators and advance pollinator count, UGA extension's Center for Urban Agriculture hosted the first ever statewide pollinator census.

Georgia citizens were asked to count pollinators on a specific pollinator plant that was blooming. The number and type of insects that landed on that plant in a fifteen-minute period were then recorded and these counts were uploaded to a universal database. These data are in the form of insects per individual count, and includes observations on honeybees, bumble bees, carpenter bees, and several other pollinating insects. This census generated data in 85 percent of Georgia counties with an average of 35 counts per county (Griffin 2019). As this data was also collected at the county level, we are able to use GIS to map it alongside our calculated economic values to see the relationship between pollinators' densities and their economic value of the services they provide.

Methodology: Applying the Bioeconomic Approach to Georgia

Our focus is on estimating the contribution of pollinators to Georgia's agriculture, so we apply a production function approach. Because pollination is an input of agricultural production, this approach is appropriate (Hein 2009). A commodity can be directly influenced by pollination when pollination affects the quantity and quality of crops or the production of seeds for future generations, or it may be indirectly influenced by pollination if, like cattle, it relies on a crop that is directly pollinated by biotic pollinators (National Research Council 2007).

In addition to their direct use value, pollinators have nonuse values derived from their existence. Currently, markets and economic values fail to capture all of the benefits produced from pollination (Potts et al. 2016). While markets do not exist for the pollination services provided by wild pollinators, they do exist for managed pollinators which can be directly purchased or rented. The economic value of managed pollinators can be determined by changed in supply and demand of these colonies based on colony rental data. However, this data is not yet fully separated into the value of honey production versus rental fees, so we estimate the economic value of pollination using a production function approach.

Our bioeconomic approach follows Gallai et al. (2009)'s modified production function applied at the county, or "local", level.[1] While criticized for assuming constant prices (Bauer and Wing 2010, Hein 2009), a partial equilibrium analysis is appropriate in our case as we focus in local markets. Local declines in pollination services should not cause a change in overall factor or crop prices, particularly as the local markets are not isolated and we are not analyzing local varieties. We investigate 51 crops grown in Georgia used directly for human consumption of which 22 are biotically pollinated.[2] Table 1 lists these crops and their pollinators. Table 2 lists the pollination dependency ratios (D) of all 51 crops considered.

According to the production function approach the change in social welfare, W, resulting from a marginal change in supply of the pollination service, *e*, (holding other inputs constant) is given by:

$$\frac{\partial W}{\partial e} = p(y^*) \times \frac{\partial y}{\partial e} \tag{1}$$

where *y*, the amount produced of the market output, depends on both biotic pollination, *e*, and other factors of production (land, labor, capital, etc). It sells for a market price *p*, that we assume farmers take as given.

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[1] Local, as defined by Hein (2009), is production that supports a farmer's income, while national level production is responsible for ensuring the food supply.

[2] This number is different than the 55 in Barfield et al. (2015) as the Farm Gate Fruit and Nut reports no longer include individual data for cherries, nectarines, pears, or plums in the years following 2009. These fruits reported as "other" in the reports beginning in 2010, so they were removed from our calculations in order to ensure consistency throughout the nine yeas being studied.

To approximate $\frac{\partial y}{\partial e}$, we ascribe the same pollination dependency ratios as in Barfield et al. (2015) in accordance with Gallai et al. (2009), using the mid-range value of Klein et al. (2007)'s ranges of potential production loss. For example, a crop listed in the "little" category with a potential production loss of 0-10 percent, receives a dependency ratio of 5 percent for our purposes. Those crops listed in the "no increase" category receive a dependency ratio of 0. Georgia crops that are biotically pollinated but were not assigned a dependency ratio by Klein et al. (2007), receive a dependency ratio of "unknown" (Table 2). These pollination dependency ratios are the most recent to have been published, so we operate under the assumption that there has been no notable change in these figures since the original study.

We expand the original estimates from the years 2009 to 2017. This allows us to look for trends in the value of pollination, as well as to see its growth within that time frame using spatial analysis. All calculated values were then adjusted for inflation and put into 2017 dollars using the All Farm Price Received Index provided by the National Agricultural Statistics Service

Calculating the Economic Contribution of Pollination.

We calculate three values for each county and for the state of Georgia—the economic value of pollination (EVP), the crop vulnerability ratio (CVR), and pollination's contribution to total farm gate value (PCV). EVP is calculated as a summation of the economic value of pollination over all crops investigated, as in Gallai et al. (2009) and Barfield et al. (2015).

$$EVP = \sum_{i=1}^{I}(P_i \times Q_i \times D_i) = \sum_{i=1}^{I}(FGV_i \times D_i) \qquad (2)$$

For each crop, P_i is the price per unit, Q_i is the quantity produced D_i is the pollination dependency ratio, and FGV_i is the farm gate value reported (computed as $P_i \times Q_i$).

The crop vulnerability ratio, or the potential production value loss in the absence of pollinators, is calculated as the ratio of EVP to economic production value (EV) (Gallai et al. 2009).

$$CVR = \frac{EVP}{EV} = \frac{\sum_{i=1}^{I}(P_i \times Q_i \times D_i)}{\sum_{i=1}^{I}(P_i \times Q_i)} = \frac{\sum_{i=1}^{I}(FGV_i \times D_i)}{\sum_{i=1}^{I}(FGV_i)} (\%) \tag{3}$$

The final variable we calculate is pollination's contribution to total farm gate value. This is the ratio of the economic value of pollination to total farm gate value, TFGV, which is reported for each county and for the state providing a summation for all values of commodities in the agricultural sector including animal products each year. PCV measures potential agricultural sector production value loss in the absence of pollinators (Barfield et al. 2015). For the state and counties producing commodities other than the 51 included in this study, we expect this value to be lower than the CVR each year.

$$PCV = \frac{EVP}{TFGV} = \frac{\sum_{i=1}^{I}(FGV_i \times D_i)}{TFGV} (\%) = \frac{\sum_{i=1}^{I}(FGV_i \times D_i)}{\sum_{i=1}^{I}(FGV_i)} (\%) \tag{4}$$

As in Gallai et al. (2007), we choose to omit the indirect value of pollination added through the dairy and cattle industries, as well as seed production for both vegetative components of other crops and on plants not intended for consumption. Omitting these crops, along with the omission of crop and soybeans due to a debatable pollination dependency ratio, we tend to underestimate the true economic value of biotic pollination. On the other hand, the production value approach, which omits production costs, is criticized for overestimating the value of pollination. While we are not able to determine which of these effects is greater, they are certainly working against each other.

