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An Economic Valuation of Biotic Pollination Services in Georgia

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ABSTRACT As agriculture faces documented decline in bees and other insect pollinators, empirical assessments of potential economic losses are critical for contextualizing the impacts of this decline and for prioritizing research needs. For the state of Georgia, we show that the annual economic value of biotic pollinators is substantial—US$367 million, equivalent to 13 percent of the total production value of crops studied and 3 percent of the total production value of Georgia's agricultural sector. Our unique Geographic Information Systems analysis reveals an irregular pattern of vulnerability. While the Georgia counties displaying the highest economic values of pollination are clustered in southern Georgia, those with the highest dependency on pollinators in terms of their contribution to crop production value are more dispersed throughout the state.

KEY WORDS agriculture, *Apis mellifera*, bee population, Geographic Information System, pollination value

Introduction

Pollination is both an ecosystem service and a production practice. As an ecosystem service, wild pollinators pollinate a large variety of plants. As a production practice, bee colonies are purchased or rented to supplement services of wild pollinators—a market demand suggesting that background pollination of crops is not sufficient to support agriculture's pollination needs. As agriculture is confronted with pollinator decline, it is vital for scientists and policy makers to be apprised of potential economic consequences.

Bees are particularly efficient pollinators, consuming solely pollen and nectar, collecting pollen grains with ease, and visiting several flowers of the same species in one trip. Honey bees and, to a lesser extent, bumble bees are favored among farmers because of their manageability and comparatively large colonial forager populations (Delaplane and Mayer 2000, Delaplane et al. 2010). Wild bees, comprising the vast majority of roughly 4,000 bee species native to North America, also contribute pollination services, although with the exception of cultured blueberry (Cane and Payne 1988, 1990, 1993; Cane 1994), their significance to commercial agriculture in the southeastern United States is poorly understood (Kremen et al. 2002, Delaplane et al. 2010, Spivak et al. 2011). In Georgia (and the Southeast in general), bumble bees (*Bombus* spp.), southeastern blueberry bees (*Habropoda laboriosa* (F.)), squash bees (*Peponapis pruinosa*, *Xenoglossa* spp.), and leaf-cutting bees (*Megachile* spp.) are particularly significant pollinators (Delaplane et al. 2010).

The United States has experienced large losses of honey bee (*Apis mellifera*) colonies beginning with the winter of 2006–2007, initiating an ongoing investigation of a syndrome now known as Colony Collapse Disorder (CCD). Colonies affected by CCD are characterized by a rapid loss of adult honey bees.[5] Since the first reportings of CCD, annual winter colony losses have averaged around 33 percent, though the 2012 winter experienced a low of 22 percent (possibly due to unusually warm weather; U.S. Department of Agriculture [USDA] 2012). Some of the decrease in honey bee colonies in the United States can be attributed to the exit of beekeepers from the industry as world honey prices decreased and honey imports increased, but the majority has been a result of bee health problems (Bauer and Wing 2010).

The 2013 USDA and EPA joint report on honey bee health raises concerns about honey bee colony survivorship rates and beekeepers' ability to meet the pollination demands of U.S. crops. In the case of just one crop—California almond—growers require >60 percent of all managed honey bee colonies in the United States (roughly 1.5–1.7 million of 2.5 million colonies).

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[5] CCD is thought to be caused by a combination of pathogens, parasites, pesticides, weakened bee immune systems, poor nutrition, habitat fragmentation, bee management practices, and other environmental stressors. (Spivak et al. 2011, USDA 2012).

If these 30 percent winter loss rates persist, the number of colonies left to pollinate other crops could be diminished, leaving growers vulnerable to honey bee supply shocks (USDA 2013).

Wild bees face many of the same health risks as managed bees, and their populations have similarly declined (Cameron et al. 2011). Wild bees are particularly efficient pollinators for certain native crops (including pumpkin, tomato, cranberry, and blueberry), and with sufficient habitat, they can provide all the necessary pollination for these crops. This efficiency makes them important resources, especially in the face of managed honey bee decline (Spivak et al. 2011, Adamson et al. 2012).

Biotic pollination is required for reproduction in roughly 70 percent of flowering plants, and bee pollination in particular is necessary for >30 percent of world crops. While the possibility of human starvation in the absence of pollinators is small (cereals, typical diet staples, are wind-pollinated), declines are possible for more nutritious foods such as fruits and vegetables, as well as meats and dairy products (which are supported by the production of bee-pollinated forage crops such as alfalfa hay; Spivak et al. 2011). Klein et al. (2007) found that 35 percent of global crop production is dependent to some degree on biotic pollination. In North America, acreage devoted to production of 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).[6]

Despite the extensive research attention given to CCD, the literature is inconsistent about its economic ramifications. Some papers (Ward et al. 2010, Carman 2011) list CCD as a contributor to increased pollination fees, while others (Rucker et al. 2011, 2012) cast doubt on the impact of CCD on these fees and related economic variables (colony stocking densities, queen or package bee prices, etc.). Regardless, CCD is not the sole concern in discussions of honey bee health, and indeed, honey bees are not the sole concern in discussions of overall pollination stability. CCD has piqued the public's and agricultural sector's interest in pollination services. Our study serves to better inform these interests.

