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The Reproductive Number of SARS-CoV-2 in Cochise County AZ: A Stratified Review

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COVID-19 has affected many people's lives around the globe in 2020, but the rate at which the virus is spread varies depending on many factors including geographic location and social distancing policies. Understanding the basic reproductive number (R_0) for COVID-19 can help locate hot spots where viral transmission is most high, helping public health leaders to know the extent of an epidemic in their community and where to focus intervention efforts. Data reported to the Arizona Department of Health Services on COVID-19 case numbers in Cochise County from March through November 2020 were analyzed to determine the R_0 on a county level and individual city level. R_0 was also calculated for pre-Arizona economic shutdown orders, during the Arizona shutdown, over the summer, while schools were reopening, and during the fall season. On a county level, the mean R_0 for Cochise County was 1.04, ranging from a max R_0 of 2.00 on some days to a min of 0.47 on other days. Sierra Vista had the highest individual city mean R_0 of 1.14, ranging from a max of 2.20 to a min of 1.00 during the year.

Introduction

COVID-19 (Coronavirus Disease 2019) is an illness caused by the severe acute respiratory coronavirus 2 (SARS-CoV-2). First discovered in Wuhan City, China in December 2019, it has caused the fifth worldwide pandemic since the flu pandemic of 1918 (Liu et al., 2020). One important metric for understanding the transmissibility or contagiousness of viruses is R_0, the basic reproductive number (Delamater et al., 2019). Essentially, the R_0 value equates to the additional cases that will arise in a susceptible population after contact with one infectious case (Dietz, 1993). If $R_0 > 1$, the virus is expected to spread. If $R_0 < 1$, the virus is expected to eventually disappear (Delamater et al., 2019).

R_0 can vary though if pathogen transmission is affected by social, behavioral, environmental, or biological factors; it can vary over time and location (Delamater et al., 2019). For this reason, although it may be beneficial to get an overall mean of R_0 across large geographical areas, it is also important to focus in on specific communities to locate hot spots where intervention efforts should be centered. Furthermore, it would also prove beneficial to look at how R_0 changes by month or timespan. Doing so will help to understand what interventions may work to prevent the continued spread of the infectious agent.

There have been many statistical models generated to predict R_0, though each have their benefit and limitations. The gold standard for calculating R_0 is an individual-level model through effective contact tracing where close contacts of an infectious individual are recorded (Pandit,

2020). The number of the number of secondary (tertiary, etc.) cases are then averaged. However, this method has its limitations where contact tracing fails to record information on all close contacts either due to interviewer limitations, forgetfulness of the infected case, or inability to contact the case. For this reason, the calculations provided in this paper will follow a population-level model.

Methods

A population-level model is the ratio of the infection rate of a population to the population's recovery rate (Breban et al, 2007). It is an average of the change in infected members of the population from day to day across the timespan of the presence of the virus (Pandit, 2020). In Arizona, COVID-19 cases are first diagnosed by physicians or pharmacists through a series of PCR or antigen tests, which are then reported to the Arizona Department of Health Services (ADHS) and local county health departments. Members of the county health department COVID-19 Case Investigations Team then contact these diagnosed cases to provide information, conduct contact tracing, and note final disposition status of the case (e.g., survived or died). Information is logged into the ADHS Medical Electronic Disease Surveillance Intelligence System (MEDSIS) for later follow-up or analysis.

This analysis aimed to quantify R_0 based on month and city of Cochise County, Arizona. Furthermore, to gauge the transmission spread during different times of the year, R_0 was also calculated over five different timespan events of the year 2020: from time of first case to March 30th, 2020 (the time of the AZ economic shutdown), the span of the AZ economic shutdown (April 1st – May 15th, 2020), the summer wave of COVID cases (May 16th – July 31st, 2020), the approximate reopening time of Cochise County schools (August – September, 2020), and the fall wave of COVID cases (October – November, 2020). The total R_0 for all of Cochise County was then averaged.