Table 1. Georgia Crops Studied and their Pollinators

Crop	Pollinators
Apples	honey bees (Apis mellifera), bumble bees (Bombus spp.), solitary bees (Andrena spp., Anthophora spp.), (Osmia lignaria propinqua), hover flies (Eristalis tenax)
Banana peppers	honey bees, bumble bees (Bombus impatiens), solitary bees (Osmia spp., Megachile spp.), hover flies (Eristalis tenax)
Bell peppers	honey bees, bumble bees (Bombus impatiens), solitary bees (Osmia spp., Megachile spp.), hover flies (Eristalis tenax)
Blackberries	honey bees, bumble bees (Bombus spp.), solitary bees (Osmia aglaia, O. lignaria propinqua), hover flies (Eristalis tenax)
Blueberries	honey bees, bumble bees (Bombus impatiens), solitary bees (Andrena vicina, Anthophora spp., Colletes spp., Habropoda laboriosa, Osmia lignaria propinqua)
Cantaloupe	honey bees, bumble bees (Bombus spp.), solitary bees (Ceratina spp., Lasioglossum spp.), ants, beetles
Cucumbers	honey bees, bumble bees (Bombus impatiens), solitary bees (Melissodes spp.), beetles
Eggplant	honey bees, bumble bees (Bombus spp.), solitary bees, butterflies, beetles, syrphid flies
Hot peppers	honey bees, bumble bees (Bombus impatiens), solitary bees (Osmia spp., Megachile spp.), hover flies (Eristalis tenax)
Lima beans	honey bees, bumble bees (Bombus spp.)
Okra	honey bees, solitary bees (Halictus spp.), bumble bees (Bombus spp.), hummingbirds
Peaches	honey bees, bumble bees (Bombus spp.), solitary bees (Osmia lignaria propinqua), flies
Pole Beans	honey bees, bumble bees (Bombus spp.)
Pumpkin	honey bees, solitary bees (Peponapis pruinosa, Xenoglossa spp., Ceratina spp., Halictus tripartitus), bumble bees (Bombus spp.)
Snap Beans	honey bees, bumble bees (Bombus spp.)
Southern peas	honey bees, bumble bees (Bombus spp.)
Strawberries	honey bees, bumble bees (Bombus spp.), solitary bees (Osmia spp.), hover flies (Eristalis tenax)
Tomato	honey bees, solitary bees (Xylocopa spp., Halictus spp.)
Watermelon	honey bees, bumble bees (Bombus impatiens), solitary bees (Halictus tripartitus, Peponapis pruinosa, Melissodes spp.)
Winter squash	honey bees, solitary bees (Peponapis pruinosa, Xenoglossa spp., Ceratina spp., Halictus tripartitus), bumble bees (Bombus spp.)
Yellow squash	honey bees, solitary bees (Peponapis pruinosa, Xenoglossa spp., Ceratina spp., Halictus tripartitus), bumble bees (Bombus spp.)
Zucchini	honey bees, solitary bees (Peponapis pruinosa, Xenoglossa spp., Ceratina spp., Halictus tripartitus), bumble bees (Bombus spp.)

Sources: Crane and Walker (1984); Delaplane and Mayer (2000); Klein et al. (2007); **Hein (2009);** Boatright and McKissick (2010a,b,c); Adamson et al. (2012); BugGuide.Net (2014).

Table 2. Georgia Crops Studied ranked by their Pollination Dependency Ratios (D)

Crop	D	Crop	D	Crop	D	Crop	D
Cantaloupe	0.95	Strawberries	0.25	Carrots	0	Onions	0
Pumpkin	0.95	Banana Peppers	0.05	Collards	0	Peanuts	0
Watermelon	0.95	Bell peppers	0.05	Corn	0	Pecans	0
Winter squash	0.95	Hot peppers	0.05	Cotton	0	Rye	0
Yellow squash	0.95	Lima beans	0.05	English Peas	0	Sorghum	0
Zucchini	0.95	Pole beans	0.05	Figs	0	Spinach	0
Apples	0.65	Snap beans	0.05	Grapes	0	Sweet Corn	0
Blackberries	0.65	Southern peas	0.05	Green onions	0	Sweet potatoes	0
Blueberries	0.65	Tomato	0.05	Irish potatoes	0	Turnip greens	0
Cucumbers	0.65	Tobacco	Unknown	Kale	0	Turnip roots	0
Peaches	0.65	Barley	0	Lettuce	0	Sweet corn	0
Eggplant	0.25	Broccoli	0	Mustard	0	Wheat	0
Okra	0.25	Cabbage	0	Oats	0		

Sources: Klein et al. (2007); Boatright and McKissick (2010a,b,c); Barfield et al. (2015)

CHAPTER 4

RESULTS

Summary of Values

We estimate the total economic value of pollination (Equation 2), crop vulnerability ratio (Equation 3), and pollination's contribution to total farm gate value (Equation 4) for the state and for each Georgia county for each year from 2009 to 2017. We also calculate average EVP, CVR, and PCV for all 159 counties for 2009 and 2017(table 3). The average CVR over all 51 crops is not reported as this only provides information on the choice of pollination dependency ratios. Similarly, total farm gate value in the state (>US$13 billion in 2009 and >US$13.6 billion in 2017) is so large in comparison to the EVP of individual crops (from US$0 for wheat to US$152 million for watermelon) and the PCV for individual crops that it provides little information to this study and is not reported.

For Georgia, we estimate the total economic value of pollination has grown from >US$425 million to 2009 to >US$488 million in 2017. Annual EVP values showed steady growth until the peak of US$532 million in 2016 (Figure 1). Our estimated crop vulnerability ratio indicated a potential production value loss for the crops studied of roughly 18.2 percent in the absence of pollinators in 2009. The CVR in 2017 showed a potential production value loss of roughly 16.7 percent for the crops studied. Pollination's contribution to Georgia's total farm gate value grew from 3.3 percent in 2009 to 3.6 percent in 2017. The average crop EVP also grew from nearly US$8.3 million in 2009 to nearly $9.6 million in 2017. The 2017 average county

CVR figure indicates that, on average, Georgia counties could anticipate potential production value loss for the crops studied of 17 percent in the absence of pollinators. The 2017 average county PCV shows that on average, pollination contributes 3.6% of each county's total farm gate value (Tables 3 and 4).

