ORIGINAL RESEARCH ARTICLE

Time-varying Reproduction Numbers of COVID-19 in Georgia, USA, March 2, 2020 to November 20, 2020

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ABSTRACT

Background: In 2020, Severe Acute Respiratory Syndrome Coronavirus 2 impacted Georgia, USA. Georgia announced a state-wide shelter-in-place on April 2 and partially lifted restrictions on April 27. We estimated the time-varying reproduction numbers (R_t) of COVID-19 in Georgia, Metro Atlanta, and Dougherty County and environs from March 2, 2020, to November 20, 2020.

Methods: We analyzed the daily incidence of confirmed COVID-19 cases in Georgia, Metro Atlanta, and Dougherty County and its surrounding counties, and estimated R_t using the R package *EpiEstim*. We used a 9-day correction for the date of report to analyze the data by assumed date of infection.

Results: The median R_t estimate in Georgia dropped from between 2 and 4 in mid-March to < 2 in late March to around 1 from mid-April to November. Regarding Metro Atlanta, Rt fluctuated above 1.5 in March and around 1 since April. In Dougherty County, the median R_t declined from around 2 in late March to 0.32 on April 26. Then, R_t fluctuated around 1 in May through November. Counties surrounding Dougherty County registered an increase in R_t estimates days after a superspreading event occurred in the area.

Conclusions: In Spring 2020, Severe Acute Respiratory Syndrome Coronavirus 2 transmission in Georgia declined likely because of social distancing measures. However, because restrictions were relaxed in late April and elections were conducted in November, community transmission continued, with R_t fluctuating around 1 across Georgia, Metro Atlanta, and Dougherty County as of November 2020. The superspreading event in Dougherty County affected surrounding areas, indicating the possibility of local transmission in neighboring counties.

INTRODUCTION

In 2020, the COVID-19 pandemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) impacted the state of Georgia as well as other jurisdictions within the US. Within Georgia, Metro Atlanta counties have been the hardest hit by the virus, with thousands of confirmed cases cumulatively: 37,238 in Fulton, 36,407 in Gwinnett, 25,853 in Dekalb, 26,255 in Cobb, and 12,314 in Hall County as of November 20, 2020.[1] Dougherty County, with Albany as the county seat, was an early COVID-19 hotspot in southeastern Georgia and reported a large number of cases (as of November 20, 2020: cumulative number, 3431; incidence rate, 3816 per 100,000 individuals).[1] In Georgia, every county government had the power to impose preventive measures to reduce viral transmission as they see fit, before the state imposed a state-wide emergency that overrode the autonomy of county governments (Table 1). On March 23, 2020, the Georgia state government issued an executive order requesting citizens with underlying conditions and those with a COVID-19 diagnosis to shelter in place.[2] Certain businesses were to remain closed and no more than 10 individuals could gather in a location without maintaining a distance of at least 6 feet. The order also called for restaurants to offer curbside pickup or delivery only.[2] On April 2, 2020, a state-wide shelter-in-place ordinance was enacted by the governor, allowing only essential services to operate (implemented on April 3).[3] The Georgia state government announced on April 27, 2020, during a press conference, that services such as beauty salons, barber shops, stores, and restaurants can reopen if they follow pertinent social distancing measures specified by the state.[4] On May 12, 2020, the state government recommended residents and visitors to the state wear face coverings, practice social distance, and limit gatherings. On July 28, 2020, and with a renewal on November 1, 2020, all individuals in the state of Georgia with a positive or suspected COVID-19 diagnosis should isolate until their infectious period is over, and those exposed to the virus should comply with a 14-day quarantine.[5] As the COVID-19 epidemic in Georgia continues, it is important to quantify the epidemiologic characteristics of COVID-19 so that we may formulate policies and implement interventions to minimize transmission and mortality.

To characterize the transmission potential of an epidemic, it is necessary to calculate the reproduction number based on the trajectory of the incidence curve.[6] The basic

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Table 1. Control measures announced and implemented by state and local government agencies in the state of Georgia, in Metro Atlanta counties and Dougherty County

Location	Date (mo/d/y)	Implemented measures
State of Georgia[5]	3/23/20	Executive order declared to limit physical interactions, including shelter-in-place if diagnosed with underlying conditions, bars closed, and no gathering with more than 10 individuals.
	4/2/20	State-wide shelter-in-place order declared.
	4/15/20	State-wide testing required for all symptomatic individuals (referral is still needed).
	4/27/20	Businesses in the state allowed to start opening according to social distancing and prevention measures.
	7/28/20	All positive or suspected COVID-19 cases should isolate until their infectious period is over, and those exposed to the virus should comply with a 14-d quarantine.
	11/1/20	Positive cases should isolate until their infectious period is over. Suspected cases should comply with a 14-d quarantine.
Bartow County[35]	3/20/20	State of emergency declared by county officials.
	3/26/20	Follow-up on the state government order to limit public gatherings to 10 people: restaurants available only for takeout or delivery, and establishments that require physical contact will be closed.
Butts County[36]	3/24/20	County declared under state of emergency. Limit public gatherings to 10 people, restaurants available for takeout or delivery only, and establishments that require physical contact will be closed.
Carroll County	3/22/20	Shelter-in-place order for the county. No public gatherings of more than 10 people, and food will be sold as takeout or delivery.[37]
	3/26/20	Citizens should stay home, and gatherings of any size are prohibited.[38]
Catoosa County[39]	3/23/20	Follow-up on state government order to limit public gatherings to 10 people: restaurants available for takeout or delivery only, and establishments that require physical contact will be closed.
Chattooga County[40]	3/16/20	Recommendation made to cancel events and large gatherings of more than 50 people, and to maintain physical distance of 6 feet.
Cherokee County[41]	3/25/20	Local state of emergency declared. Limit public gatherings to 10 people. Restaurants available for takeout or delivery only. Individuals of at-risk groups should shelter-in-place; those with a positive diagnosis will stay quarantined in their house.
Clayton County[42]	3/13/20	Citizens encouraged to avoid public gatherings and public events.
	3/24/20	State of emergency amended to include limiting gatherings to 10 individuals.
Cobb County[43]	3/24/20	State of emergency declared according to the state-level ordinance to emphasize social distancing. Essential business will open from 6 am to 9 pm; no dine-in services will be available.
Coweta County[44]	3/26/20	State of emergency declared according to the state-level ordinance to emphasize social distancing and voluntary shelter at home. No dine-in services will be available.
DeKalb County[45]	3/23/20	Gatherings of 10 or more people prohibited; citizens will shelter-in-place; curfew established from 9 pm to 6 am; playgrounds, parks, and gyms will remain closed; and food services will be delivery or takeout only.
Dougherty County[46]	3/21/20	Shelter-in-place order declared. Nonessential activities will be canceled. Restaurants will provide drive-through, pickup/curbside, and delivery services.
Douglas County[47]	3/23/20	Shelter-in-place order declared for county residents. Public gatherings of more than 10 are prohibited, and restaurants will be available for takeout or delivery only.
Fayette County[48]	4/1/20	Public gatherings of 10 or more are prohibited. Restaurants will only provide curbside, takeout, or delivery services.
	4/8/20	Shelter-in-place declared in compliance with state-level ordinance.