Statistical software used for this analysis was SAS University Edition. COVID-19 case data was exported from MEDSIS and de-identified. Patients that were listed as "not a case" or "suspect" were excluded to promote a confident R_0 value based only on confirmed PCR or probable antigen cases. Test date for confirmed cases were then grouped by month and timeframe of events listed above. Cases were also organized by city of residence, and cases that lived in cities outside of Cochise County were excluded. Frequencies of case diagnosis were then exported to Excel, where rate of infection and rate of recovery were then calculated. The Centers for Disease Control (CDC, 2020) have defined that cases with moderate COVID-19 symptoms may remain infectious for up to 10 days since onset of symptoms. For this analysis, all cases were presumed to be infectious for at least 10 days after symptom onset. Equation 1 illustrates the daily basic R_0 calculation, where β = infection rate and μ = recovery rate. R_0 was then averaged over the course of each month, event, city, and the entire county.

Equation 1: $$R0 = \beta\mu$$

Results

Table 1 presents the total number of confirmed COVID-19 cases in each respective city of Cochise County. For simplicity, analysis of R_0 by city was only analyzed for cities which had 50 or more cases during the timeframe of March 12th, 2020 (date of the first confirmed COVID-19 case in Cochise County) through November 30th, 2020. Table 2 presents the calculated R_0 for Cochise County AZ. Table 3 presents R_0 for Benson, Bisbee, and Douglas AZ, Table 4 presents R_0 for Fort Huachuca, Hereford, and Huachuca City AZ, Table 5 presents R_0 for Naco, Pirtleville, and Sierra Vista AZ, and Table 6 presents R_0 for Willcox AZ. Each table is stratified by month, event, and the year leading up to November 30th. The mean R_0 over these timeframes is presented along with the median, minimum, and maximum daily R_0 values within those corresponding timeframes.

Table 1: Number of COVID-19 cases for each city of Cochise County from March 12th – November 30th, 2020, and their corresponding % of Cochise County cases.

City	Number of COVID-19 Cases	% of all Cochise County Cases
Benson	141	3.43
Bisbee	159	3.87
Bowie	14	0.34
Cochise	17	0.41
Douglas	1992	48.48
Dragoon	5	0.12
Elfrida	29	0.71
Fort Huachuca	65	1.58
Hereford	119	2.90
Huachuca City	51	1.24
McNeal	18	0.44
Naco	92	2.24
Pearce	29	0.71
Pirtleville	93	2.26
Pomerene	3	0.07
Saint David	43	1.05
San Simon	23	0.56
Sierra Vista	738	17.96
Sunsites	2	0.05
Tombstone	21	0.51
Willcox	451	10.98
Winchester Mountains	1	0.02
Unknown City	3	0.07

Table 2: Mean R0 and median, min, and max daily R0 for COVID-19 in Cochise County AZ, stratified by year total through November 30th, 2020, month, and event.

	Mean R0 (SD)	Median R0	Min R0	Max R0
Cochise County				
March 12th – Nov. 30th	1.04 (0.17)	1.01	0.47	2.00
Month				
March	1.15 (0.32)	1.00	1.00	2.00
April	1.00 (0.23)	1.00	0.71	1.86
May	1.11 (0.23)	1.08	0.75	2.00
June	1.05 (0.05)	1.05	0.96	1.14
July	0.98 (0.07)	0.98	0.85	1.17
August	0.97 (0.19)	0.98	0.47	1.74
September	1.02 (0.11)	1.01	0.79	1.27
October	1.05 (0.09)	1.04	0.90	1.34
November	1.05 (0.08)	1.05	0.91	1.27
Event				
Pre-AZ Shutdown	1.15 (0.32)	1.00	1.00	2.00
AZ Shutdown	1.03 (0.25)	1.00	0.71	2.00
1st Wave (Post-AZ Shutdown)	1.04 (0.11)	1.03	0.85	1.70
Back-to-School	1.00 (0.16)	1.00	0.47	1.74
2nd Wave (Fall)	1.05 (0.09)	1.04	0.90	1.34

Abbreviations: (SD) Standard Deviation

Table 3: Mean R0 and median, min, and max daily R0 for COVID-19 in Benson, Bisbee, and Douglas AZ, stratified by year total through November 30th, 2020, month, and event.