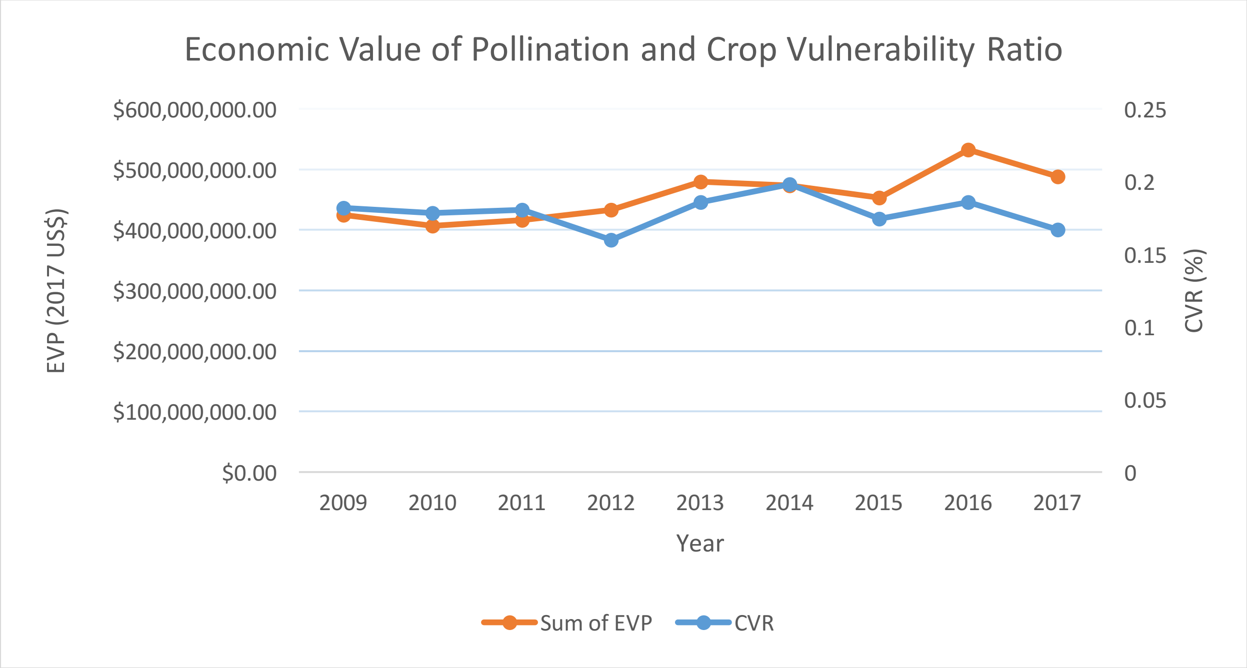


Fig. 1. Economic Value of Pollination and Crop Vulnerability Ratio (2009-2017)

Table 3. Measure of Pollination's Economic Significance to Georgia 2009 and 2017

Georgia totals and averages (2009)	2009	2017
Total farm gate value (US$)	13,041,440,576	13,609,088,226
Total farm gate value: crops studied [EV] (US$)	2,337,400,670	2,926,630,580
Total economic value of pollination [EVP] (US$)	425,189,971	488,243,861
Crop vulnerability ratio [CVR]	18.2%	16.7%
Pollination's contribution to total farm gate value [PCV]	3.3%	3.6%
Average county EVP (US$)	2,674,150	3,070,716
Average crop EVP (US$)	8,337,058	9,573,409
Average County CVR	23.2%	17.3%
Average County PCV	3.3%	3.6%

Authors' calculations

Unfortunately, as in Barfield et al. (2015). a limitation to this paper is the inability to delineate between wild and managed pollinators' contributions to the economic value of pollination in Georgia. The crops in this study are recipients of both managed and unmanaged pollination services. Data on colony rentals is necessary to determine what amount of pollination was "free", but it is not available. The annual farm gate value reports do provide honeybees as a commodity and include rentals, sales, honey production, and "other honeybees" (Barfield et al. 2015). In 2017, the value of honeybees was reported to be US$46.7 million by the farm gate value report. Honey production in Georgia was reported to be US$6.7 million in 2017 by the National Agricultural Statistics Service (USDA 2017). Though the individual values for "honeybees" and "honey" were reported by different agencies, the difference between these figures would infer the estimated value of honeybee rentals to be US$40 million in 2017. This is one order of magnitude lower than the contribution we estimate in this paper.

We were also able to compare the correlation between pollinator densities and EVP values using scatter plots (Figures 2 and 3). We found a negative correlation between insect densities and EVP values with a correlation coefficient (r) of -0.0558. Upon removing outliers and influential observations that seem to be driving the negative correlation, we found this negative relationship decreased significantly with a new r value of -0.0382. However, this correlation is still negative and may indicated a potential problem in the future for pollinator counts to meet the demand for their services in agriculture.

