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An Economic Valuation of Pollination Services in Georgia

Ashley Barfield

Department of Agricultural and Applied Economics, University of Georgia

309 Conner Hall, 147 Cedar St., Athens, GA 30602

770-815-3290, adro88@uga.edu

Co-Authors:

Dr. John Bergstrom

Department of Agricultural and Applied Economics, University of Georgia

208C. Conner Hall, 147 Cedar St., Athens, GA 30602

706-542-0746, jberg@uga.edu

Dr. Susana Ferreira

Department of Agricultural and Applied Economics, University of Georgia

313C. Conner Hall, 147 Cedar St., Athens, GA 30602

706-542-0086, sferreir@uga.edu

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Introduction

For centuries, American farmers have used colonies of European honey bees to pollinate crops (Kremen et al. 2002; Spivak et al. 2011). Pollination is an ecosystem service and a production practice. As an ecosystem service, wild pollinators pollinate many crops. As a production practice, social bee colonies are bought or rented to supplement the services of wild pollinators, indicating an existing insufficiency of wild pollinators to support agriculture's pollination needs. As agriculture is confronted with pollinator decline, it is necessary to assess the potential consequential loss of economic value (Gallai et al. 2009).

The U.S. experienced large losses of honey bee colonies during the winter of 2006-2007, leading to an investigation which identified a host of symptoms now known as Colony Collapse Disorder (CCD). Hives affected by CCD are characterized by a rapid loss of adult honey bees. CCD is thought to be caused by a combination of pathogens, parasites, pesticides, weakened bee immune systems, poor nutrition and other environmental stressors (USDA 2010; Spivak et al. 2011). Between 2006 and 2010, annual colony losses ranged from 29-36 percent. These losses are problematic for beekeepers and industries dependent upon bee-pollination services (USDA 2010). Rental fees for pollinators could increase as a consequence of pollinator decline and growing costs of pest control (National Research Council 2007).

Biotic pollination is required for reproduction in roughly 70 percent of flowering plants, and bee pollination in particular is necessary for more than 30 percent of world crops. While the possibility of human starvation in the absence of pollinators is small (cereals, the staples of most diets, are abiotically pollinated), declines are possible for more nutritious foods (fruits, vegetables, meats and dairy products [the latter are supported by the production of forage crops such as alfalfa hay]) (Spivak et al. 2011). Klein et al. (2007) found that globally, 35 percent of

crop production is dependent to some degree on biotic pollination (Bauer and Wing 2010). Over the last 50 years, there has been a 300 percent increase in the production of bee-pollinated crops and an increase in the number of managed bee hives of only 45 percent. In North America, acreage devoted to bee-pollinated crops is at an all time high while the number of managed hives has decreased by 50 percent since the 1950s (Spivak et al. 2011).

For Georgia, the economic impact of changes in pollination services is potentially substantial. The Georgia food and fiber sectors employed over 690,000 workers in 2009, more than any other sector, and were responsible for more sales than any other sector, pulling in \$106.9 billion. Food and fiber contributed 13.2 percent of employment, 15.5 percent of production output, and 10.9 percent of value added to the state economy (Kane and Wolfe 2010). Nationally, Georgia ranks 14th in market value of agricultural products sold, according to the 2007 Census of Agriculture Report.

To determine the economic value of pollination services in Georgia, we develop a theoretical model, identify Georgia crops reliant on biotic pollination, collect quantitative production value data on goods and services rendered by pollination services, and use this data to estimate the economic value of pollination services in Georgia using the theoretical model.

Conceptual Background

Pollination's economic impact is felt mainly through the productivity of a few crops. Pollinator decline has potential effects beyond direct losses associated with decreased crop production, but impacts on total agricultural and ecosystem productivity are difficult to assess given the complex "causal chains" linking pollinators, plants, food web structure and ecosystem health (Bauer and Wing 2010). Demand for pollination arises from direct use value (enjoying consumption of fruits from pollinated crops) and nonuse value (existence value of pollinators

and the bequest value of their services). Markets do not exist for the pollination services of wild bees (estimating their economic value requires the use of nonmarket valuation techniques), but markets do exist for the pollination services of managed pollinators. Their economic value can be estimated by examining changes in supply and demand (National Research Council 2007).