(continued on following page)

Table 1. Control measures announced and implemented by state and local government agencies in the state of Georgia, in Metro Atlanta counties and Dougherty County (continued)

Location	Date (mo/d/y)	Implemented measures
Forsyth County[49]	3/18/20	Public gatherings of 10 or more are prohibited.
Fulton County[50]	3/18/20	Senior centers, art centers, and libraries will be closed to the public.
	3/24/20	All libraries will be closed to the public.
	3/24/20	Maintain less than 10 people in 1 location, restaurants will not have dine-in services, and residents must stay at home.
	4/8/2020	Follow-up on statewide judicial emergency: services and hearings suspended.
Hall County[51]	3/13/20	Libraries and parks in the county will be closed.
	3/19/20	Commissioners place a stay-at-home mandate.
	3/24/020	Closure of dine-in services mandated.
Haralson County[52]	3/25/20	Shelter-in-place order declared and public gatherings prohibited. Travel for essential activities only.
Heard County[53]	3/26/20	Shelter-in-place order made official.
Henry County[54]	4/1/20	Shelter-in-place order declared for county residents. Public gatherings of more than 10 are prohibited. Restaurants will be available for takeout or delivery only.
Jasper County[55]	3/26/20	Curfew mandated from 10 pm to 6 am. Public gatherings of 10 or more are prohibited. Restaurants will provide curbside, takeout, or delivery only.
Lamar County[56]	4/3/20	Shelter-in-place order mandated by county government.
Meriwether County[57]	3/20/20	State of emergency declared by county officials. Curfew from 9 pm to 6 am.
	3/24/20	Public gatherings of 10 or more are prohibited. Restaurants will provide curbside, takeout, or delivery services only. Businesses for which physical interaction is needed will be closed. Curfew is imposed from 9 pm to 6 am.
Newton County[58]	3/31/20	Shelter-in-place order mandated for county residents. Public gatherings of more than 10 are prohibited. Restaurants available for takeout or delivery services only.
Paulding County[59]	3/26/20	Persons showing symptoms shall refrain from entering public buildings. Restaurants will refrain from providing dine-in services. Nonessential businesses will remain closed. No gatherings of more than 10 people are permitted.
Pickens County[60]	3/24/20	Residents must shelter in their homes. All gatherings are suspended. All travel is limited to essential travel needs.
Walton County[61]	3/26/20	Public gatherings of 10 or more are prohibited. Restaurants will provide curbside, takeout, or delivery services only.

Note that most of these control measures began to be implemented the day after the announcement. For example, Georgia's state-wide shelter-in-place was announced on April 2, 2020 to be implemented on April 3, 2020.

reproduction number, R_0, is the average number of secondary cases that 1 primary case can generate in a completely susceptible population in the absence of behavioral changes or public health interventions.[6] The estimated values of R_0 for SARS-CoV-2 vary across geographic locations. An early study of the epidemic in Wuhan reported an R_0 value of 2.2, assuming a serial interval of 7.5.[7] A more recent study of the epidemic in China, adjusted for the changing case definition, estimated an R_0 value of 1.8 to 2.0 (assuming a serial interval of 7.5) or 1.4 to 1.5 (assuming a serial interval of 4.7).[8] Assuming a serial interval of 4.4, our analysis of confirmed COVID-19 cases in Iran estimated the mean R_0 value as 3.5 or 4.4, depending on the statistical method chosen.[9]

In contrast, the time-varying reproduction number, R_t, is a time-dependent estimate of the secondary cases that arise from 1 case at time t, when depletion of the susceptible population, behavioral changes, and measures to control transmission of disease have taken place.[10,11] As with R_0, if $R_t > 1$, it indicates there is sustainable transmission in the population. When $R_t < 1$, disease transmission cannot be sustained, and it is used as an indication of the effectiveness of infection control measures.[6,10]

Various statistical methods have been proposed to estimate R_t. Their strengths and weaknesses have been recently assessed by researchers who compared the performance of different methods using synthetic epidemic data[12,13] and observed COVID-19 incidence data.[14] We chose to use

an oft-used method, known as the instantaneous reproduction number method, as implemented in the R package *EpiEstim* version 2.2-3 (R Version 1.2.5033 Windows NT 10.0; R Core Team, Vienna, Austria).[10,11] This Bayesian method provides an estimate of the average R_t over a short time window specified by the user (in our study, a 7-day window that ends at time t). It treats the fluctuation in incidence data as signals of an increasing or decreasing reproduction number. This method has been used to estimate COVID-19 R_t values in jurisdictions such as mainland China,[15] Hong Kong,[16] Iran,[17] South Korea,[18] Italy,[19] Nigeria,[20] and Switzerland.[21]

Our study aimed to estimate R_t for COVID-19 in Georgia, urban Metro Atlanta counties, and rural Dougherty County and its surrounding counties, analyzing data from March 2, 2020, through November 20, 2020, as the state incrementally implemented and then relaxed social distancing interventions (Table 1).