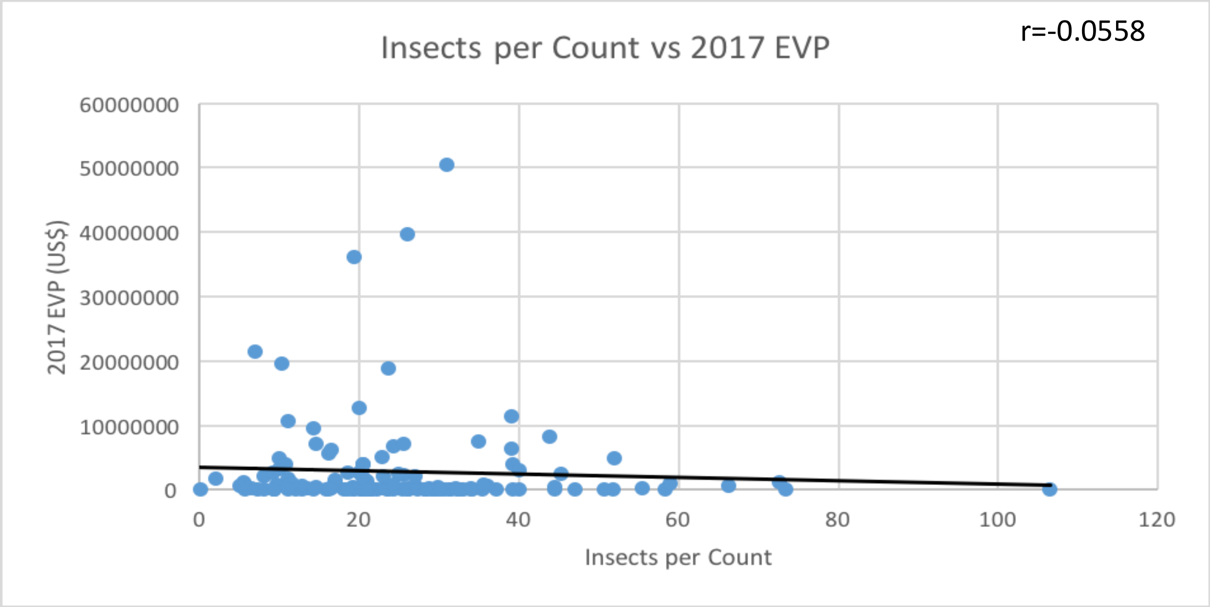


Fig. 2. Insects per Count vs. 2017 EVP

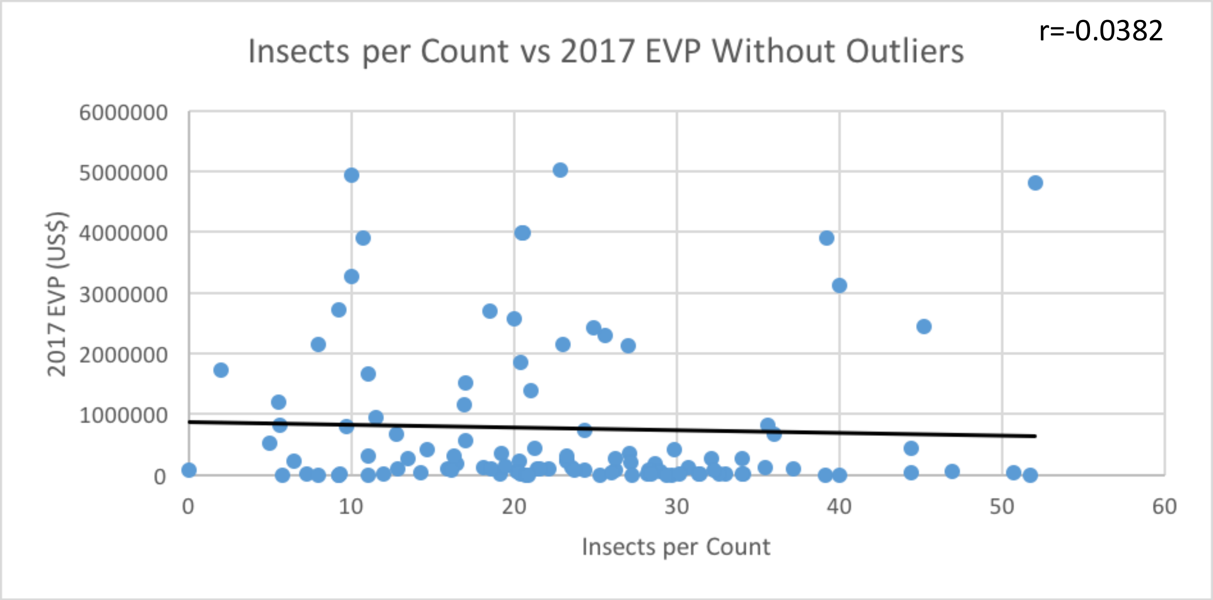


Fig. 3. Insects per Count vs. 2017 EVP Without Outliers

The relationship between insect densities and CVR values at the county level also showed a negative correlation with r=-0.0993 (Figure 3). Adjusting for outliers caused the r value to decrease to -0.0453 though it did remain negative (Figure 4). This shows a trend of counties more vulnerable to a decline in pollinators having relatively lower pollinator counts.

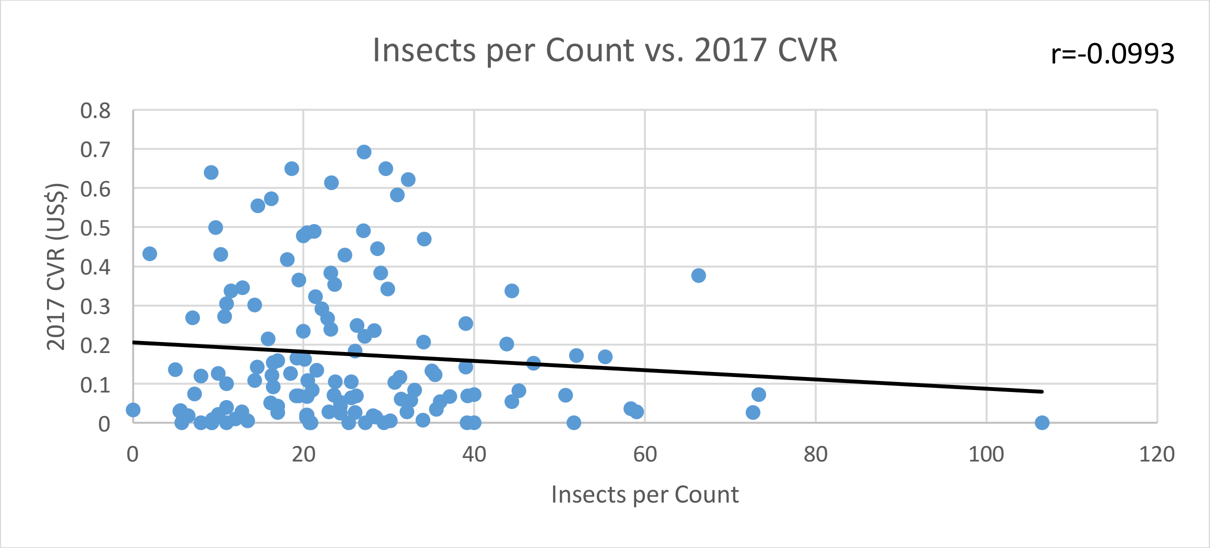


Fig. 4. Insects per Count vs. 2017 CVR

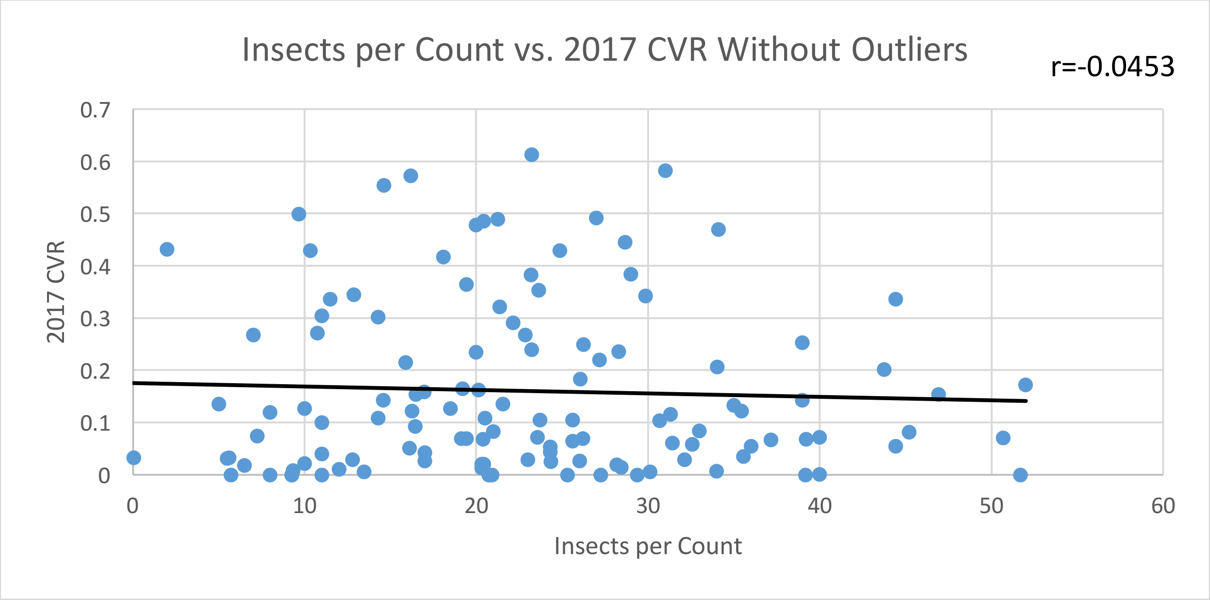
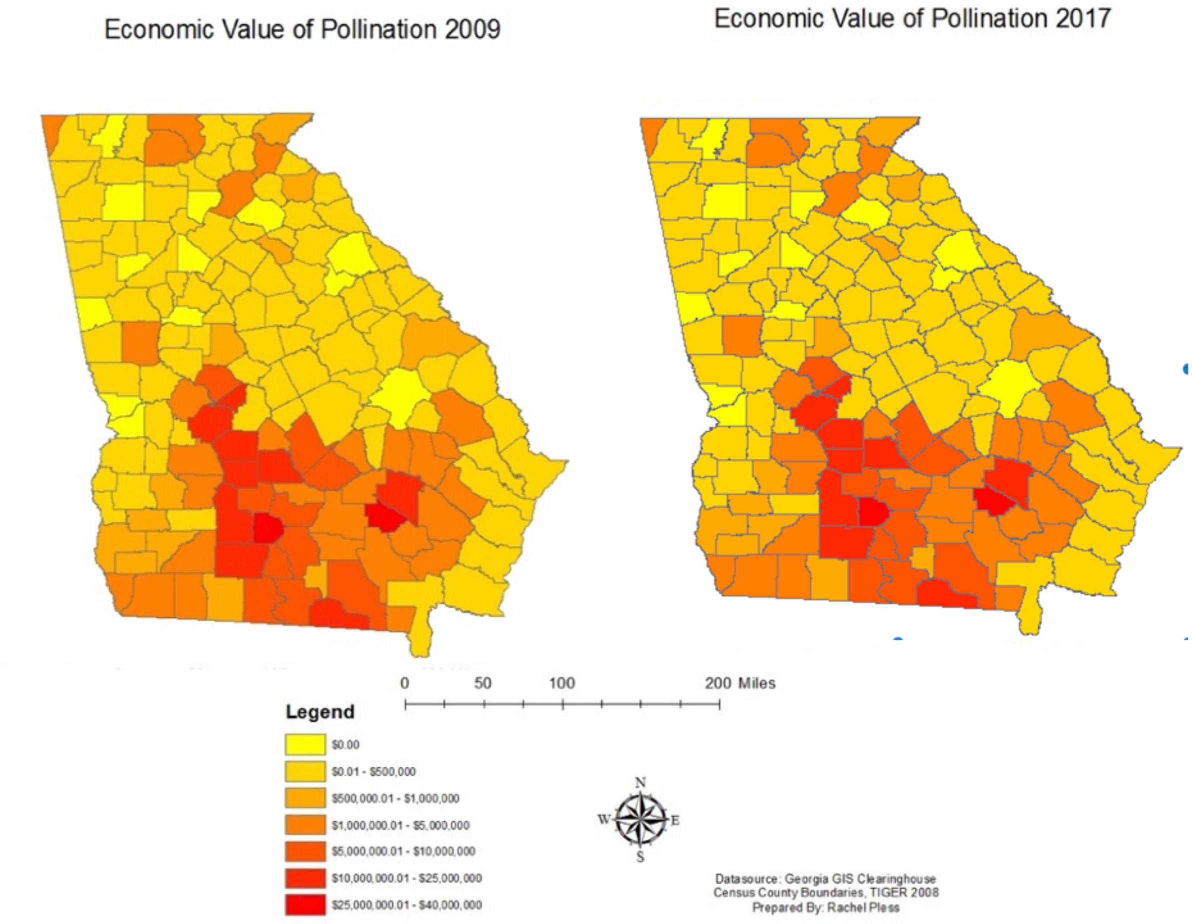