Pollination is valuable to commercial agriculture and natural ecosystems. Pollination provides numerous benefits to a wide range of commodities – the commodity may itself be the direct product of pollination (fruits), it may be indirectly propagated by pollination (seeds used to grow the next generation of crops), or it may have its quality affected by pollination (size and appeal is linked to pollination frequency). Commodities may also be indirectly affected by pollination – the meat industry is affected by the production of alfalfa seed, a bee-pollinated crop that is used to grow hay for livestock (National Research Council 2007).¹

As pollination is a production input for agriculture², the production function approach is its most appropriate valuation method (Hein 2009). The replacement cost method has been used by studies such as Allsopp, de Lange and Veldtman (2008), but these are not true welfare measures (Hein 2009; Bauer and Wing 2010). For pollination services provided by wild pollinators, nonmarket value estimates can be calculated.³ Four methods have been used to estimate the value of commercial pollination services. One is to set the value of pollination services equal to rental fees paid for them, as Rucker et al. (2005) did, estimating the annual

¹ Attributing the total value of these effects to pollination services is an overstatement of value, as indirect goods like alfalfa hay and cattle have several inputs, only one of which is alfalfa seed. Furthermore, the alfalfa seed itself has many inputs aside from pollination (National Research Council 2007).

² Measuring the economic value of pollination is more difficult in natural ecosystems than agriculture. The number of species to consider and the limited information available are particularly complicating elements. Previous studies have not focused on value estimates for the maintenance of natural plant communities provided by pollination services, though it is undoubtedly substantial (National Research Council 2007).

³ Southwick and Southwick (1992), Prescott-Allen and Prescott-Allen (1986), and Losey and Vaughan (2006) have variously estimated the value of wild pollinators' services to be \$2-\$3 billion annually (National Research Council 2007)

value of honey bee pollination in the U.S. to be \$150 million. But this fails to capture consumer willingness to pay to ensure quality pollination and ignores production costs (National Research Council 2007).

Another method is to calculate the total value of insect-pollinated crops. Levin (1984) estimated the annual value of honey bee pollination in the U.S. to be \$19 billion (National Research Council 2007). Costanza et al. (1997) estimated this same value to be \$2 billion and extrapolated to find a world value of \$20 billion. Pimentel et al. (1997) used the Robinson et al. (1989) figure of \$8 billion as the value of U.S. crops dependent on insect pollination, increased this to \$40 billion to account for pollination's impact on the cattle and dairy industries, and extrapolated this value to \$200 billion for the world. This approach is problematic because it attributes a crop's full value to pollination, while the production of most crops suffers only to some degree in the absence of insect pollinators (Gallai et al. 2009).

An improvement to this approach is to multiply a crop's total value by a coefficient representing the crop's dependency on pollination. This method, the bioeconomic approach, has been employed by Robinson et al. (1989), estimating the annual value of honey bee pollination in the U.S. to be \$9.7 billion, and by Morse and Calderone (2000), estimating the same value to be \$14.6 billion (National Research Council 2007; Gallai et al. 2009). This approach attributes crop market value solely to pollination, ignoring the contribution of other inputs (National Research Council 2007).

Assuming a lack of substitutability among most types of produce, Gallai et al. (2009) investigates global loss of insect pollinators⁴ using the bioeconomic approach and dependence ratios given by Klein et al. (2007) for crops used directly for human consumption to calculate the

⁴ Gallai et al. (2009) measures the value of both managed and wild pollinators, where Morse and Calderone (2000) and Robinson et al. (1989) examine managed bees alone and Losey and Vaughan (2006) examine wild bees alone (Bauer and Wing 2010).

economic value of pollination for different world regions. Klein et al. (2007) sorts crops by impact of biotic pollination (increased fruit set, weight and/or quality, seed volume and/or quality, and/or pollen deposition), into five categories: essential (pollinator loss would lead to production loss of at least 90 percent); great (potential production loss of 40-90 percent); modest (potential production loss of 10-40 percent); little (potential production loss of 0-10 percent); and no increase (pollinators do not increase production). Gallai et al. (2009) determines 39 percent of the 2005 world production value of crops used for direct human consumption to be attributable to insect-pollinated direct crops, and finds the global economic value of insect pollination to be €153 billion (~\$200 billion). The authors find a wide spectrum of CVRs among different crop categories, ranging from 0-39 percent, with a CVR of world agriculture of 9.5 percent. The North American zone is calculated to have an EVP of €14.4 billion and a CVR of 11 percent. Also calculated are values of relative overproduction prior to and following pollinator loss and estimates of consumer surplus loss which reference Southwick and Southwick (1992).

These methods all fail to acknowledge that a shift in honey bee supply could increase crop prices and change demand for pollination services. Criticisms of the bioeconomic approach are its failures to address production costs and alternatives to biotic pollination, and its assumptions of perfectly elastic demand and constant prices. Some of these criticisms are addressed by examining changes to producer and consumer surplus caused by loss of pollination services (Bauer and Wing 2010). Southwick and Southwick (1992) estimated price elasticities of demand for U.S. crops, and, attributing all values to direct crop value, estimated the annual value of honey bee pollination in the U.S. to be \$1.6-\$5.7 billion (National Research Council 2007).