METHODS

This study uses data from the COVID-19 pandemic, March 2, 2020 to November 20, 2020, in the state of Georgia, all Metro Atlanta counties (Supplemental Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12[a]), and Dougherty County and its surrounding counties. Metro Atlanta is defined by the US Office of Management and Budget as the "Atlanta-Sandy Springs-Alpharetta, Georgia Metropolitan Statistical Area."[22] The list of Metro Atlanta counties is provided in Table 2.

Data Acquisition

We downloaded the cumulative data of confirmed cases on November 21, 2020. The analyzed data set includes the cumulative incidence reports from March 2, 2020, to November 20, 2020, for the entire state of Georgia and its counties from the *New York Times* GitHub data repository.[23] *New York Times* GitHub data are published by date of report. To account for the median number of days from SARS-CoV-2 symptom onset to the day of testing among positive cases (approximately 3 days), and time from exposure to the virus to symptom onset (approximately 6 days), we corrected the day of report by a total of 9 days to estimate the assumed date of infection for every jurisdiction included in this study (Supplemental Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22[a]).[12,24] The first case in Georgia was reported on March 2, 2020, and the assumed date of infection was estimated as February 22, 2020.[23] Our cutoff point for all jurisdictions was the date of report of November 20, 2020, 6 days before Thanksgiving Day and 18 days after the presidential elections in the US. We verified the numbers with official statistical reports from the Georgia Department of Public Health.[1] If any inconsistencies were found, the numbers from the Georgia Department of Public Health were used as the standard. We searched the local government web pages to verify whether any control measures were established. Such information is presented in Table 1.

Statistical Analyses

The R_t value was estimated using the R package *EpiEstim*. The R_t estimate is also known as an instantaneous reproduction number.[11] For this analysis, we implemented the R_t estimate measure as defined by Cori et al[11] as the ratio between I_t, the number of incident cases at time t, to Λ_t, the total infectiousness of all the infected individuals at time t (see Supplemental Materials[a] for details).

The R_t estimate reported here is an average of the estimate over 7 days before time t. Using a Bayesian framework with a gamma-distributed prior for $R_{t,\tau}$, Cori et al derived an analytical expression of the posterior distribution of R_t and thus estimated its median, the variance, and the 95% credible interval (CrI).[11] In our study, the data were analyzed using *EpiEstim* version 2.2-3[10,11] (R Core Team).

Sensitivity Analysis

We performed a sensitivity analysis, assuming that asymptomatic infections account for 10% of all infections respectively. This is the lower bound estimate presented in the Centers for Disease Control and Prevention's pandemic planning scenario web page,[24] and it is an approximate of the lower 95% confidence interval bound estimated by Byambasuren et al.[25] We multiplied the daily case count by 0.11 and then repeated the R_t estimation. The sensitivity analysis results are discussed in the Supplemental Materials.[a]

Ethics

The Georgia Southern University Institutional Review Board made a nonhuman subjects determination for this project (H20364) under the G8 exemption category.

RESULTS

Community transmission of SARS-CoV-2 remained ongoing in Georgia based on incidence data by assumed date of infection from February 22, 2020, to November 11, 2020 (date of report: March 2, 2020–November 20, 2020). As of November 11, 2020, the median *EpiEstim* R_t estimate was 1.03 (95% CrI: 1.03, 1.03). The same results were observed for Metro Atlanta, with an R_t estimate equal to 1.03 (95% CrI: 1.03, 1.03). The transmission may have been under control for Dougherty County, with the R_t estimate being 1.01 (95% CrI: 1.00, 1.02) (Table 2).

As social distancing measures unfolded and then relaxed in Georgia during our study period, the median

Table 2. Estimates for the time-varying reproduction number, R_t, for the state of Georgia, Metro Atlanta counties, Dougherty County, and counties surrounding Dougherty County, using the instantaneous reproduction number method as implemented in the R package *EpiEstim*