Fig. 5. Insects per Count vs. 2017 CVR Without Outliers

Spatial Analysis

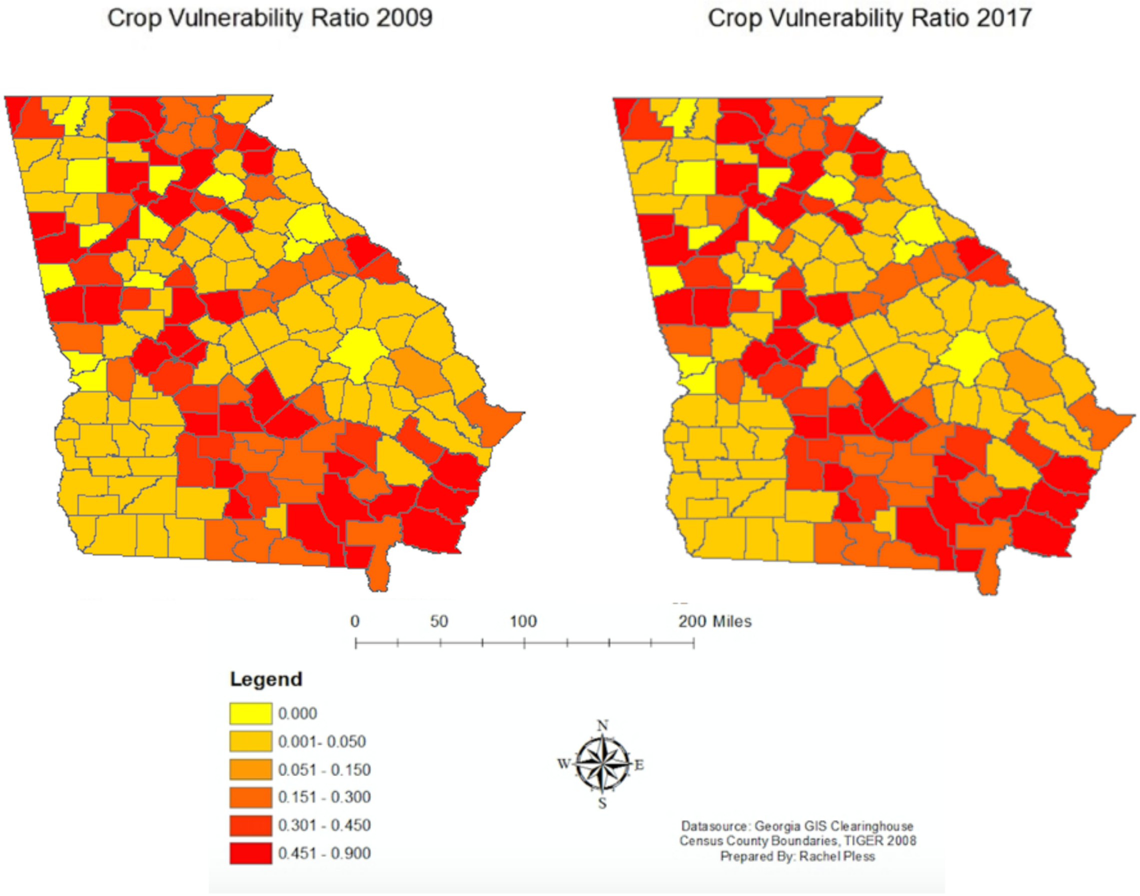
Geographic Information Systems (GIS) analysis of our results from both 2009 and 2017 reveal patterns similar to those found by Barfield et al. (2015). Both the EVP and PCV maps from each year provide visualizations of clear patterns of spatial variation, while the maps displaying CVR values show less distinct patterns (Figures 6-8). With the exception of a few scattered counties in the northern part of the state, the counties with the highest EVP and PCV values remained clustered in the south central portion of Georgia from 2009-2017. This region is known to be the largest contributor to Georgia's agricultural sector, so these results were not surprising. CVR values showed little clustering in each year, with high CVR values being dispersed fairly evenly throughout the state. The counties with high CVR values in the northern and southeastern portions of the state are particularly interesting. These areas showed low to average PCV and EVP values, but they are growing crops that are certainly vulnerable to pollinator decline such as watermelon and blueberries. This suggests that pollination has continued to affect the entire state over the past decade, regardless of the magnitude of agricultural production in each region. The disparity between the spatial visualizations of EVP and CVR values has been consistent from 2009-2017. South Georgia stands to lose the most in total economic value in the face of pollinator decline, while the northern and coastal regions would also be greatly affected by this decline.