For Georgia, the economic impact of changes in pollination services is potentially substantial. In 2011, the Georgia food and fiber sectors were responsible for more jobs (nearly 708,000) and more sales (nearly US$111 billion) than any other sector in the state. Food and fiber contributed 13.7 percent of employment, 15.3 percent of production output, and 11.1 percent of value added to the state economy (Kane and Wolfe 2013). Nationally, Georgia ranks 14th in market value of agricultural products sold, according to the 2007 Census of Agriculture Report (USDA 2009).

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

Materials and Methods

Conceptual Background. Pollination provides numerous benefits to a wide range of commodities—a commodity may be the direct product of pollination (fruits); it may be indirectly propagated by pollination (seeds used to grow the next generation of crops); or its quality may be affected by pollination (size and appeal are 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 used to grow hay for livestock forage (National Research Council 2007). Demand for pollination arises from both direct use value (consumption of fruits from pollinated crops) and nonuse value (existence value of pollinators, bequest value of their services). Markets do not exist for pollination services of wild pollinators, but they do exist for the services of managed pollinators, whose economic value can be estimated by examining changes in supply and demand (National Research Council 2007).

As pollination is a production input for agriculture, the production function approach is an appropriate valuation method (Hein 2009).[7] The replacement cost method has been used by studies such as Allsopp et al. (2008), though these estimates are not true welfare measures (Hein 2009, Bauer and Wing 2010). For pollination ecosystem services, nonmarket value estimates can be calculated (Prescott-Allen and Prescott-Allen [1986], Southwick and Southwick [1992], and Losey and Vaughan [2006]). The production function approach involves two steps in this application: 1) assessing physical effects on economic activity (agricultural production) resulting from a change in pollination services, and 2) valuing these impacts by analyzing the changes in the marketed output associated with this economic activity (Hein 2009). The change in social welfare, W, resulting from a marginal change in the

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[6] Aizen et al. (2009) distinguish between pollinator declines and pollinator shortages. Where pollinator decline is a decrease in population size or biodiversity, a pollinator shortage is the outstripping of pollinator supply by pollination demand. While the current literature provides little evidence of pollinator shortages, increases in acreage devoted to pollinator-dependent crops, declines in supply of managed pollinators, increases in rental fees for honey bee colonies, and decreases in the number of managed honey bee colonies employed per hectare since 1963 all suggest potential for pollinator shortages.

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

supply of the pollination service, e (holding other inputs constant) is given by:

$$\frac{\partial W}{\partial e} = p\left(y^{*}\right) \times \frac{\partial y}{\partial e}, \qquad (1)$$

where y, the amount produced of the marketed output, depends on biotic pollination, e, and other factors of production (land, labor, capital, etc), and sells for a market price p. Social welfare (the sum of producer and consumer surplus) resulting from the production of y is $W(y)$. Assuming farmers must take prices as given in a perfectly competitive economy, equilibrium production is y^{*} (Freeman 2003, Hein 2009).[8]

Three primary methods have been used to estimate the value of pollination services. One is to set the value of pollination services equal to the rental fees paid for them. For example, Rucker et al. (2012) estimated that U.S. beekeepers have recently received around US$350 million in annual rental fees. But this method, estimating fees (costs) paid, fails to capture potential consumer willingness to pay (WTP) to ensure quality pollination and ignores beekeepers' production costs (National Research Council 2007). It provides a lower bound on true WTP for pollination services, as benefits received from pollination services are not necessarily equivalent to input costs.

Another method is to calculate the total value of biotically pollinated crops, i.e., multiplying a crop's market price by its market quantity (Levin 1984, Robinson et al. 1989, Costanza et al. 1997, Pimentel et al. 1997). This approach, however, is problematic because it attributes a crop's full value to pollination services, while the production of most crops suffers only to some degree in the absence of pollinators (Gallai et al. 2009).

An improvement to this approach is to multiply a crop's total value by a coefficient between zero and one representing the crop's dependency on pollination services for production (i.e., $0 \leq \partial y/\partial e \leq 1$). Setting this coefficient equal to one would produce the same results as just calculating the total value of biotically pollinated crops, with the same disadvantages as previously described. This third method, the bioeconomic approach, is a variation of the conventional production function method and has been employed by Robinson et al. (1989) and Morse and Calderone (2000) in the case of managed bees. This approach does not account for production costs, however (National Research Council 2007).

Assuming a lack of substitutability among most types of produce, Gallai et al. (2009) investigate global loss of both managed and wild insect pollinators using the bioeconomic approach for crops used directly for human consumption to calculate the economic value of pollination for different world regions. Their dependence ratios come from Klein et al. (2007), who sort 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).