Location	Assumed date of infection of the first reported case (mo/d/y)	As of 6/5/20		As of 11/11/20	
		Median R_t (2.5%, 97.5% quantiles)	Mean R_t (standard deviation)	Median R_t (2.5%, 97.5% quantiles)	Mean R_t (standard deviation)
Georgia	2/22/20	1.14 (1.11, 1.17)	1.14 (0.02)	1.03 (1.03, 1.03)	1.03 (0.001)
Metro Atlanta	2/22/20	1.02 (0.98, 1.06)	1.02 (0.02)	1.03 (1.03, 1.03)	1.03 (0.001)
Dougherty	3/6/20	1.03 (0.72, 1.41)	1.04 (0.18)	1.01 (1.00, 1.02)	1.01 (0.01)
Baker	3/15/20	1.00 (0.88, 1.13)	1.00 (0.06)	1.02 (0.95, 1.09)	1.02 (0.04)
Bartow	3/2/20	0.73 (0.46, 1.08)	0.74 (0.16)	1.04 (1.03, 1.05)	1.04 (0.01)
Butts	3/13/20	0.47 (0.11, 1.27)	0.53 (0.30)	1.03 (1.01, 1.06)	1.03 (0.01)
Calhoun	3/17/20	1.05 (0.99, 1.11)	1.05 (0.03)	0.99 (0.95, 1.04)	0.99 (0.02)
Carroll	3/11/20	0.89 (0.63, 1.22)	0.90 (0.15)	1.04 (1.03, 1.06)	1.04 (0.01)
Cherokee	2/28/20	1.06 (0.83, 1.33)	1.07 (0.13)	1.05 (1.04, 1.06)	1.05 (0.004)
Clayton	3/6/20	1.06 (0.79, 1.16)	1.07 (0.10)	1.03 (1.02, 1.03)	1.03 (0.003)
Cobb	2/27/20	1.15 (1.03, 1.27)	1.15 (0.06)	1.03 (1.03, 1.04)	1.03 (0.002)
Coweta	3/5/20	1.00 (0.75, 1.31)	1.01 (0.14)	1.04 (1.03, 1.05)	1.04 (0.01)
Dawson	3/11/20	0.94 (0.36, 1.93)	0.99 (0.41)	1.03 (1.01, 1.06)	1.03 (0.01)
DeKalb	2/29/20	0.97 (0.86, 1.08)	0.97 (0.06)	1.01 (1.00, 1.02)	1.01 (0.006)
Douglas	3/11/20	1.10 (0.85, 1.40)	1.11 (0.14)	1.03 (1.02, 1.04)	1.03 (0.005)
Fayette	2/29/20	1.15 (0.68, 1.79)	1.17 (0.28)	1.04 (1.02, 1.05)	1.04 (0.007)
Forsyth	3/7/20	1.10 (0.82, 1.43)	1.10 (0.16)	1.04 (1.03, 1.05)	1.04 (0.005)
Fulton	2/22/20	0.94 (0.83, 1.05)	0.94 (0.06)	1.03 (1.02, 1.03)	1.03 (0.002)
Gwinnett	2/27/20	1.05 (0.97, 1.12)	1.05 (0.04)	1.03 (1.02, 1.03)	1.03 (0.002)
Hall	3/7/20	0.96 (0.81, 1.13)	0.96 (0.08)	1.02 (1.01, 1.03)	1.02 (0.004)
Haralson	3/17/20	0.90 (0.35, 1.85)	0.95 (0.39)	1.08 (1.06, 1.10)	1.08 (0.02)
Heard	3/11/20	1.44 (0.65, 2.71)	1.50 (0.53)	1.04 (1.00, 1.09)	1.04 (0.02)
Henry	3/4/20	1.16 (0.93, 1.43)	1.17 (0.13)	1.03 (1.03, 1.04)	1.03 (0.004)
Jasper	3/15/20	0.89 (0.42, 1.62)	0.93 (0.31)	1.05 (1.01, 1.08)	1.05 (0.02)
Lamar	3/11/20	0.68 (0.20, 1.63)	0.74 (0.37)	1.04 (1.01, 1.07)	1.04 (0.02)
Lee	3/2/20	1.01 (0.97, 1.05)	1.01 (0.02)	1.02 (1.00, 1.05)	1.02 (0.01)
Meriwether	3/15/20	1.07 (0.66, 1.61)	1.08 (0.24)	1.01 (0.99, 1.04)	1.01 (0.01)
Mitchell	3/15/20	1.01 (0.98, 1.05)	1.01 (0.02)	1.01 (0.99, 1.04)	1.01 (0.01)
Morgan	3/14/20	1.05 (0.15, 3.50)	1.25 (0.89)	1.03 (1.00, 1.06)	1.03 (0.01)
Newton	3/6/20	0.91 (0.61, 1.31)	0.92 (0.18)	1.03 (1.02, 1.04)	1.03 (0.01)
Paulding	3/7/20	1.15 (0.87, 1.49)	1.16 (0.16)	1.04 (1.03, 1.05)	1.04 (0.01)
Pickens	3/11/20	1.48 (0.83, 2.40)	1.51 (0.40)	1.06 (1.04, 1.08)	1.06 (0.01)
Pike	3/19/20	1.11 (0.52, 2.01)	1.15 (0.38)	1.04 (1.02, 1.07)	1.04 (0.01)
Rockdale	3/10/20	1.18 (0.82, 1.63)	1.19 (0.21)	1.03 (1.01, 1.04)	1.03 (0.01)
Spalding	3/11/20	1.04 (0.66, 1.56)	1.06 (0.23)	1.03 (1.01, 1.05)	1.03 (0.01)
Terrell	3/11/20	1.00 (0.95, 1.05)	1.00 (0.03)	1.01 (0.98, 1.04)	1.01 (0.02)
Walton	3/19/20	0.81 (0.54, 1.17)	0.82 (0.16)	1.02 (1.00, 1.05)	1.02 (0.01)
Worth	3/11/20	1.06 (1.01, 1.11)	1.06 (0.02)	1.10 (1.03, 1.17)	1.10 (0.03)

The analysis used a serial interval following a gamma distribution with a mean of 4.60 days and a standard deviation of 5.55 days, with $\alpha = 0.05$. Data were analyzed with 2 cutoff points: the dates of report of June 14, 2020, and November 20, 2020 (ie, the assumed date of infection of June 5, 2020, and November 11, 2020).

EpiEstim R_t estimate in Georgia dropped from 1.14 (95% CrI: 1.11, 1.17) on June 14, 2020 to 1.03 (95% CrI: 1.03, 1.03) until November 11, 2020, as the assumed date of infection. The median R_t estimate fluctuated around 1 from mid-March to November 11, 2020 (Figure 1).