Gallai et al. (2009)'s estimate of consumer surplus loss assumes constant price elasticity of demand for all crops. Bauer and Wing (2010) suggests that Gallai et al. (2009)'s partial

equilibrium analysis may be inappropriate at the global level, as it ignores economy-wide impacts of crop productivity decreases and overestimates direct impacts for farmers while underestimating economy-wide impacts of price effects. This does not pose a problem for our study, however, as Hein (2009) points out that when a farmer is producing for a national or international market, local declines in pollination do not generally cause a change in overall food prices, and therefore do not directly impact consumer surplus. In these situations, partial equilibrium analysis is a valid option. Only when local markets are isolated or a local variety is impacted would local consumers feel effects. Without a price effect, any change in economic value is wholly attributed to a change in producer surplus (Hein 2009).

Data

Our primary data source is the 2009 Georgia Farm Gate Value Report (Boatright and McKissick 2010[a.]). The 2009 Georgia Farm Gate Fruit and Nut Report and 2009 Georgia Farm Gate Vegetable Report (Boatright and McKissick 2010 [b.] and [c.]) are also consulted.⁵ The Georgia Farm Gate Value Report is a collection of annual production information provided by Cooperative Extension personnel. Surveys are distributed to county Extension offices and agents are given suggested crop prices and asked to provide county acreage and yields for crops. These suggested prices are adjusted for all government payments associated directly with each crop's production, and based on county conditions, agents may adjust them. Average yearly production quantity and value for each county are determined from these surveys (Boatright and McKissick 2010[a.]). For all 159 Georgia counties and for the state of Georgia, we examine 55 row and forage, fruit and vegetable crops from these Reports [\[see table 1\]](#).

⁵ This data is supplemented by a data set, provided by the Reports' authors, which furnishes county level values for all crops which are either aggregated into conglomerate categories in the Value Report or which are included in the Vegetable Report but do not have county level values given.

Methodology

We use the bioeconomic approach, following Gallai et al. (2009)'s modified production function for application at the state level. This partial equilibrium analysis is an appropriate application because our study can be considered a "local" one, as defined by Hein (2009). We investigate crops grown in Georgia used directly for human consumption, categorizing them by Klein et al. (2007)'s classification system. We ascribe crops pollination dependency ratios in accordance with Gallai et al. (2009), using the mid-range value of Klein et al. (2007)'s ranges of potential production loss – i.e., a crop grouped in the "little" category for impact of biotic pollination, with potential production loss of 0-10 percent, receives a dependency ratio of 5 percent. Crops in the "no increase" category receive a dependency ratio of 0. Crops known to be biotically pollinated but which have not been studied by Klein et al. (2007) receive a dependency ratio of "unknown."

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. As in Gallai et al. (2009), EVP is calculated as a summation of the economic value of pollination over all crops investigated. EVP can be stated as:

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

Where, for each crop i , $i \in [1:I]$ (where $I = 55$ in this study), (Q_i) is the quantity produced, (D_i) is the pollination dependency ratio, (P_i) is the price per unit, and (FGV_i) is the Farm Gate Value reported.

Also as in Gallai et al. (2009), CVR, the potential production value loss attributable to lack of pollinators, is calculated as the ratio of EVP to economic production value (EV). CVR can be stated as:

$$CVR = \frac{EVP}{EV} = \frac{\sum_{i=1}^I (P_i \times Q_i \times D_i)}{\sum_{i=1}^I (P_i \times Q_i)} = \frac{\sum_{i=1}^I (FGV_i \times D_i)}{\sum_{i=1}^I (FGV_i)} \quad (\%) \quad (2)$$

Unlike Gallai et al. (2009), we also calculate PCV, the ratio of EVP to Total Farm Gate Value, TFGV, which is reported for each county and for the state and is a summation of values for all agricultural sector goods and services in the Farm Gate Value Report, including animal products. PCV therefore measures potential agricultural sector production value loss attributable to lack of pollinators. For the state and for counties producing agricultural goods and services beyond those we investigate, this value is expected to be lower than CVR. PCV can be stated as:

$$PCV = \frac{EVP}{TFGV} = \frac{\sum_{i=1}^I (FGV_i \times D_i)}{TFGV} \quad (\%) \quad (3)$$