These methods all fail to acknowledge that a decrease in honey bee supply could increase crop prices and change quantity of pollination services demanded. Additional criticisms of the bioeconomic approach are its failure to address production costs and alternatives to biotic pollination, and its assumptions of perfectly elastic demand and constant prices.[9] Some of these criticisms are addressed by examining changes to producer and consumer surplus caused by loss of pollination services (Bauer and Wing 2010). For example, Southwick and Southwick (1992) estimate price elasticities of demand for U.S. crops in their valuation.

Bauer and Wing (2010) suggest 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. In addition, Hein (2009) criticizes Gallai et al. (2009)'s assumption of constant prices for crops at the global level—global pollinator decline would cause price increases in biotically pollinated crops that would need to be accounted for in a general equilibrium analysis. Depending on the price elasticities of the crops investigated, it is possible for the sum of consumer and producer surpluses to be different (larger or smaller) than the value arrived at using the bioeconomic approach.[10]

This does not pose a problem for our study, however. When a farmer is producing for a national or international market, local declines in pollination do not generally cause a change in overall factor or food prices, and therefore do not directly impact consumer surplus.

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[8] With nonmarginal changes in ecosystem service supply, it is necessary to integrate the social welfare function over e. This requires construction of both demand and supply curves in order to analyze the production and cost functions and the levels of y^{*} associated with different levels of e (Hein 2009).

[9] Another measurement issue with the production function method (and therefore, the bioeconomic approach) occurs when the ecosystem service being valued affects the total natural resource stocks or biotic populations in the systems where economic value ultimately results. When these stock effects are insignificant, modeling the value of changes in the ecosystem service as effects only on current production and prices (i.e. in a static model) is appropriate. But if stock effects are significant, it is important to value the market impact of changes in the ecosystem service over all affected future time periods (i.e. in a dynamic model; Barbier 2007).

[10] Hein (2009) evaluates valuation methods for different production scales and finds that locally, the value of pollination services varies depending on market and crop conditions. He argues that locally, pollination supports farm income, but nationally, it supports the food supply as a whole. These different (institutional and ecological) scales have different producers, consumers, and related surpluses, and different valuation methods should be used. He also claims that there are no existing studies that provide a reliable estimate of the global value of the pollination service.

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).[11] Consequently, the value resulting from the pollination service at the local level is—

$$\omega = S \times \Delta q \times \left(p - c\right), \tag{2}$$

where ω is the change in producer surplus (US\$), S is total crop output (kg), Δq is the change in crop output resulting from pollination ($\partial S/\partial e$, where e is pollination services), p is the farm-gate crop price (US\$/kg), and c is the average variable cost of crop harvest (US\$/kg). Rewriting this expression we obtain—

$$\begin{aligned}\omega &= \Delta q \times \left(S \times p - S \times c\right)\\ &= \Delta q \times (TR - TVC)\\ &= \Delta q \times producer\,surplus, \end{aligned}\tag{3}$$

where S is the amount produced of a pollination-dependent crop (kg), Δq ($\partial S/\partial e$) can be construed as the pollination dependency ratios employed by the bioeconomic approach (recall that a pollination dependency ratio is the change in output caused by a change in pollination services, e), TR is total revenue, and TVC is total variable costs associated with producing a crop. This derivation illustrates why the bioeconomic approach is criticized for not accounting for production costs in its calculation of pollination's impact on social welfare—it essentially represents a calculation of the first half of this expression, $\Delta q \times TR$, ignoring TVC.

We use the bioeconomic approach, following Gallai et al. (2009)'s modified production function applied at the county level. This partial equilibrium analysis is appropriate because our study can be considered a "local" one, as defined by Hein (2009). We investigate 55 crops grown in Georgia used directly for human consumption, categorized using Klein et al. (2007)'s classification system. We ascribe 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 were not studied by Klein et al. (2007) receive a dependency ratio of "unknown." Where local expert opinion allows us to more accurately connect pollination biology to the crops we examine, we improve upon Gallai et al. (2009) by selecting pollination dependency ratios that better reflect Georgia's specific agricultural practices (Tables 1 and 2).

Data. Our primary data sources are the 2009 Georgia Farm Gate Value, Farm Gate Fruit and Nut, and Farm Gate Vegetable Reports (Boatright and McKissick 2010a,b,c). These reports are supplemented by a data set, provided by the Reports' authors, which furnishes county-level values for all crops which are either aggregated in the Value Report or which are included in the Vegetable Report but not given county-level values.

The Georgia Farm Gate Value Report is a collection of annual production information provided by University of Georgia 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. These suggested prices are adjusted for all government payments associated directly with each crop's production, and agents may adjust them based on county conditions. Average yearly production quantity and value for each county are determined from these surveys (Boatright and McKissick 2010a). We examine 55 row and forage, fruit and vegetable crops from these Reports for all 159 Georgia counties and for the state of Georgia.