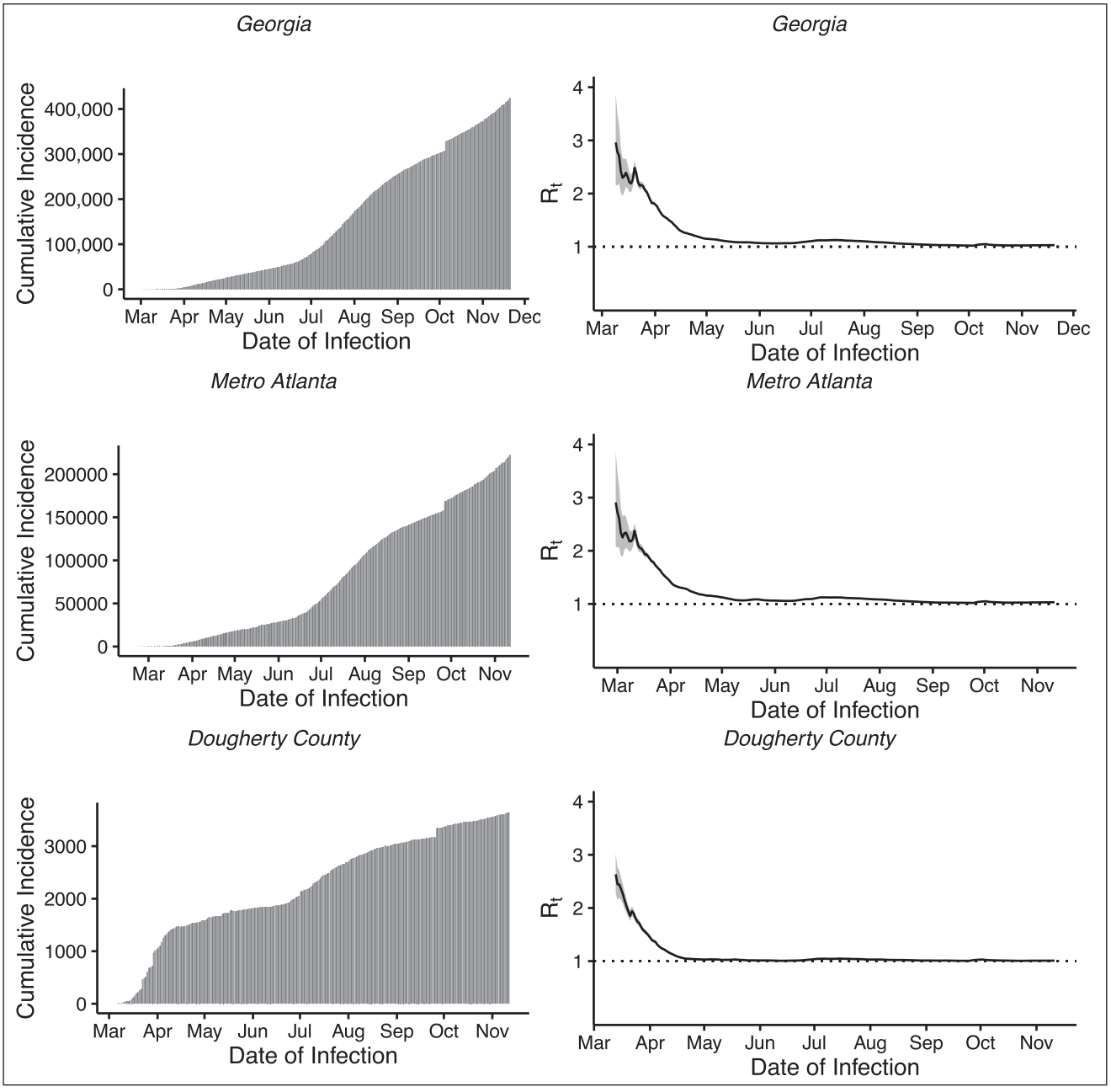

Figure 1. Comparison between incidence by assumed date of infection and time-varying reproduction numbers (R_t) for Georgia, Metro Atlanta, and Dougherty County, USA, February 22, 2020 to November 11, 2020 (assumed date of infection), estimated using the instantaneous reproduction number method implemented in the *EpiEstim* package.

Regarding Metro Atlanta (Figure 1), the *EpiEstim* R_t estimate fluctuated above 1.5 before the end of March and gradually decreased to around 1 by May through November 11. The R_t estimates for each of the Metro Atlanta counties fluctuated around 1 during our study period (Table 2, Supplemental Figures 2, 3, 4, 5, and 6[a]).

For Dougherty County (Figure 1), we observed a speedy decline in *EpiEstim* R_t estimates from around 2 in mid-March to around 1 in mid-April; these values were maintained around 1 up to November 11, 2020, when the mean R_t estimate was observed at 1.01 (95% CrI: 1.00, 1.02). This finding was driven primarily by the early epidemic observed in Dougherty County, where large clusters

of cases were infected via 2 funerals that happened to be superspreading events.[26] On March 13, 2020, the mean R_t estimate for Dougherty County was 2.63 (CrI: 2.27, 3.02). Counties surrounding Dougherty (Baker, Calhoun, Lee, Mitchell, Terrell, and Worth counties) presented mean *EpiEstim* R_t estimates around 2.00, as its outbreak developed (Figure 2, Supplemental Figure 1[a]). It was observed that the surrounding counties around Dougherty also obtained mean R_t estimates reaching 2 in all of them, except for Baker County, which had the greatest R_t median estimate of 1.78 (CrI: 1.14, 2.56) for March 26, 2020 (Figure 2). A week after the first case was reported in Dougherty County, Calhoun, Mitchell, Terrell, and Worth counties presented estimates greater than 2 (Table 3). The R_t median estimates decreased to near 1.00 up to November 11, with the exception of Calhoun County, which presented a median point estimate of 0.99 (95% CrI: 0.95, 1.04) (Table 2).