Like Gallai et al. (2009), we address neither insect pollination's "indirect" impact on the dairy and cattle industries, nor its impact on seed production for vegetative components of other crops used for direct human consumption, and do not account for seed production for ornamental plants, uses for crops besides direct consumption, or nonuse values. Therefore, like Gallai et al. (2009), our estimate of EVP may be considered a conservative one. Gallai et al. (2009) assumes accurate market pricing of crops, attributes full market value of crops to pollination processes, simplifies varietal differences that may affect pollination dependency to a uniform response for each crop, and fails to account for the subsistence farming sector (Potts et al. 2010). We also make these assumptions, which are more likely to hold in regard to pricing and varietal differences: our data source uses better estimates of true crop prices than aggregated global crop price data, and at the state level, varietal differences among crops are less likely.

Also like Gallai et al. (2009), we clarify that our valuation cannot be considered a "scenario assessment" in response to pollinator decline - consumers could change their purchases

to substitutes and producers could switch to less pollinator-dependent crops or modify pollination techniques. It is also possible for pollinator-dependent crops with relatively inelastic demand that producer surplus, though limited by competition, may temporarily rise.

Results

We calculate estimates of total EVP (see equation [1]), CVR (see equation [2]) and PCV (see equation [3]) for the state and for each Georgia county. We also calculate average values of EVP, CVR and PCV over all 159 counties, and an average value of EVP over all 55 crops studied [see table 2]. As each crop's individual CVR is the pollination dependency ratio selected for that crop, an average of this value over all 55 crops studied is not reported as it reflects information only about choice of pollination dependency ratios and not pollination's economic significance to Georgia. Likewise, because of the difference in magnitude between TFGV for the state (over \$11 billion) and the EVP for individual crops (from \$0 to over \$178 million), PCV for individual crops at the state level are so small (0 – 1.6 percent), the average of these figures provides little information to this study and is not reported [see table 3 for total EVP for crops with non-zero impact of biotic pollination].

For Georgia, we estimate total EVP to be nearly \$608 million. Our estimated CVR indicates a potential production value loss for the crops studied of roughly 21.1 percent in the absence of pollinators. Our estimated PCV indicates that the pollination service contributes around 5.4 percent of the TFGV for the state. Also for Georgia, we estimate average crop EVP to be just over \$11 million (with a median crop EVP of \$8,125), and average county EVP to be nearly \$4 million. Our estimated average county CVR indicates that, on average, Georgia counties can anticipate potential production value loss for the crops studied of just over 22.4

percent in the absence of pollinators. Our estimated average county PCV indicates that, on average, the pollination service contributes around 4.7 percent of each county's TFGV.

Regrettably, delineation between wild and managed pollinators' contributions to the economic value of pollination in Georgia is possible for only one crop. Figs are pollinated by a single species of wasp, *Blastophaga psenes*, so their total EVP (\$50) can be attributed to ecosystem services (Klein et al 2007). All other biotically pollinated crops evaluated in this study are potential recipients of managed pollination services, and without data on pollinator rental expenditures, it cannot be determined whether or not these services were freely received.

We find 151 Georgia counties to have a non-zero EVP. The eight counties with an estimated EVP of \$0 (and thusly, a CVR and PCV of zero) either grow none of the crops studied or grow only those crops studied which have a pollination dependency ratio of zero. County EVP estimates range from \$0 to over \$43 million with a median value of \$540,238. County CVR estimates range from 0 to nearly 90 percent with a median value of 16.48 percent. County PCV estimates range from 0 to over 34 percent with a median value of 1.80 percent. It is useful to compare these results with the value added by agricultural products and with values sometimes used as proximate measures for the economic value of pollination, such as the value of honeybee rentals and value of honey production for the state [\[see table 4\]](#).

The value reported for "honeybees" in the 2009 Farm Gate Value Report (nearly \$18 million) is an aggregation of production values from honey bee colony sales and rentals and honey itself (McKissick 2011). According to the National Agricultural Statistics Service's 2011 Honey Report, the value of honey production for Georgia was nearly \$4 million in 2009. Though the figures for "honeybees" and "honey" are reported by different agencies using similar, but different, methodologies, as the value of honeybees includes production values of both honey

bee rentals and honey, it can be inferred that the difference between “honeybees” and “honey” values, nearly \$14 million, is an estimate of the 2009 value of honey bee rentals for Georgia.