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

$$\begin{aligned}EVP &= \sum\nolimits_{i=1}^{I} \left(P_i \times Q_i \times D_i\right)\\ &= \sum\nolimits_{i=1}^{I} \left(FGV_i \times D_i\right)\end{aligned}\tag{4}$$

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 $P_i \times Q_i$).

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

$$\begin{aligned}CVR = \frac{EVP}{EV} &= \frac{\sum\nolimits_{i=1}^{I} \left(P_i \times Q_i \times D_i\right)}{\sum\nolimits_{i=1}^{I} \left(P_i \times Q_i\right)}\\ &= \frac{\sum\nolimits_{i=1}^{I} \left(FGV_i \times D_i\right)}{\sum\nolimits_{i=1}^{I} \left(FGV_i\right)}\ (\%)\end{aligned}\tag{5}$$

In addition, we calculate pollination's contribution to total farm gate value, the ratio of the economic value of

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[11] Hein (2009) argues that local farmers face increased costs associated with pollination loss, but if other producers continue to supply affected crops, it is possible for local farmers to benefit from increased market prices associated with scarcity. In the long term, large decreases in crop production resulting from pollination decline could cause farmers to switch to different production methods or substitute crops with greater income potential.

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
Cherries	honey bees, bumble bees (*Bombus* spp.), solitary bees (*Osmia lignaria propinqua*), flies
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.)
Nectarines	honey bees, bumble bees (*Bombus* spp.), solitary bees (*Osmia lignaria propinqua*), flies
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
Pears	honey bees, bumble bees (*Bombus* spp.), solitary bees (*Osmia* spp.), hover flies (*Eristalis tenax*)
Plums	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*)
Tobacco	honey bees, other insects and hummingbirds
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	Plums	0.65	Broccoli	0	Oats	0
Pumpkin	0.95	Eggplant	0.25	Cabbage	0	Onions	0
Watermelon	0.95	Okra	0.25	Carrots	0	Peanuts	0
Winter squash	0.95	Strawberries	0.25	Collards	0	Pecans	0
Yellow squash	0.95	Banana peppers	0.05	Corn	0	Rye	0
Zucchini	0.95	Bell peppers	0.05	Cotton	0	Sorghum	0
Apples	0.65	Hot peppers	0.05	English peas	0	Soybeans	0
Blackberries	0.65	Lima beans	0.05	Figs	0	Spinach	0
Blueberries	0.65	Pole beans	0.05	Grapes	0	Sweet corn	0
Cherries	0.65	Snap beans	0.05	Green onions	0	Sweet potatoes	0
Cucumbers	0.65	Southern peas	0.05	Irish potatoes	0	Turnip greens	0
Nectarines	0.65	Tomato	0.05	Kale	0	Turnip roots	0
Peaches	0.65	Tobacco	Unknown	Lettuce	0	Wheat	0
Pears	0.65	Barley	0	Mustard	0		

Sources: Klein et al. (2007); Boatright and McKissick (2010a,b,c); Abney (2014); Roberts (2014); Toews (2014).

pollination 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 the crop vulnerability ratio.

$$PCV = \frac{EVP}{TFGV} = \frac{\sum_{i=1}^{I} (FGV_i \times D_i)}{TFGV}\ (\%) \qquad (6)$$

Like Gallai et al. (2009), we omit pollination's indirect impact on the dairy and cattle industries and its impact on seed production for vegetative components of other crops used for direct human consumption, as well as seed production for ornamental plants, uses for crops besides direct consumption, and nonuse values. This omission tends to underestimate the true economic value of pollination, whereas the bioeconomic approach's (criticized) omission of production costs tends to overestimate the true economic value of pollination. While we do not have the necessary data to assess which of these countervailing effects dominates in Georgia, the fact that the two work in opposition is reassuring.

Gallai et al. (2009) assume accurate market pricing of crops, simplify varietal differences that may affect pollination dependency to a uniform response for each crop, and fail 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 in this study. 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 likely less substantial.

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 (though these changes would incur out-of-pocket and opportunity costs). It is also possible for pollinator-dependent crops with relatively inelastic demand that producer surplus, though limited by competition, may temporarily rise. Our main interest is to provide estimates of the economic contribution of the current, existing stock of biotic pollinators to the agricultural sector in Georgia.

Results

We estimate the total economic value of pollination (equation 4), crop vulnerability ratio (equation 5), and pollination's contribution to total farm gate value (equation 6) 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 (Table 3). As each crop's individual CVR is its pollination dependency ratio, an average of this value over all 55 crops studied is not reported, as it reflects information only about choice of pollination dependency ratios. Likewise, because of the difference in magnitude between total farm gate value for the state (>US$11 billion) and the EVP for individual crops (from US$0 to >US$132 million), PCV for individual crops at the state level are so small (0–1.2 percent), the average of these figures provides little information to this study and is not reported.