DISCUSSION

Community transmission of SARS-CoV-2 remained ongoing in Georgia as of November 11, 2020 (ie, approximately 3 weeks after the presidential election). On April 27, after implementing strict social distancing measures, Georgia reopened some sectors of the economy, with specific guidelines pertinent to social distancing.[4] As the economy slowly reopened and unprotected social mixing increased, and events such as the presidential election occurred, an increase in the daily number of new confirmed cases was observed starting in June and continuing until November (study period) as SARS-CoV-2 transmission continued unabated.[1] Our study documents the decrease in R_t following social distancing interventions in Georgia and provides further evidence that social distancing measures remained important to keep COVID-19 under control. Our findings are supported by the analysis of Lau et al (2020), in which they also registered a decreased in the effective reproductive number for Dougherty County after the shelter-in-place order was mandated, with estimates decreasing from 5.19 (95% CrI: 5.01, 5.31) to less than 1, and then fluctuating around 1 weeks later.[27]

Furthermore, many residents in both rural and urban Georgia are medically vulnerable. A recent analysis by The Surgo Foundation[28] estimated the COVID-19 community vulnerability index for Dougherty County, by combining epidemiologic risk factors for infection and sociodemographic factors, at very high levels (COVID-19 community vulnerability index = 0.87) when compared with counties in Metro Atlanta (Fulton county's COVID-19 community vulnerability index = 0.42). The *EpiEstim* R_t estimates for Dougherty County fluctuated near 1 since April, with a slight increase near August and then continuing to fluctuate near 1 up to November 11, 2020.

The relaxation of social distancing measures should be implemented with an abundance of caution because of the population's vulnerability. With the mean R_t estimates in Georgia and almost all counties included in our study remaining near 1 for more than 6 months, we believe that mandating nonpharmaceutical interventions, such as wearing facemasks when outdoors,[29] could help decrease the mean R_t estimates even more. Another important factor for consideration is access to health care and surge capacity in hospitals, especially in rural Georgia. The health-care system in Dougherty County was impacted heavily by the surge of COVID-19 patients driven by superspreading events.[26]

Our study evidences the negative effects the superspreading event in Dougherty County caused in surrounding counties. One week after the increase in cases in Dougherty County, neighboring areas showed an increase in their mean R_t estimates. These results reflect local transmission of SARS-CoV-2 in rural areas in Georgia as the epidemic spread from Dougherty County to neighboring counties.

The resumption of economics activities, mobility of young adults, and reopening of educational institutions led to the resurgence of COVID-19 cases in Georgia, as observed in July and August.[30] Further research into the spatiotemporal variation of SARS-CoV-2 transmission potential, and its association with economic and medical vulnerability will shed light on the disease and economic burden of COVID-19 in Georgia.

Our study estimated R_t values using the instantaneous reproduction number method implemented in the R package *EpiEstim*.[10,11] The *EpiEstim* estimate is sensitive to fluctuation in daily incident case counts as the instantaneous reproduction number method treats such changes as meaningful signals reflecting genuine increases or decreases in transmission potential. The instantaneous reproduction number method in the *EpiEstim* package can be used if the purpose is to identify time-dependent changes in the R_t estimate that reflect the implementation or relaxation of social distancing measures over time. However, cautious interpretation is needed, especially at the beginning of the outbreak, as the case count was small and the R_t estimate was unstable.

Regarding the time window chosen for *EpiEstim*, we used a window of 7 days in our analysis. We did not use a window of < 7 days, because a weekend effect was observed in the data (ie, the daily number of cases reported during the weekend was consistently less than those reported during the weekdays before or after the weekend).

Limitations

Our study is limited by several factors. First, we used the *New York Times* data set, in which data were recorded by