GIS analysis of our results reveals patterns in spatial variation which are clear for EVP and PCV but less distinct for CVR [see figures 1-3]. With exception to a handful of counties along the northern border, counties with the highest EVP and PCV values appear to be clustered in the south central part of the state. Counties in the south eastern and south western regions also present with high EVP and PCV values. Georgia’s agricultural sector is known to be anchored in these regions (below the “fall line”), so these results are unsurprising. CVR values display less clustering, and the higher CVR values are more dispersed across the state. The presentation of the most extreme values for CVR in the north central parts of the state and in south eastern counties with lower EVP and PCV values is quite interesting, however. The disparity between the spatial manifestations of these measure shows how, even at state level, pollination can have radically different regional significance and different regional consequences in its absence.

Discussion

Using the bioeconomic approach, this paper estimates the economic value of pollination services (\$608 million), the crop vulnerability ratio (21 percent), and pollination’s contribution to total farm gate value (5 percent) for Georgia using 2009 county level production value data for 55 crops used directly for human consumption. These estimates are also made for all Georgia counties. Pollination’s contribution to total agricultural production value, a new measure unique to this paper, quantifies pollination’s significance to the whole agricultural sector, not just to the crops evaluated. Due to its collection methodology, our data set provides more accurate, disaggregated crop prices and quantities than Gallai et al. (2009)’s and other studies’, yielding more precise estimates. Also unique to this paper is a spatial analysis of our estimates using GIS,

which finds distinct patterns of regional variation within the state. These results indicate the potential benefit of addressing pollinator decline at the local, rather than state or national level.

Our estimate of the economic value of pollination services represents a lower-bound, as we consider pollination's direct use value for agriculture only using data on only a small selection of all agricultural products. Yet our estimate of \$608 million is an order of magnitude greater than the reported values of honey bee rentals (~\$14 million) and honey (\$4 million). In fact, it is four times the figure Rucker et al. (2003) estimated for the entire U.S. using honey bee rental fees.

While this paper provides useful information for policy making and for Cooperative Extension efforts with county agriculture, there are several potentially valuable research extensions. This study provides a snapshot of the economic value of pollination services for Georgia, and it would be interesting to examine the change in this value over time (particularly in relation to changes in acreage devoted to biotically pollinated crops), which could be done using data from previous Georgia Farm Gate Value, Fruit and Nut, and Vegetable Reports (available from 1999-2009). Additionally, accounting for production costs, either by estimating these costs and subtracting them from the Farm Gate Value figures and multiplying this net value by a pollination dependency ratio, or by collecting data on pollinator rental expenditures and subtracting these expenditures from our EVP estimates, would allow us to address the most prominent criticism of the bioeconomic approach.

Tables and Figures

Table 1. Georgia Crops Studied and their Pollination Dependency Ratios

Crop	D	Crop	D	Crop	D	Crop	D
Barley	0	Peaches	0.65	Collards	0	Pumpkin	0.95
Corn	0	Pecans	0	Cucumbers	0.65	Snap Beans	0.05
Cotton	0.25	Strawberries	0.25	Eggplant	0.25	Southern Peas	0.05
Oats	0	Pears	0.65	English Peas	0	Spinach	0
Peanuts	0.05	Cherries	0.65	Green Onions	0	Sweet Corn	0
Rye	0	Figs	0.25	Hot Peppers	0.05	Sweet Potatoes	0
Sorghum	0	Nectarines	0.65	Irish Potatoes	0	Tomato	0.05
Soybeans	0.25	Plums	0.65	Kale	0	Turnip Greens	0
Tobacco		Banana Peppers	0.05	Lettuce	0	Turnip Roots	0
Wheat	0	Bell Peppers	0.05	Lima Beans	0.05	Watermelon	0.95
Apples	0.65	Broccoli	0	Mustard	0	Winter Squash	0.95
Blackberries	0.65	Cabbage	0	Okra	0.25	Yellow Squash	0.95
Blueberries	0.65	Cantaloupe	0.95	Onions	0	Zucchini	0.95
Grapes	0	Carrots	0	Pole Beans	0.05		

Source: Klein et al. (2007)

Table 2: Measures of Pollination’s Economic Significance to Georgia

Georgia Totals and Averages (2009)	Value
Total Farm Gate Value (\$)	11,256,734,510.00
Total Farm Gate Value: Crops Studied [EV] (\$)	2,879,568,941.00
Total Economic Value of Pollination [EVP] (\$)	607,688,596.50
Crop Vulnerability Ratio [CVR]	0.21103
Pollination’s Contribution to Total Farm Gate Value [PCV]	0.05398
Average County EVP (\$)	3,821,940.80
Average Crop EVP (\$)	11,048,883.57
Average County CVR	0.22404
Average County PCV	0.04681

Source: Boatright and McKissick (2010[a.])