Using data provided by the Great Georgia Pollinator Census conducted by UGA Extension in August 2019, we were able to map pollinator densities per county. This data is in the form of number of insects found per count and includes honeybees, bumblebees, butterflies, and several other pollinating insects. The simultaneous visualization of CVR values and pollinator densities shows no distinct pattern among areas most vulnerable to pollinator decline and where they are currently located (Figure 9). The map of EVP values and pollinator densities also shows no clear relation between the values, with higher pollinator densities being dispersed throughout the entire state (Figure 10). This data helps raise concerns in certain counties where pollination values and vulnerability ratios are high, but pollinator densities remain low. While pollinator data was collect in 2019 and our calculated figures are from 2017, we can draw the conclusion that pollinators are not primarily located among counties with the highest agricultural demand for them, but are well dispersed despite the size of the regional agricultural sector. The data in these two figures could have important implications for future policies regarding pollinator protection at both the county and state levels.



Datasource: Georgia GIS Clearinghouse
Census County Boundaries, TIGER 2008
Prepared By: Rachel Pless

Fig. 6. Economic Value of Pollination (2009 and 2017)

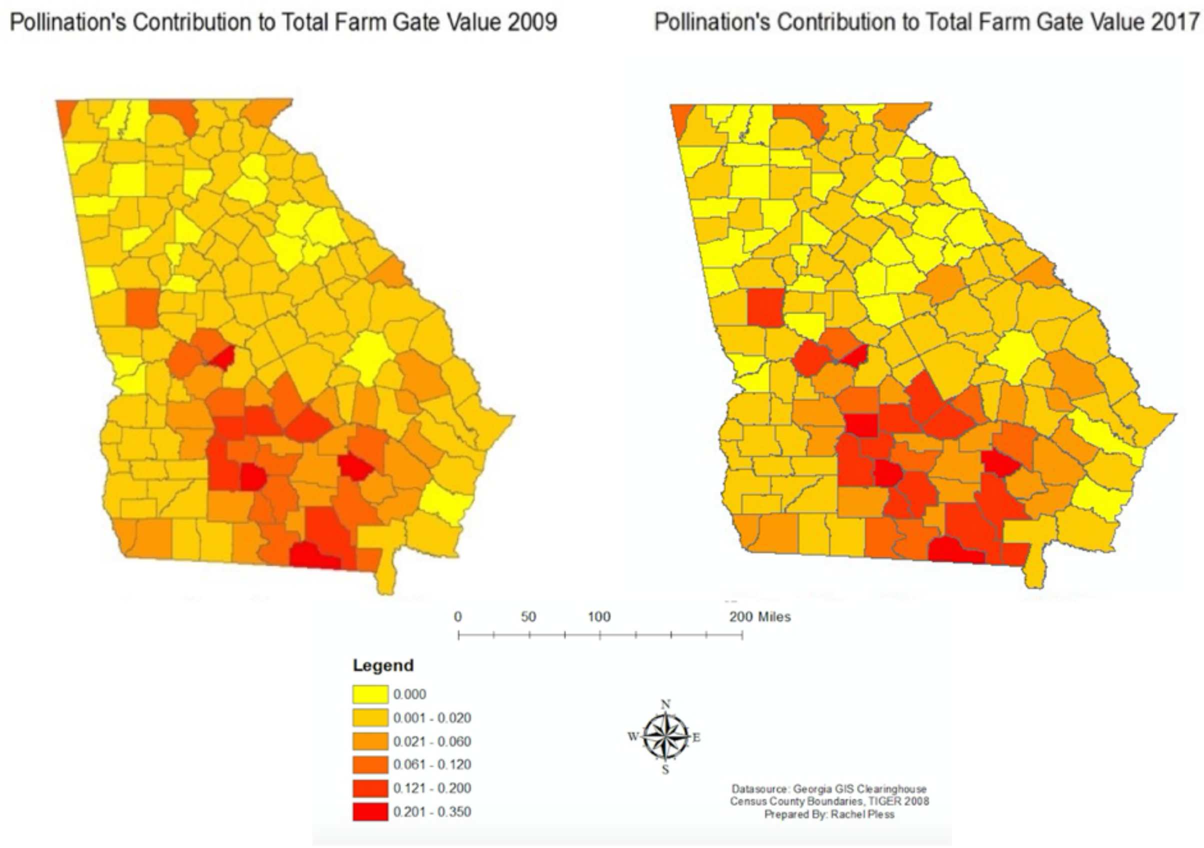


Crop Vulnerability Ratio 2009

Crop Vulnerability Ratio 2017

Datasource: Georgia GIS Clearinghouse
Census County Boundaries, TIGER 2008
Prepared By: Rachel Pless

Fig. 7. Crop Vulnerability Ratio (2009 and 2017)



Pollination's Contribution to Total Farm Gate Value 2009

Pollination's Contribution to Total Farm Gate Value 2017

Datasource: Georgia GIS Clearinghouse
Census County Boundaries, TIGER 2008
Prepared By: Rachel Pless

Fig. 8. Pollination's Contribution to Total Farm Gate Value (2009 and 2017)