		Mean R0 (SD)	Median R0	Min R0	Max R0
Benson					
March 12th – Nov. 30th		1.03 (0.27)	1.00	0.00	3.00
Month					
	March	0.00 (0.00)	0.00	0.00	0.00
	April	0.98 (0.28)	1.00	0.00	2.00
	May	1.04 (0.21)	1.00	0.67	2.00
	June	1.10 (0.23)	1.00	0.80	2.00
	July	0.95 (0.15)	0.95	0.70	1.33
	August	0.97 (0.32)	1.00	0.00	2.00
	September	1.07 (0.42)	1.00	0.50	3.00
	October	1.03 (0.30)	1.00	0.00	2.00
	November	1.08 (0.25)	1.00	0.75	2.00
Event					
	Pre-AZ Shutdown	1.00 (0.00)	1.00	1.00	1.00
	AZ Shutdown	0.99 (0.23)	1.00	0.00	2.00
	1st Wave (Post-AZ Shutdown)	1.03 (0.22)	1.00	0.67	2.00
	Back-to-School	1.02 (0.38)	1.00	0.00	3.00
	2nd Wave (Fall)	1.06 (0.27)	1.00	0.00	2.00
Bisbee					
March 12th – Nov. 30th		1.02 (0.29)	1.00	0.00	3.00
Month					
	March	1.00 (0.00)	1.00	1.00	1.00
	April	0.97 (0.18)	1.00	0.00	1.00
	May	1.07 (0.21)	1.00	1.00	2.00
	June	1.06 (0.46)	1.00	0.00	3.00
	July	0.97 (0.16)	0.95	0.57	1.25
	August	0.90 (0.28)	1.00	0.00	1.25
	September	1.08 (0.26)	1.00	0.80	2.00
	October	1.03 (0.48)	1.00	0.00	3.00
	November	1.08 (0.21)	1.07	0.75	1.63
Event					
	Pre-AZ Shutdown	1.00 (0.00)	1.00	1.00	1.00
	AZ Shutdown	0.98 (0.15)	1.00	0.00	1.00
	1st Wave (Post-AZ Shutdown)	1.04 (0.33)	1.00	0.00	3.00
	Back-to-School	0.99 (0.28)	1.00	0.00	2.00
	2nd Wave (Fall)	1.06 (0.37)	1.00	0.00	3.00
Douglas					
March 12th – Nov. 30th		1.04 (0.27)	1.00	0.00	3.00
Month					
	March	1.13 (0.35)	1.00	1.00	2.00
	April	1.05 (0.47)	1.00	0.50	3.00
	May	1.10 (0.32)	1.00	0.00	2.00
	June	1.06 (0.11)	1.04	0.93	1.46
	July	0.98 (0.09)	0.98	0.81	1.26
	August	0.97 (0.32)	0.99	0.35	2.44
	September	1.05 (0.29)	1.00	0.46	1.75
	October	1.08 (0.14)	1.05	0.79	1.50
	November	1.05 (0.10)	1.03	0.89	1.40
Event					
	Pre-AZ Shutdown	1.13 (0.35)	1.00	1.00	2.00
	AZ Shutdown	1.05 (0.45)	1.00	0.00	3.00
	1st Wave (Post-AZ Shutdown)	1.04 (0.14)	1.02	0.81	1.75
	Back-to-School	1.01 (0.30)	1.00	0.35	2.44
	2nd Wave (Fall)	1.06 (0.12)	1.04	0.79	1.50

Abbreviations: (SD) Standard Deviation

Table 4: Mean R0 and median, min, and max daily R0 for COVID-19 in Fort Huachuca, Hereford, and Huachuca City AZ, stratified by year total through November 30th, 2020, month, and event.