Table 3. Total EVP for Biotically Pollinated Georgia Crops

Rank	Crop	EVP (\$)	Rank	Crop	EVP (\$)	Rank	Crop	EVP (\$)
1	Cotton	178,166,688.80	11	Pumpkin	7,617,188.35	21	Lima Beans	301,640.20
2	Watermelon	132,051,668.20	12	Bell Peppers	6,464,055.15	22	Hot Peppers	291,907.05
3	Blueberries	66,602,381.30	13	Blackberries	5,137,637.70	23	Banana Peppers	232,306.45
4	Soybeans	42,112,694.75	14	Apples	4,392,934.00	24	Okra	202,883.25
5	Peaches	38,699,948.30	15	Eggplant	3,880,928.50	25	Plums	83,443.75
6	Cucumbers	34,172,113.95	16	Tomato	3,193,773.75	26	Pole Beans	57,629.00
7	Cantaloupe	27,609,175.50	17	Snap Beans	1,763,803.15	27	Pears	44,218.85
8	Peanuts	20,059,901.40	18	Winter Squash	1,411,610.70	28	Nectarines	8,125.00
9	Yellow Squash	18,969,934.40	19	Strawberries	1,230,133.25	29	Cherries	7,800.00
10	Zucchini	12,316,664.50	20	Southern Peas	605,357.30	30	Figs	50.00

Table 4. Georgia Comparative Values

Georgia Totals, 2009 (\$)	Value Added to the U.S. Economy by the Agricultural Sector	Total Farm Gate Value, Honeybees	Value of Honey Production	Calculated EVP
Value	2,974,995,000.00	17,889,132.00	3,918,000.00	607,688,596.50

Sources: Boatright and McKissick (2010[a.]); U.S. Department of Agriculture, Economic Research Service (2011); U.S. Department of Agriculture, National Agricultural Statistics Service (2011)