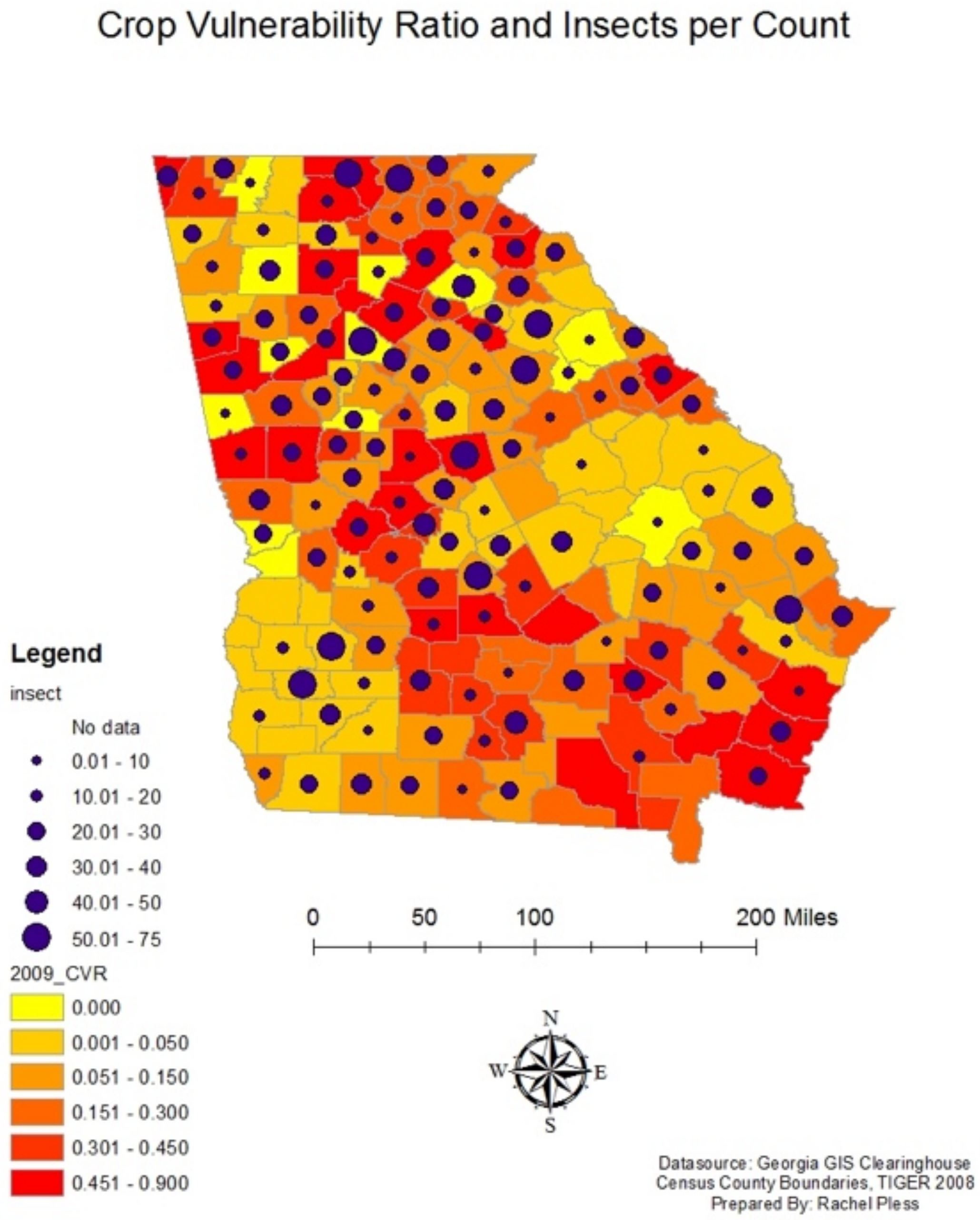
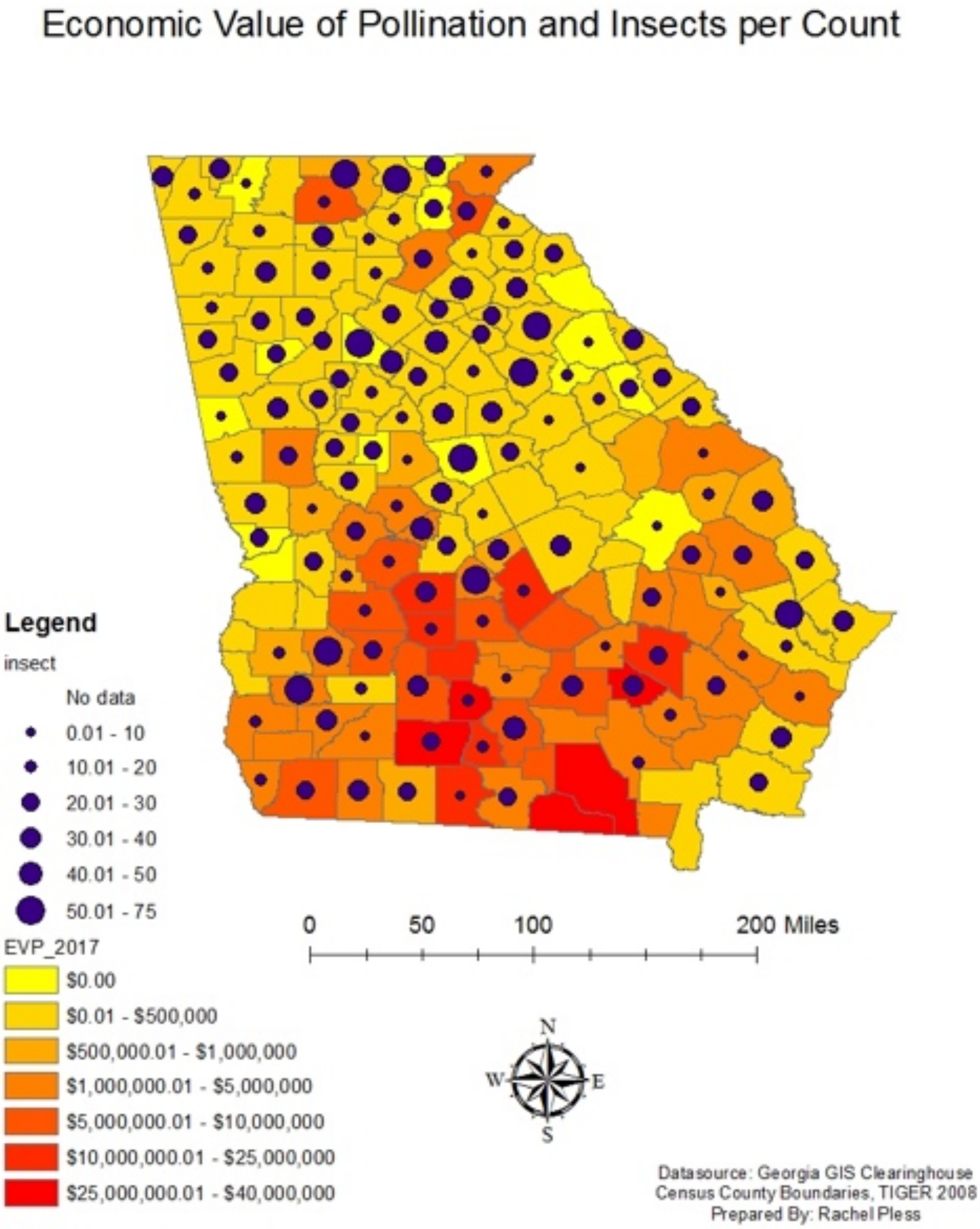


Fig. 9. Crop Vulnerability Ratio and Insect Densities (2017 and 2019)



Economic Value of Pollination and Insects per Count

Datasource: Georgia GIS Clearinghouse
Census County Boundaries, TIGER 2008
Prepared By: Rachel Pless

Fig. 10. Economic Value of Pollination and Insect Densities (2017 and 2019)

CHAPTER 5

SUMMARY AND CONCLUSIONS

We use an bioeconomic approach to estimate the economic value of pollination in Georgia from 2009 (US$425 million) to 2017 (US$488 million). We also calculate the crop vulnerability ratio in 2009 (18 percent) and 2017(16 percent) as well as pollination's contribution to total farm gate value which grew from 3.3 percent in 2009 to 3.6 percent in 2017. These values were calculated using 51 crops in Georgia used directly for human consumption throughout the entire period being studied.