For Georgia, we estimate the total economic value of pollination to be >US$367 million. Our estimated crop vulnerability ratio indicates a potential production value loss for the crops studied of roughly 13 percent in the absence of pollinators. Our estimate of pollination's contribution to total farm gate value indicates that the pollination service contributes around 3 percent of the total farm gate value for the state. Also for Georgia, we estimate average crop EVP to be nearly US$7 million and average county EVP to be >US$2 million. Our estimated average county CVR indicates that, on average, Georgia counties could anticipate potential production value loss for the crops studied of 16 percent in the absence of pollinators. Our estimated average county PCV indicates that, on average, the pollination service contributes around 3 percent of each county's TFGV (Table 3).

Table 3. Measures of pollination's economic significance to Georgia

Georgia totals and averages (2009)	Value
Total farm gate value (US$)	11,256,734,500
Total farm gate value: crops studied [EV] (US$)	2,879,568,900
Total economic value of pollination [EVP] (US$)	367,349,300
Crop vulnerability ratio [CVR]	13%
Pollination's contribution to total farm gate value [PCV]	3%
Average county EVP (US$)	2,310,400
Average crop EVP (US$)	6,679,100
Average county CVR	16%
Average county PCV	3%

Boatright and McKissick (2010a), authors' calculations.

Regrettably, delineation between wild and managed pollinators' contributions to the economic value of pollination in Georgia is not possible. All crops evaluated in this study are potential recipients of managed and unmanaged pollination services, and without data on pollinator rental expenditures, it cannot be determined whether these services were freely received.

It is useful to compare these results with values sometimes used as proximate measures for the economic value of pollination, such as the value of honey bee rentals and value of honey production. The value reported for "honeybees" in the 2009 Farm Gate Value Report (nearly US$18 million) is an aggregation of production values from honey bee colony sales and rentals and honey itself (McKissick 2011).[12] According to the National Agricultural Statistics Service's 2011 Honey Report, the value of honey production for Georgia was nearly US$4 million in 2009 (USDA 2011). Though the figures for "honeybees" and "honey" are reported by different agencies, it can be inferred that the difference between "honeybees" and "honey" values, nearly

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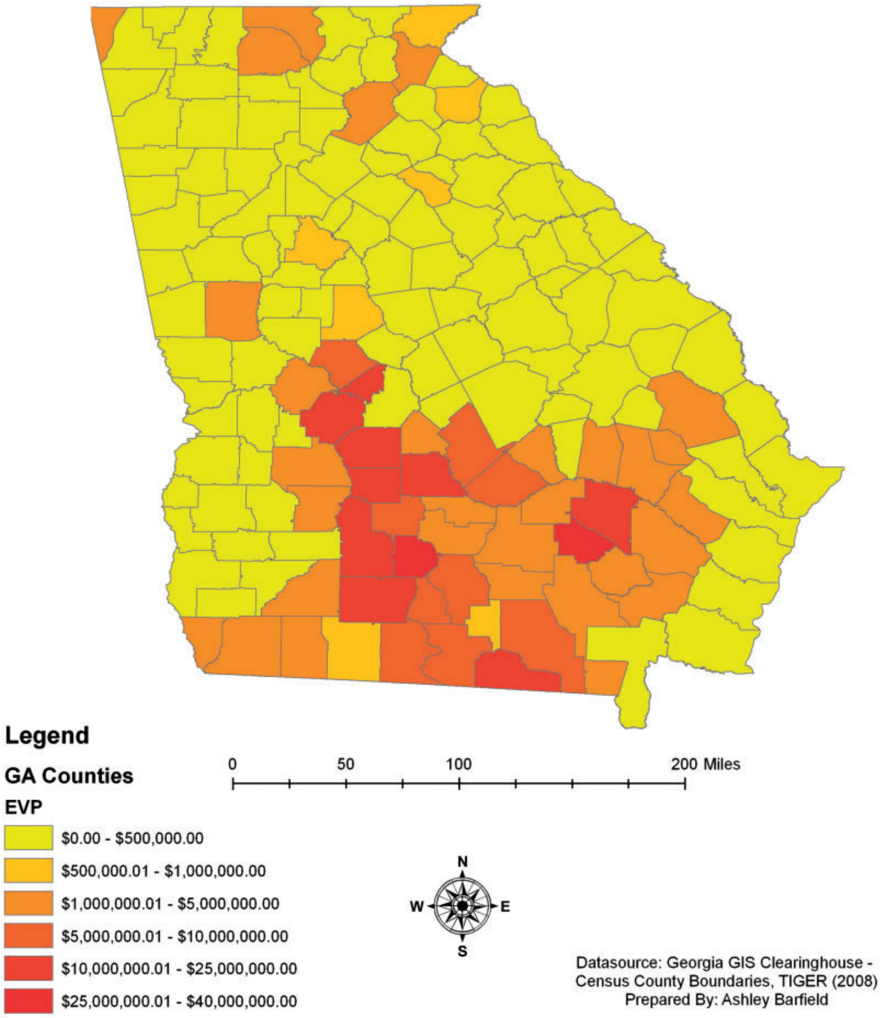
[12] This aggregation is the result of typical pollination market contracts. With pollination as an input to the crop production process, both honey and crop yields are outputs. Generally, farmers keep the crop yield and pay pollination rental fees; beekeepers keep the honey. In this sense, the total value of honey bees to beekeepers is the sum of honey revenues and rental fees. The variation of honey quantity and quality output among crops, therefore, drives associated pollination fees (better honey-yielding crops receive lower rental rates, and vice versa; Rucker et al. 2012). It is likely that, for Georgia, the value of honey bees reflects mainly the value of pollination services; while Georgia's blueberry production is increasing, the statewide production of other pollinator-dependent, honey-yielding remains insignificant.