Figure 1. Georgia Counties Map: EVP

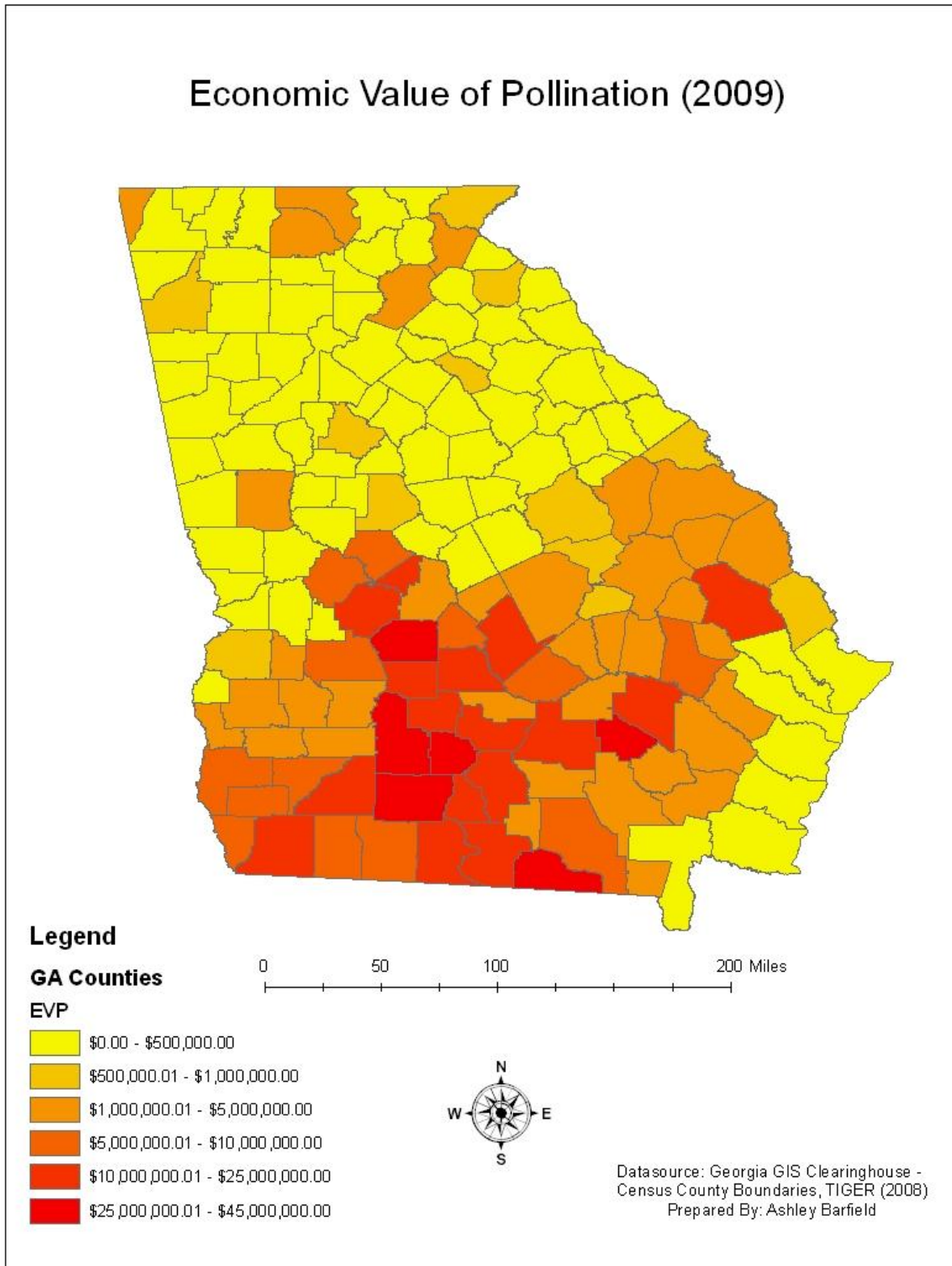


Figure 2. Georgia Counties Map: CVR

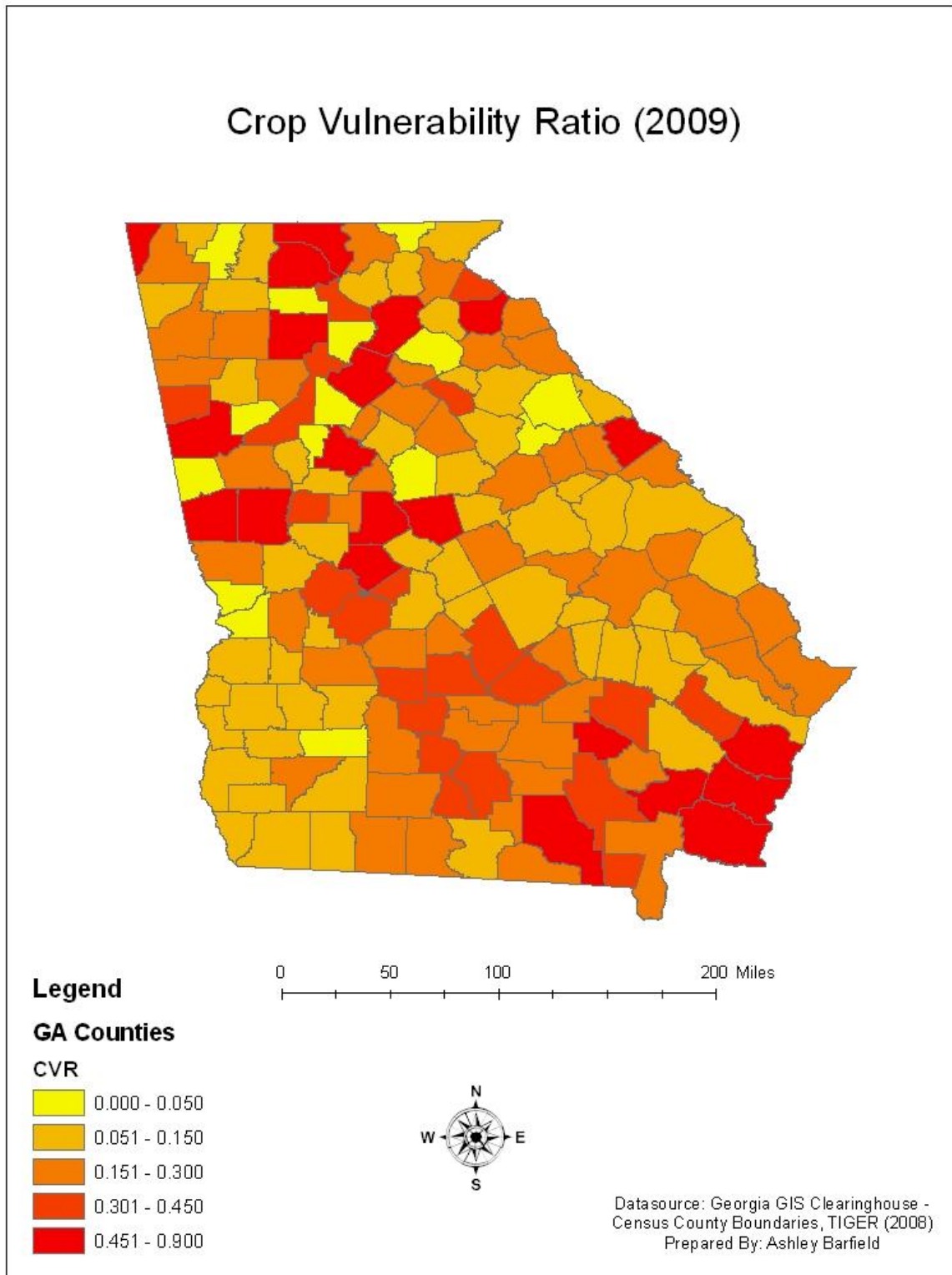