	Mean R0 (SD)	Median R0	Min R0	Max R0
Fort Huachuca				
March 12th – Nov. 30th	1.01 (0.29)	1.00	0.00	3.00
Month				
March	0.00 (0.00)	0.00	0.00	0.00
April	0.00 (0.00)	0.00	0.00	0.00
May	0.96 (0.23)	1.00	0.00	1.50
June	1.09 (0.27)	1.00	0.75	2.00
July	0.96 (0.21)	1.00	0.50	1.50
August	1.02 (0.44)	1.00	0.00	3.00
September	0.93 (0.30)	1.00	0.00	1.50
October	1.01 (0.36)	1.00	0.00	2.00
November	1.13 (0.35)	1.00	0.50	2.33
Event				
Pre-AZ Shutdown	0.00 (0.00)	0.00	0.00	0.00
AZ Shutdown	0.00 (0.00)	0.00	0.00	0.00
1st Wave (Post-AZ Shutdown)	1.01 (0.27)	1.00	0.00	2.00
Back-to-School	0.97 (0.38)	1.00	0.00	3.00
2nd Wave (Fall)	1.07 (0.35)	1.00	0.00	2.33
Hereford				
March 12th – Nov. 30th	1.03 (0.34)	1.00	0.00	3.50
Month				
March	1.00 (0.00)	1.00	1.00	1.00
April	0.98 (0.28)	1.00	0.00	2.00
May	0.97 (0.18)	1.00	0.00	1.00
June	1.09 (0.38)	1.00	0.75	3.00
July	1.00 (0.26)	1.00	0.63	2.00
August	0.97 (0.22)	1.00	0.00	1.50
September	1.07 (0.40)	1.00	0.33	2.00
October	1.07 (0.48)	1.00	0.33	3.00
November	1.15 (0.47)	1.10	0.57	3.50
Event				
Pre-AZ Shutdown	1.00 (0.00)	1.00	1.00	1.00
AZ Shutdown	0.99 (0.23)	1.00	0.00	2.00
1st Wave (Post-AZ Shutdown)	1.02 (0.31)	1.00	0.00	3.00
Back-to-School	1.02 (0.32)	1.00	0.00	2.00
2nd Wave (Fall)	1.11 (0.47)	1.00	0.33	3.50
Huachuca City				
March 12th – Nov. 30th	1.02 (0.41)	1.00	0.00	6.00
Month				
March	0.00 (0.00)	0.00	0.00	0.00
April	1.00 (0.00)	1.00	1.00	1.00
May	0.97 (0.18)	1.00	0.00	1.00
June	1.04 (0.37)	1.00	0.00	2.00
July	1.04 (0.33)	1.00	0.50	2.33
August	0.94 (0.20)	1.00	0.00	1.00
September	1.02 (0.35)	1.00	0.00	2.00
October	0.95 (0.20)	1.00	0.00	1.00
November	1.25 (0.98)	1.00	0.40	6.00
Event				
Pre-AZ Shutdown	1.00 (0.00)	1.00	1.00	1.00
AZ Shutdown	0.98 (0.15)	1.00	0.00	1.00
1st Wave (Post-AZ Shutdown)	1.03 (0.31)	1.00	0.00	2.33
Back-to-School	0.98 (0.29)	1.00	0.00	2.00
2nd Wave (Fall)	1.10 (0.71)	1.00	0.00	6.00

Abbreviations: (SD) Standard Deviation

Table 5: Mean R0 and median, min, and max daily R0 for COVID-19 in Naco, Pirtleville, and Sierra Vista AZ, stratified by year total through November 30th, 2020, month, and event.