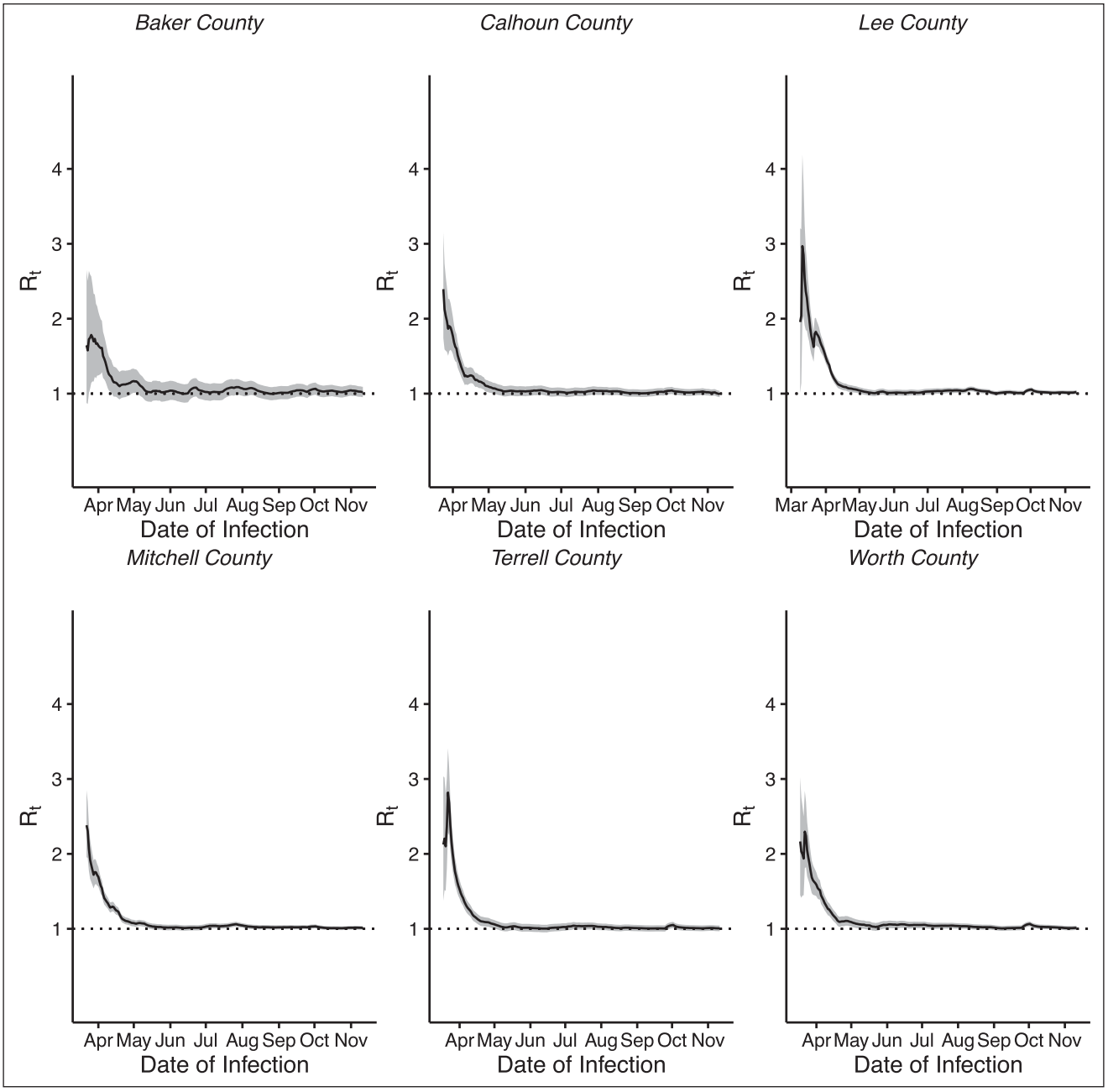

Figure 2. Comparison between time-varying reproduction numbers (R_t) for counties surrounding Dougherty County, USA, February 22, 2020 to November 11, 2020 (assumed date of infection), estimated using the instantaneous reproduction number method implemented in the *EpiEstim* package.

reported date and not by day of symptom onset. However, we implemented a date correction of 9 days to account for the period of date of infection and date of testing.[24]

Second, our data do not differentiate between imported and community transmission cases. Although this distinction was important during the early stage of the epidemic, community transmission has been responsible for the majority of cases since April, and thus this absence of such distinction in our data does not affect our R_t estimate substantially since April.

Third, the data used here are an aggregated number of reported cases that do not distinguish different types of local transmission. Transmission in congregate facilities, such as long-term care facilities,[31] correctional facilities,[32] and factories,[33] may show dynamics that are different from community transmission in noncongregate settings.

Table 3. Estimates for the time-varying reproduction number, R_t, for the first weeks of the pandemic for Dougherty County and its surrounding counties, using the instantaneous reproduction number method as implemented in the R package *EpiEstim*

County	Start date by assumed date of infection (mo/d/y)	End date by assumed date of infection (mo/d/y)	Median R_t (2.5%, 97.5% quantiles)
Dougherty	3/7/20	3/13/20	2.63 (2.27, 3.02)
	3/8/20	3/14/20	2.45 (2.15, 2.76)
	3/9/20	3/15/20	2.44 (2.19, 2.71)
	3/10/20	3/16/20	2.35 (2.14, 2.57)
	3/11/20	3/17/20	2.26 (2.08, 2.44)
	3/12/20	3/18/20	2.14 (1.99, 2.29)
	3/13/20	3/19/20	2.03 (1.90, 2.16)
	3/14/20	3/20/20	1.94 (1.82, 2.05)
	3/15/20	3/21/20	1.85 (1.75, 1.95)
	3/16/20	3/22/20	1.94 (1.85, 2.03)
	3/17/20	3/23/20	1.89 (1.81, 1.98)
	3/18/20	3/24/20	1.80 (1.73, 1.87)
Baker	3/16/20	3/22/20	1.64 (0.88, 2.65)
	3/17/20	3/23/20	1.58 (0.86, 2.50)
	3/18/20	3/24/20	1.73 (1.01, 2.64)
	3/19/20	3/25/20	1.75 (1.07, 2.59)
	3/20/20	3/26/20	1.78 (1.14, 2.56)
	3/21/20	3/27/20	1.75 (1.16, 2.46)
	3/22/20	3/28/20	1.70 (1.16, 2.33)
	3/23/20	3/29/20	1.73 (1.23, 2.32)
	3/24/20	3/30/20	1.66 (1.20, 2.20)
	3/25/20	3/31/20	1.67 (1.24, 2.17)
Calhoun	3/18/20	3/24/20	2.39 (1.74, 3.15)
	3/19/20	3/25/20	2.12 (1.59, 2.73)
	3/20/20	3/26/20	2.04 (1.57, 2.56)
	3/21/20	3/27/20	1.97 (1.56, 2.43)
	3/22/20	3/28/20	1.87 (1.51, 2.26)
	3/23/20	3/29/20	1.9 (1.57, 2.26)
	3/24/20	3/30/20	1.88 (1.59, 2.21)
	3/25/20	3/31/20	1.83 (1.57, 2.12)
Lee	3/3/20	3/9/20	1.96 (1.01, 3.21)
	3/4/20	3/10/20	2.04 (1.14, 3.19)
	3/5/20	3/11/20	2.97 (1.96, 4.19)
	3/6/20	3/12/20	2.85 (2.04, 3.80)
	3/7/20	3/13/20	2.54 (1.91, 3.27)
	3/8/20	3/14/20	2.37 (1.85, 2.95)
	3/9/20	3/15/20	2.28 (1.84, 2.77)
	3/10/20	3/16/20	2.13 (1.76, 2.53)
	3/11/20	3/17/20	2.02 (1.70, 2.36)
	3/12/20	3/18/20	1.87 (1.60, 2.17)
	3/13/20	3/19/20	1.77 (1.53, 2.03)
	3/14/20	3/20/20	1.70 (1.48, 1.94)

(continued on following page)

Table 3. Estimates for the time-varying reproduction number, R_t, for the first weeks of the pandemic for Dougherty County and its surrounding counties, using the instantaneous reproduction number method as implemented in the R package *EpiEstim* (continued)