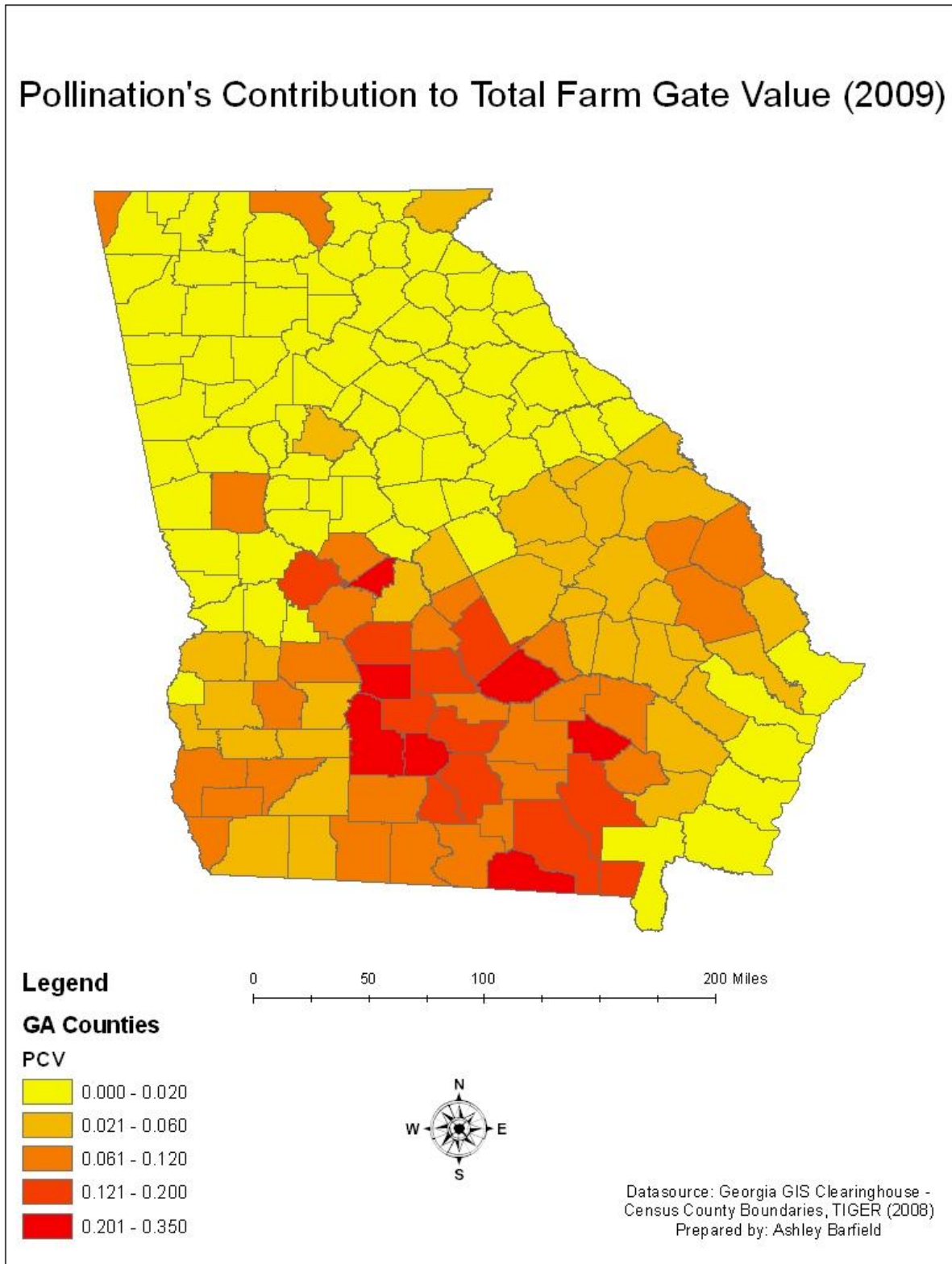


Figure 3. Georgia Counties Map: PCV



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