Datasource: Georgia GIS Clearinghouse - Census County Boundaries, TIGER (2008)
Prepared By: Ashley Barfield

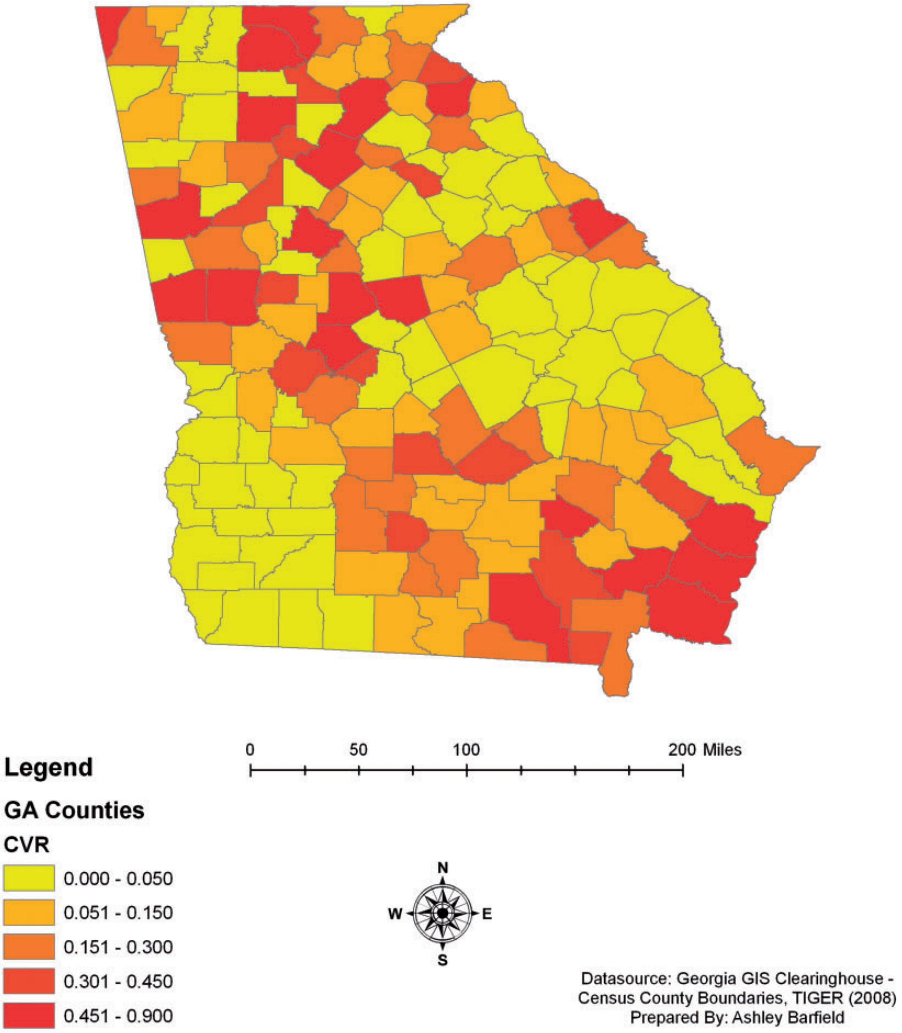
Fig. 1. Economic value of pollination (2009).

US$14 million, is an estimate of the 2009 value of honey bee rentals for Georgia.

Spatial Analysis. Geographic Information Systems (GIS) analysis of our results reveals patterns in spatial variation that are clear for the economic value of pollination and pollination's contribution to total farm gate value but less distinct for the crop vulnerability ratio (Figs. 1–3). With exception to a few 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. Georgia's agricultural sector is known to be anchored in this region, 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 highest values for CVR in the north central parts of the state and in south eastern counties with lower EVP and PCV values is also quite interesting. It indicates that most Georgia counties are growing crops that are moderately to severely vulnerable to pollinator decline, whether their local economies are largely agrarian or not. The disparity between the spatial manifestations of these measures shows how, even at the state level, pollination can have radically different regional significance and consequences in its absence: the South Georgia farm-belt would shoulder the largest (nominal and proportional) impacts, but there are farmers in the coastal, piedmont, and Northern regions who would also be greatly affected.