Both EVP and PCV values in Georgia have grown throughout the nine years being studied, while CVR is falling. This may be positive news for the state, as agricultural production becomes less vulnerable to a decline in pollinators despite their increasing value. The D values have not changed, so this decrease in CVR may be driven by a change in the composition of the crops being grown. In 2009, the crop with the highest EVP was watermelon at US$152 million and a D of 0.95. By 2017, the crop with the highest EVP had become blueberries which have a significantly lower pollination dependency ratio of 0.65. The increase in state EVP on the other hand could be explained by the increase in aggregate farm gate value. While changes in production levels of certain highly pollination dependent crops such as yellow squash with EVP growth of over US$6 million between 2009 and 2017 certainly contribute to this increase, the total farm gate value growth of over US$567 million explains much of the increase in the economic value of pollination.

Pollination's contribution to total farm gate value was a figure unique to the Barfield et al. (2015) study and allows for the evaluation of the importance of pollination in the entire agricultural sector, not just the crops studied. The growth of this value throughout the nine years studied shows that pollination has only gained importance as a contributor to agriculture in Georgia. Our study was unique in that it included a visualization of pollinator densities at the county level along with our calculated economic values. These maps allow for a closer look at pollinator abundance and could better influence policies at the local level. An example of this is Gilmer county which shows very high CVR and EVP values due to their high production of apples which are heavily reliant on biotic pollination. Despite Gilmer county's heavy reliance on pollinators, they have relatively low insect densities with an average of 10-20 pollinators per count. Another example of a county with high CVR values and relatively low insect densities is Liberty county because of their production of blueberries with a D value of 0.65. The dependence of Liberty County's agriculture on this highly vulnerable blueberry crop raises concern for the ability of this small insect population to meet the county's demand for their services.

Our comparison between insect densities and economic values showed a negative relationship between pollinator counts and both EVP and CVR values. This negative correlation could indicate potential problems in the future as insect populations are not increasing with the economic value added by their services. In addition, upon excluding counties with influential pollinator density, EVP, and CVR values, we saw a much smaller correlation between the variables. One example of an excluded county was Tift because of the EVP of its watermelon crop being over US$15 million while its density was relatively low with an average of 10-20 insects per count. An additional county that was removed was Jones as it had unusually high pollinator counts and only six total counts submitted. The transformation from figures 2 and 4 to figures 3 and 5 show just how influential outlier counties were in driving that negative correlation.

Throughout the entire time period being studied, blueberries and watermelon remained the top two Georgia crops in terms of EVP values. These crops made up over half (US$230 million in 2009 and US$275 million in 2017) of the states total EVP due to the combined effects of their high pollination dependency ratios and high total farm gate values each year (Tables 4 and 5). It is important to note that our figures vary slightly from those found in the original study due to the exclusion of cherries, nectarines, pears, and plums. In addition, we follow Barfield et al. (2015) in excluding cotton and soybeans as crops dependent on biotic pollination. The pollination dependency ratios of both crops is somewhat debatable and was set to zero to avoid an overestimation of pollination's economic value (Klein et al. 2007). Cotton and soybeans have continued to bring significant value to Georgia's farm gate value through 2017 so assigning any pollination dependency ratio greater than zero would significantly impact our estimates for all nine years.

Our results have policy implications regarding pollinator protection at both the state and local levels. This extension of the Barfield et al. (2015) study allows us to show the continuing importance of pollination in Georgia's economy. The economic value of pollination has grown greatly since 2009 (by US$63 million) and shows no sign of a future decline in the presence of a healthy population of biotic pollinators. Protecting pollinator diversity would help meet the demand for biotic pollination as an "insurance policy" in the case of pollinator shortages. Wild pollinators are fully capable of meeting this demand under environmental conditions that encourage diverse pollinator communities (Chaplin-Kramer et al. 2011). Knowing the value of pollinators along with the current densities per county based on the 2019 pollinator census allows local governments and invested residents to identify their own methods to manage pollinator decline. Thesis pollinator density figures should be tracked over time as well as wild versus managed pollinator in order to gain a more well-rounded understanding of pollinator population growth and locations. Estimated EVP values allows for a cost-benefit analysis of possible responses to the continued documented pollinator decline across the entire state and at the county level.

Although global monitoring and conservation efforts are needed, policy changes at the local level such as limited pesticide use or the implementation of pollinator gardens represent the acknowledgement of the importance of pollinators. These are important steps towards protection and are piloting policy innovations that have potential to expand to state and national level policy instruments (Hall and Steiner 2019).

While this study provided a view of the economic value of pollination over time, further research potential exists in relating these values to land use over time. It may be beneficial to compare the acreage devoted to agricultural production and indicators of landscape diversity in Georgia with the growing value of biotic pollination over these nine years. GIS analysis would also benefit this expansion to determine where pollination adds value as an ecosystem service in relation to land use.

In addition, if provided with more detailed data on honey bee rentals, further research could be done to distinguish the value added by wild versus managed pollinators. The production value approach would allow for this differentiation provided the data was available and the values from this approach are reasonable estimates. These results would provide vital information needed to create well-informed pollinator conservation strategies for native pollinators. Finally, more detailed data on Georgia pollinator locations would be beneficial in determining counties most sensitive to wild pollinator decline. For example, a county that is heavily reliant on one biotic pollinator may benefit from information specific to the population of that pollinator. In this case, said county may benefit most from conservation strategies targeted towards that specific pollinator.

Table 4. Statewide 2009 EVP for Biotically Pollinated Crops

Rank	Crop	EVP (US$)	Rank	Crop	EVP (US$)	Rank	Crop	EVP(US$$)
1	Watermelon	152,988,698	9	Bell peppers	7,488,942	17	Southern peas	701,337
2	Blueberries	77,162,309	10	Blackberries	5,952,219	18	Lima beans	349,465
3	Peaches	44,835,895	11	Apples	5,152,980	19	Banana Peppers	269,139
4	Cucumbers	39,590,164	12	Eggplant	4,496,256	20	Okra	235,050
5	Cantaloupe	31,986,659	13	Tomato	3,700,152	21	Pole beans	156,127
6	Yellow squash	21,977,652	14	Snap beans	2,043,457	22	Hot peppers	93,742
7	Zucchini	14,269,493	15	Winter squash	1,635,423			
8	Pumpkin	8,824,907	16	Strawberries	1,425,173			

Authors' calculations

Table 5. Statewide 2017 EVP for Biotically Pollinated Crops

Rank	Crop	EVP (US$)	Rank	Crop	EVP (US$)	Rank	Crop	EVP(US$$)
1	Blueberries	147,313,201	9	Apples	6,475,131	17	Pole beans	822,426
2	Watermelon	128,111,288	10	Bell peppers	5,764,744	18	Hot peppers	776,513
3	Cucumbers	50,903,973	11	Pumpkin	5,691,844	19	Okra	350,398
4	Yellow squash	28,158,061	12	Blackberries	2,905,312	20	Southern peas	266,317
5	Zucchini	22,020,226	13	Tomato	2,461,997	21	Lima beans	92,685
6	Peaches	19,507,531	14	Strawberries	2,359,530	22	Banana peppers	33,181
7	Cantaloupe	18,621,889	15	Winter squash	1,968,807			
8	Eggplant	7,363,358	16	Snap beans	1,181,084			

Authors' calculations

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