		Mean R0 (SD)	Median R0	Min R0	Max R0
Naco					
March 12th – Nov. 30th		1.02 (0.23)	1.00	0.00	2.33
Month					
	March	0.00 (0.00)	0.00	0.00	0.00
	April	0.00 (0.00)	0.00	0.00	0.00
	May	0.00 (0.00)	0.00	0.00	0.00
	June	1.07 (0.15)	1.00	0.90	1.50
	July	0.98 (0.23)	1.00	0.33	1.50
	August	0.93 (0.36)	1.00	0.00	2.00
	September	1.00 (0.00)	1.00	1.00	1.00
	October	1.02 (0.40)	1.00	0.00	2.33
	November	1.13 (0.29)	1.00	0.75	2.00
Event					
	Pre-AZ Shutdown	0.00 (0.00)	0.00	0.00	0.00
	AZ Shutdown	0.00 (0.00)	0.00	0.00	0.00
	1st Wave (Post-AZ Shutdown)	1.02 (0.17)	1.00	0.33	1.50
	Back-to-School	0.96 (0.25)	1.00	0.00	2.00
	2nd Wave (Fall)	1.08 (0.35)	1.00	0.00	2.33
Pirtleville					
March 12th – Nov. 30th		1.01 (0.26)	1.00	0.00	2.00
Month					
	March	0.00 (0.00)	0.00	0.00	0.00
	April	0.00 (0.00)	0.00	0.00	0.00
	May	0.98 (0.27)	1.00	0.00	2.00
	June	1.12 (0.38)	1.00	0.40	2.00
	July	0.99 (0.22)	1.00	0.50	1.83
	August	0.92 (0.26)	1.00	0.00	1.00
	September	0.97 (0.18)	1.00	0.00	1.00
	October	1.07 (0.41)	1.00	0.00	2.00
	November	1.04 (0.11)	1.00	0.88	1.33
Event					
	Pre-AZ Shutdown	0.00 (0.00)	0.00	0.00	0.00
	AZ Shutdown	1.02 (0.15)	1.00	1.00	2.00
	1st Wave (Post-AZ Shutdown)	1.02 (0.31)	1.00	0.00	2.00
	Back-to-School	0.94 (0.23)	1.00	0.00	1.00
	2nd Wave (Fall)	1.06 (0.30)	1.00	0.00	2.00
Sierra Vista					
March 12th – Nov. 30th		1.14 (0.20)	1.09	1.00	2.20
Month					
	March	1.18 (0.37)	1.00	1.00	2.00
	April	1.13 (0.22)	1.00	1.00	2.00
	May	1.19 (0.31)	1.00	1.00	2.00
	June	1.14 (0.08)	1.13	1.00	1.30
	July	1.10 (0.07)	1.08	1.00	1.26
	August	1.11 (0.11)	1.09	1.00	1.36
	September	1.12 (0.24)	1.00	1.00	2.20
	October	1.13 (0.09)	1.11	1.00	1.31
	November	1.17 (0.12)	1.13	1.02	1.50
Event					
	Pre-AZ Shutdown	1.18 (0.37)	1.00	1.00	2.00
	AZ Shutdown	1.14 (0.27)	1.00	1.00	2.00
	1st Wave (Post-AZ Shutdown)	1.14 (0.14)	1.11	1.00	2.00
	Back-to-School	1.12 (0.18)	1.08	1.00	2.20
	2nd Wave (Fall)	1.15 (0.11)	1.13	1.00	1.50

Abbreviations: (SD) Standard Deviation

Table 6: Mean R0 and median, min, and max daily R0 for COVID-19 in Wilcox AZ, stratified by year total through November 30th, 2020, month, and event.

	Mean R0 (SD)	Median R0	Min R0	Max R0
Willcox				
March 12th – Nov. 30th	1.03 (0.25)	1.00	0.00	3.00
Month				
March	0.00 (0.00)	0.00	0.00	0.00
April	1.00 (0.00)	1.00	1.00	1.00
May	1.09 (0.38)	1.00	0.00	2.33
June	1.03 (0.14)	1.04	0.60	1.30
July	1.00 (0.14)	0.96	0.81	1.46
August	0.95 (0.44)	1.00	0.00	3.00
September	1.03 (0.24)	1.00	0.50	1.50
October	1.11 (0.26)	1.00	0.67	2.00
November	1.04 (0.14)	1.05	0.80	1.49
Event				
Pre-AZ Shutdown	0.00 (0.00)	0.00	0.00	0.00
AZ Shutdown	0.98 (0.15)	1.00	0.00	1.00
1st Wave (Post-AZ Shutdown)	1.06 (0.24)	1.00	0.60	2.33
Back-to-School	0.99 (0.36)	1.00	0.00	3.00
2nd Wave (Fall)	1.08 (0.21)	1.02	0.67	2.00

Abbreviations: (SD) Standard Deviation

Discussion

Nine cities and one military base in Cochise County had 50 or more COVID-19 cases confirmed between March 12th and November 30th, 2020. The first confirmed case occurred on March 12th, 2020 in Sierra Vista, though Benson, Huachuca City, and Willcox did not experience their first cases until April. Fort Huachuca and Pirtleville did not have their first cases until May, and Naco did not have its first case until June. Bisbee did have cases in March but not in April, Naco did not have any cases during September, and Huachuca City did not have any cases during the months of August and October. This indicates that in the months following when they again had confirmed cases of COVID-19, SARS-CoV-2 was once again re-introduced to these cities after being successfully eliminated or individuals with the virus were not tested for COVID-19. It is interesting to note that almost 49 percent of all COVID-19 cases in Cochise County were based out of the city of Douglas.