Discussion

Using the bioeconomic approach, we estimate the economic value of pollination (US$367 million), the crop vulnerability ratio (13 percent), and pollination's



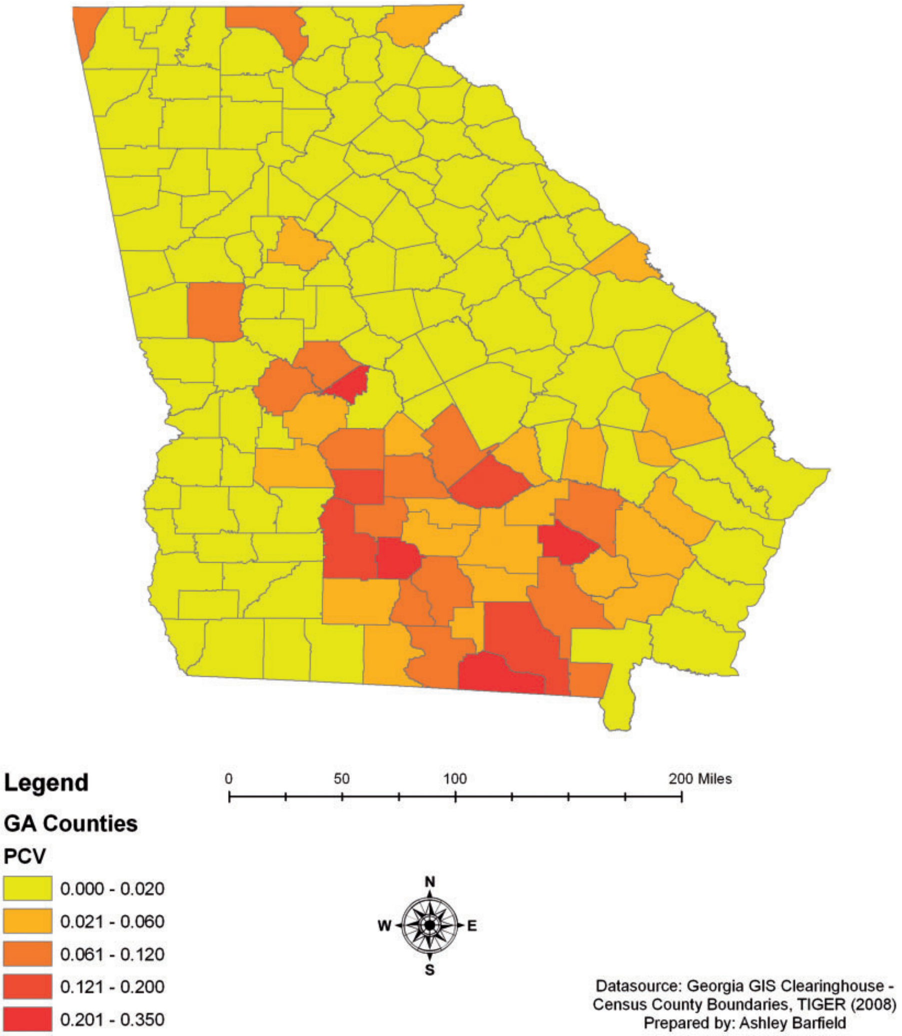
Datasource: Georgia GIS Clearinghouse -
Census County Boundaries, TIGER (2008)
Prepared By: Ashley Barfield

Fig. 2. Crop vulnerability ratio (2009).

contribution to total farm gate value (3 percent) for Georgia using 2009 county level production value data for 55 crops used directly for human consumption. Pollination's contribution to total agricultural production value, a measure unique to this article, quantifies pollination's significance to the agricultural sector, not just to the crops evaluated. Our data set provides more accurate, disaggregated crop prices and quantities than previous studies', yielding more precise estimates that are further refined by our choice of more locally representative pollination dependency ratios. Also unique to this article is a GIS spatial analysis of our estimates, which finds distinct patterns of regional variation within Georgia. These results indicate the potential benefit of addressing pollinator decline at the local, rather than state or national, level.

While we only consider pollination's direct use value for agriculture using data on only a small selection of all agricultural products, our estimate of US$367 million is an order of magnitude greater than the reported values of honey bee rentals (~US$14 million) and honey (US$4 million) for 2009. Over half of this value can be attributed to Georgia's watermelon and blueberry crops. It is worth noting, though, that we place both cotton and soybeans in the "no increase" category for impact of biotic pollination, as pollinators' contributions to the productivity of these crops is somewhat debatable (Klein et al. [2007] place "seedcotton" and soybeans in the "modest" category). Cotton and soybeans are highly significant agricultural commodities in Georgia, and assigning them any pollination dependency ratio other than zero would result in a substantial increase in the total economic value of pollination.