County	Start date by assumed date of infection (mo/d/y)	End date by assumed date of infection (mo/d/y)	Median R_t (2.5%, 97.5% quantiles)
Mitchell	3/16/20	3/22/20	2.38 (1.96, 2.85)
	3/17/20	3/23/20	2.31 (1.94, 2.70)
	3/18/20	3/24/20	2.07 (1.77, 2.39)
	3/19/20	3/25/20	1.92 (1.67, 2.19)
	3/20/20	3/26/20	1.85 (1.63, 2.09)
	3/21/20	3/27/20	1.78 (1.58, 2.00)
	3/22/20	3/28/20	1.72 (1.54, 1.91)
	3/23/20	3/29/20	1.76 (1.59, 1.93)
	3/24/20	3/30/20	1.75 (1.60, 1.92)
	3/25/20	3/31/20	1.72 (1.58, 1.86)
Terrell	3/12/20	3/18/20	2.12 (1.37, 3.03)
	3/13/20	3/19/20	2.20 (1.52, 3.02)
	3/14/20	3/20/20	2.10 (1.51, 2.79)
	3/15/20	3/21/20	2.36 (1.80, 3.00)
	3/16/20	3/22/20	2.82 (2.28, 3.41)
	3/17/20	3/23/20	2.68 (2.25, 3.15)
	3/18/20	3/24/20	2.38 (2.05, 2.74)
	3/19/20	3/25/20	2.16 (1.89, 2.45)
	3/20/20	3/26/20	2.01 (1.78, 2.26)
	3/21/20	3/27/20	1.88 (1.68, 2.09)
	3/22/20	3/28/20	1.77 (1.59, 1.95)
	3/23/20	3/29/20	1.70 (1.54, 1.87)
Worth	3/12/20	3/19/20	2.17 (1.45, 3.02)
	3/13/20	3/20/20	2.03 (1.41, 2.76)
	3/14/20	3/21/20	2.00 (1.44, 2.63)
	3/15/20	3/22/20	1.94 (1.45, 2.50)
	3/16/20	3/23/20	2.30 (1.81, 2.84)
	3/17/20	3/24/20	2.24 (1.82, 2.70)
	3/18/20	3/25/20	2.05 (1.70, 2.43)
	3/19/20	3/26/20	1.95 (1.65, 2.28)
	3/20/20	3/27/20	1.87 (1.60, 2.16)
	3/21/20	3/28/20	1.77 (1.54, 2.02)
	3/22/20	3/29/20	1.69 (1.48, 1.91)
	3/23/20	3/30/20	1.65 (1.46, 1.85)

The analysis used a serial interval following a gamma distribution with a mean of 4.60 days and a standard deviation of 5.55 days, with $\alpha = 0.05$.

Fourth, cases may be underreported as a result of limited testing capacity, or they may be mild or asymptomatic cases. Testing capacity was expanded in March and April, and it has been stable since then. Thus, variation in case numbers and R_t estimates should reflect changing transmission dynamics and not changes in testing capacity. Meanwhile, the degree to which asymptomatic transmission has changed over time cannot be estimated using our data. Age distribution of cases has changed over time and may reflect a changing fraction of asymptomatic cases among all infections.

Fifth, our analysis is right-censored by November 20, 2020 (date of report), and sixth, the observed fluctuations in the R_t estimates, could be a result of low case numbers reported that could result in unstable estimates. Future studies can extend the analysis further as the pandemic progresses.

Seventh, in addition to the method used here, there are other statistical methods that estimate R_t[12,13] (eg, the case reproduction number method as proposed by Wallinga and Teunis[34]). However, the case reproduction number method

estimates the transmission potential of time t using the number of cases observed after time t and does not meet the need of this study because we attempted to estimate R_t up to the nearest possible time.

CONCLUSION

The R_t estimate of SARS-CoV-2 has been fluctuating around 1 for Georgia, Metro Atlanta, and Dougherty County and its neighboring counties since the Georgia economy reopened in late-April 2020. Social distancing and other personal protective behavior (such as face coverings) appear to keep the SARS-CoV-2 transmission potential at a reduced level. Government agencies should weigh carefully the next steps of their COVID-19 response plans for their communities, considering ongoing transmission across Georgia and the potential surge after the holiday season. ❖

Supplemental Material

[a]*Supplemental Material is available at: www.thepermanentejournal.org/files/2021/20.232supp.pdf*

Disclosure Statement

The authors have no conflicts of interest to disclose.

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Authors' Contributions

Kamalich Muniz-Rodriguez, DrPH, and Gerardo Chowell, PhD, contributed equally as first coauthors. Kamalich Muniz-Rodriguez, DrPH, participated in conceptualization, data curation, formal analysis, validation, visualization, writing of the original draft, and manuscript review and editing. Gerardo Chowell, PhD, participated in conceptualization, data curation, funding acquisition, methodology, resources, supervision, validation, visualization, writing of the original draft, and manuscript review and editing. Jessica S Schwind, PhD, participated in data curation and manuscript review and editing. Randall Ford, DDS, Sylvia K Ofori, MPH, Chigozie A Ogwara, BS, Margaret R Davies, BS, Terrence Jacobs, BS, and Chi-Hin Cheung, MS, participated in data curation. Logan T Cowan, PhD, and Andrew R Hansen, DrPH, participated in data curation and manuscript review and editing. Isaac Chun-Hai Fung, PhD, participated in conceptualization, formal analysis, funding acquisition, methodology, project administration, resources, supervision, validation, visualization, writing of the original draft, and manuscript review and editing.

Note from Isaac Chun-Hai Fung, PhD: I have a team of colleagues and students who collected COVID-19 data manually, before the New York Times *made their COVID-19 data set publicly available. My team of data curators are all included as coauthors, given their time and efforts contributed to the project that eventually takes shape in its current form.*

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Disclaimer

The opinions expressed in this paper do not necessarily represent the official positions of the Centers for Disease Control and Prevention or the US government.

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