Other studies have shown the mean R_0 for the United States around 1.61, and other countries to possibly be up to 2.79 (Al-Reei, 2020). Despite the fast spread of COVID-19, however, mean R_0 for Cochise County was calculated at 1.04. Nevertheless, other R_0 models have found the mean reproductive number for COVID-19 to also range around 1.00 (Virol, 2020, Elkenberry et al., 2020). Prior to the April 1st Arizona economic shutdown, the mean R_0 for Cochise County was calculated to be 1.15, and the mean R_0 of during the AZ shutdown was calculated at 1.03, illustrating the effectiveness of stay-at-home orders. During the time of school re-openings between August and September 2020 the county-wide mean R_0 was figured at 1.00, which suggests the virus was not spreading fast among individuals but spread was not slowing towards eradication either. The Fall season wave of COVID-19 cases did bring $R_0 > 1$ again due

to a quickened spread. These trends are similar throughout each individual city of Cochise County.

As noted previously, the value of R_0 represents the number of secondary cases that can arise after contact with one infectious case. To put this in perspective, an R_0 of 1.05 could be interpreted as the equivalent of each infected case only infecting one other person during their period of infectivity, and after 20 cases have been infected, two people were then infected by the 21st case. This number is an average across all cases, for where one case may infect two other people another case may not infect any. These calculated values may be an underestimate for several reasons. This analysis only included confirmed and probable cases, not suspect cases. This may of course have excluded positive cases that did not have a confirmed diagnosis. Furthermore, untested/undiagnosed cases would not have been reported to the County Health Department and therefore would not have been included in the calculation. For this analysis, an infectious period of 10 days was assumed for all patients, but other more severe cases are expected to have an infectious period of up to 20 days (CDC, 2020). This could have extended the R_0 to be higher due to a longer time of infectivity.

The purpose for including the minimum and maximum R_0 value was to identify whether there were days when spread of COVID-19 may have been higher than others. For Cochise County as a whole, R_0 was found to be as low as 0.47 on certain days, while ranging up to as high as 2.00 on other days. These of course were means over the whole county, and while some cities as mentioned above had experienced an R_0 of zero on certain days, four cities experienced an R_0 of 3.00 on at least one day during various months: Douglas (April), Fort Huachuca (August), Benson (September), and Bisbee (June and October). In the month of November, Hereford had a daily max R_0 of 3.50 and Huachuca City had a daily max R_0 of 6.00. If caught in a timely manner, these dates are important for identifying hot spots of COVID-19 spread in these cities and thus areas in need of intervention or more extreme quarantine precautions. Dates when the R_0 is higher than average could be viewed as dates when COVID-19 is spread to more contacts than usual and therefore more secondary cases can be expected to appear in subsequent days. This will of course extend the length of time SARS-CoV-2 will be actively circulating in the population.

Limitations of the population-level model include limits on the amount of information provided. If individuals infected with COVID-19 are not tested or diagnosed (e.g., they believe their symptoms are the result of a cold, allergies, etc.), the data is not as likely to be accurate. This model also assumes that exposure to COVID-19 for all members of Cochise County occurred within the boundaries of the county, which we know to not be true since many cases commonly reported visiting friends or family in other locations within Arizona (e.g., Tucson and Phoenix). Douglas, a border town with Mexico, also had residents reporting often visiting friends or family members in the neighboring Mexico border town of Agua Prieta. Furthermore, many cases were lost to follow-up, and the final disposition of each of these cases are assumed to be "survived" unless medical records reported through MEDSIS list them as deceased.

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