Our results have several policy and management implications. It has been shown that managing for pollinator diversity has the potential to meet pollination



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Census County Boundaries, TIGER (2008)
Prepared by: Ashley Barfield

Fig. 3. Pollination's contribution to total farm gate value (2009).

Table 4. Statewide EVP for biotically pollinated crops

Rank	Crop	EVP (US$)	Rank	Crop	EVP (US$)	Rank	Crop	EVP (US$)
1	Watermelon	132,051,668	10	Blackberries	5,137,638	19	Hot peppers	291,907
2	Blueberries	66,602,381	11	Apples	4,392,934	20	Banana peppers	232,306
3	Peaches	38,699,948	12	Eggplant	3,880,929	21	Okra	202,883
4	Cucumbers	34,172,114	13	Tomato	3,193,774	22	Plums	83,444
5	Cantaloupe	27,609,176	14	Snap beans	1,763,803	23	Pole beans	57,629
6	Yellow squash	18,969,934	15	Winter squash	1,411,611	24	Pears	44,219
7	Zucchini	12,316,665	16	Strawberries	1,230,133	25	Nectarines	8,125
8	Pumpkin	7,617,188	17	Southern peas	605,357	26	Cherries	7,800
9	Bell peppers	6,464,055	18	Lima beans	301,640			

Authors' calculations.

requirements for many crops, thereby providing insurance in the case of pollinator shortages (Kremen et al. 2002). Providing an estimate of the economic value of pollination is important for cost–benefit analyses of proposed responses to observed or anticipated pollinator decline (and subsequent decreases in overall biodiversity). Local governments, farmers, and nonfarm residents can identify their own best-practice solutions, possibly coordinating with neighbors and adjacent counties to form regional action plans.[13]

Our estimates and spatial analyses of pollination values and vulnerabilities provide information that is useful for the selection of the most appropriate pollinator management strategies for different stakeholders. For instance, a group of seven counties that border one another and display high values for the economic value of pollination, the crop vulnerability ratio, and pollination's contribution to total farm gate value (Turner, Tift, Colquitt, Brooks, Echols, Lowndes, and Cook counties) are among the "top ten" in production of both zucchini and squash. These crops are significant contributors of EVP (Table 4) [partially due to their high pollination dependence (Table 2)], share the same potential pollinators (Table 1), and have similar production practices. Given these that these counties also fall within the same Georgia Cooperative Extension District (Southwest), locally administered pollinator management strategies may be most effective.

While this research provides useful information for policy and management and for Cooperative Extension efforts with county-level agriculture, there are several valuable research potentialities. This study provides a snapshot of the economic value of pollination services for Georgia, and it would be useful to examine the change in this value over time, particularly in relation to changes in acreage devoted to biotically pollinated crops. 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 county level data on pollinator rental expenditures and subtracting these expenditures from our economic value of pollination estimates, could allow us to address the most prominent criticism of the bioeconomic approach.

Collection of data on pollinator rental expenditures at the county level could also help to delineate between the contributions of unmanaged and managed pollinators. For counties with positive economic value of pollination values but no farmer expenditures on honey bee rentals, it is reasonable to assume that wild pollinators contributed these values. These findings could be further analyzed using GIS to determine what role spatial variation in land use patterns has in the provision of pollination ecosystem services. To this end, it would be beneficial to determine where the wild pollinators for Georgia crops (Table 1) are prevalent and their relative abundances. In so doing, we could rank-order Georgia's biotically pollinated crops in terms of vulnerability to both managed and wild pollinator decline. For example, a crop would be more at risk if it was known to be responsive to multiple native pollinator species that were rare in the region than if it was known to be responsive to a few pollinator species that were regionally abundant.

Finally, a more complete assessment of pollination's economic value in Georgia could be made by relaxing our assumption of partial equilibrium and determining whether Georgia crops represent a sufficient market share to cause price effects (and, consequently, changes in consumer surplus) if crop production were to suffer as a result of pollinator decline. If a general equilibrium analysis is warranted, we could follow methodological examples provided by Southwick and Southwick (1992), Gallai et al. (2009), and Bauer and Wing (2010) in this estimation.

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[13] The literature recommends a host of possible adaptation and mitigation measures. Generally speaking, "habitat enhancement, judicious and targeted pesticide use, improved colony management techniques, and improved disease- and pest-resistant stocks of bees," ought to be employed in the pursuit of improved bee health conditions (USDA 2013). Specific recommendations for increasing numbers of bumble bees, soil-nesting bees, and wood-nesting bees, as well as an overview of how to establish and install bee pasture, are provided by Delaplane et al. (2010).

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